May 2016

Test Report

StoveTeam International, Ecocina Stove with Wood Fuel

Air Pollutant Emissions and Fuel Efficiency

Prepared by:
James J. Jetter, P.E.
Seth Ebersviller, Ph.D.
Guofeng Shen, Ph.D.

U.S. Environmental Protection Agency

Cookstove Testing Facility operated by:
Craig Williams
Jerroll Faircloth

ARCADIS U.S., Inc.
A contractor to the U.S. Environmental Protection Agency

Research Triangle Park, North Carolina, USA

Notice

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, has financially supported the testing described here. This document has been reviewed by the Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA for use.

Prepared by:

James J. Jetter, P.E., Principal Investigator

Seth Ebersviller, Ph.D., EPA Post-Doctoral Fellow

Guofeng Shen, Ph.D., Oak Ridge Institute for Science and Education Post-Doctoral Fellow

Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency

Executive Summary

The U.S. Environmental Protection Agency's (EPA's) cookstove testing program was first developed to assist the EPA-led Partnership for Clean Indoor Air (1) and is now part of the U.S. Government's commitment to the Global Alliance for Clean Cookstoves (the Alliance) (2). Goals of the testing program are to:

1. Support the development of testing protocols and standards for cookstoves through ISO (International Organization for Standardization) TC (Technical Committee) 285: Clean Cookstoves and Clean Cooking Solutions (3).
2. Support the development of international Regional Testing and Knowledge Centers (many sponsored by the Alliance) for scientifically evaluating and certifying cookstoves to international standards (4).
3. Provide an independent source of data to Alliance partners.

This work supports EPA's mission to protect human health and the environment. Household air pollution, mainly from solid-fuel cookstoves in the developing world, is estimated to cause approximately four million premature deaths per year (5), and emissions of black carbon and other pollutants from cookstoves affect regional and global climate (6). An Alliance-coordinated multi-national multi-disciplinary approach, including the development of standards and testing, is designed to improve global health and the environment through clean cooking solutions (7).

This report provides testing results for a cookstove system consisting of the stove, cooking vessels, fuel, and operating procedure. A detailed description of the system is provided in the body of the report. During testing, the stove was operated as intended by the manufacturer. Actual performance of a cookstove used in the field may vary if the system is different (e.g., a different fuel is used) or is not operated as intended.

The cookstove system was tested using the Water Boiling Test (WBT) Version 4.2.3 (8) and following the ISO IWA (International Workshop Agreement) 11-2012, Guidelines for Evaluating Cookstove Performance (9) (10), unanimously affirmed by more than 90 stakeholders at the ISO International Workshop on Cookstoves on February 28-29, 2012 in The Hague, Netherlands. IWA 11:2012 provides guidelines for rating cookstoves on tiers of performance for four important indicators: [1] Efficiency/fuel use, [2] Total Emissions, [3] Indoor Emissions, and [4] Safety; and the guidelines are being used while further development of testing protocols and standards is underway through ISO Technical Committee 285 (3). For measuring air pollutant emissions, the "total capture" method (also known as the "hood" method) was used, as described on Pages 60-61 of the WBT protocol (8) and similar to EPA Method 5G (11). The protocol specifies that the stove be tested at high power (cold- and hot-start phases) and low power (simmer phase). The cold-start phase begins with the stove at ambient temperature, and the hot-start phase begins with the stove at operating temperature. During both phases, the stove is operated at high power to heat water in the cooking vessel from ambient to boiling temperature. During the simmer phase, the stove is operated at low power to maintain the target water temperature at 3°C below the boiling point. Fuel burning rates determine the power levels. During testing, variation in fuel burning rates between test replications is minimized. Actual performance of a cookstove used in

the field may vary if the stove is operated at different fuel burning rates and hence at different power levels.

Test results summarized on Page iv were obtained in accordance with IWA 11:2012 guidelines, and tier ratings range from 0 (baseline) to 4 (best). Tier 0 represents the performance of typical traditional open three-stone fires used for cooking, and Tier 4 represents aspirational goals for solid-fuel cookstoves. Efficiency/fuel use, total emissions, and indoor emissions are tested at high- and low-power operating conditions, and sub-tier values and ratings are reported for the two power levels, while the overall rating is the lowest sub-tier rating, as specified in the IWA. Sub-tier values and ratings for many different stove types are compared in Figures 4 and 6-9 of this report. Following are brief descriptions of performance indicators specified in the IWA.

Efficiency/fuel use is an important indicator, especially for cookstoves used in areas where fuel is scarce or expensive or where forest degradation is an issue due to unsustainable harvesting of wood for fuel. Greater fuel efficiency is desirable, but increased efficiency does not always correlate with reduced emissions of air pollutants. Efficiency/fuel use tier levels are based on thermal efficiency at high power and specific energy use at low power, per the IWA.

Total emissions of air pollutants from cookstoves have potential impact on human health and climate change. CO (carbon monoxide) and $PM_{2.5}$ (fine particulate matter) are indicator pollutants specified in IWA 11:2012, and emissions of additional pollutants are quantified in this report, including gaseous pollutants CO_2 (carbon dioxide), THC (total hydrocarbons), CH_4 (methane), and NO_X (nitrogen oxides), as well as particulate OC (organic carbon), EC (elemental carbon), and BC (black carbon). Total emission tier levels are based on the mass of pollutant emitted per unit of useful energy delivered at high power and the specific emission rate at low-power, per the IWA.

Indoor emissions have a potential direct impact on human health, and emissions may be reduced by stoves with cleaner combustion and/or with chimneys (flues). Stoves without chimneys are tested for total emissions into the indoor space, and stoves with chimneys are tested for fugitive emissions from the stove. Indoor emissions tier levels are based on emission rates, per the IWA.

Safety is also an important indicator included in IWA 11:2012 for evaluation of stoves for protection from risk of burns and other injuries, but safety is not evaluated in this report.

Cooking power is not an IWA performance indicator, but it is reported in the summary because it can be important for meeting user needs.

Fuel burning rates are reported to define the test conditions.

IWA tier ratings are based on the performance of the stove system operated as intended with low-moisture fuel. Additional test results are provided in this report for energy efficiency, fuel use, and air pollutant emissions for low- and high-moisture fuel and for use of the stove with an optional cooking griddle. Discussion of results, observations, and quality assurance is also included in the report.

Stove Manufacturer & Model	**StoveTeam International**, Eugene, OR, USA **Ecocina Stove**
Testing Center	EPA-Research Triangle Park, North Carolina, USA
Test Protocol	WBT Version 4.2.3, EPA Rev. 4 [see Reference (8)]
Fuel Used	Red oak wood, 7.7% moisture (wet basis), 2 x 2 x 36 cm
Cooking Vessel Used	Standard flat-bottom 7 L pot with 5 L of water, with pot skirt

Test results were obtained in accordance with ISO (International Organization for Standardization) IWA (International Workshop Agreement) 11:2012. See previous page for brief description.

		Metric	Value	Unit	Sub-Tier
Efficiency / Fuel Use					
Tier	**2**	High Power Thermal Efficiency	27	%	2
		Low Power Specific Energy Use	0.038	MJ / (min L)	2
Total Emissions					
Tier	**1**	High Power CO	5.23	g / $MJ_{delivered}$	4
		Low Power CO	0.12	g / (min L)	2
		High Power $PM_{2.5}$	578	mg / $MJ_{delivered}$	1
		Low Power $PM_{2.5}$	2.8	mg / (min L)	2
Indoor Emissions					
Tier	**0**	High Power CO	0.37	g / min	4
		Low Power CO	0.48	g / min	3
		High Power $PM_{2.5}$	43.4	mg / min	0
		Low Power $PM_{2.5}$	11.8	mg / min	2

Tiers 0 → 4 (best)

	Value	Unit
Cooking Power (average of Cold Start and Hot Start phases)	1219	W
Fuel burning rate (average for Cold Start, based on equivalent dry fuel consumed)	13.9	g / min
Fuel burning rate (average for Hot Start, based on equivalent dry fuel consumed)	16.5	g / min
Fuel burning rate (average for Simmer, based on equivalent dry fuel consumed)	9.0	g / min

Acronyms and Abbreviations

Alliance	Global Alliance for Clean Cookstoves
ASTM	American Society for Testing and Materials (now known as ASTM International)
BC	black carbon
C	carbon
C_3H_8	propane
CH_4	methane
cm	centimeter(s)
CO	carbon monoxide
CO_2	carbon dioxide
CPC	condensation particle counter
EC	elemental carbon
EPA	U.S. Environmental Protection Agency
g	gram(s)
HEPA	high-efficiency particulate air
ISO	International Organization for Standardization
IWA	International Workshop Agreement
kg	kilogram(s)
kJ	kilojoule(s)
L	liter(s)
MCE	modified combustion efficiency
Met Lab	Metrology Laboratory
mg	milligram(s)
min	minute(s)
MJ	megajoule(s)
$MJ_{delivered}$	megajoule(s) of useful energy delivered
mm	millimeter(s)
n.a.	not applicable
NIOSH	National Institute for Occupational Safety and Health
NO_X	nitrogen oxides
OC	organic carbon
$PM_{2.5}$	particulate matter with an aerodynamic diameter ≤ 2.5 micrometers
PTFE	polytetrafluoroethylene
QA	quality assurance
RTP	Research Triangle Park
SD	standard deviation
SOP	Standard Operating Procedure
TC	Technical Committee
TC	total carbon, the sum of EC (elemental carbon) and OC (organic carbon)
THC	total hydrocarbon
W	Watt(s)
WBT	Water Boiling Test

Contents

List of Figures

List of Tables

Cookstove Testing Program

The U.S. Environmental Protection Agency's (EPA's) cookstove testing program was first developed to assist the EPA-led Partnership for Clean Indoor Air (1) and is now part of the U.S. Government's commitment to the Global Alliance for Clean Cookstoves (the Alliance) (2). Goals of the testing program are to:

1. Support the development of testing protocols and standards for cookstoves through ISO (International Organization for Standardization) TC (Technical Committee) 285: Clean Cookstoves and Clean Cooking Solutions (3).
2. Support the development of international Regional Testing and Knowledge Centers (many sponsored by the Alliance) for scientifically evaluating and certifying cookstoves to international standards (4).
3. Provide an independent source of data to Alliance partners.

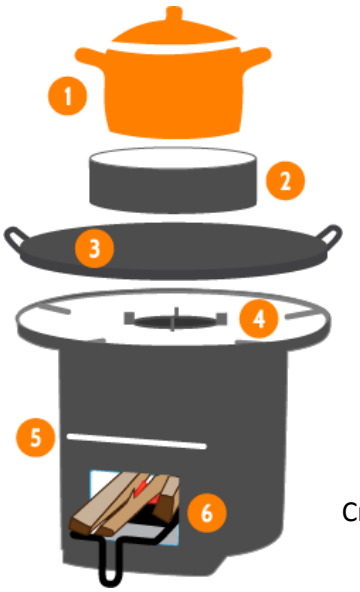
This work supports EPA's mission to protect human health and the environment. Household air pollution, mainly from solid-fuel cookstoves in the developing world, is estimated to cause approximately 4 million premature deaths per year (5), and emissions of black carbon and other pollutants from cookstoves affect regional and global climate (6). An Alliance-coordinated multi-national multi-disciplinary approach, including the development of standards and testing, is designed to improve global health and the environment through clean cooking solutions (7).

Description of Cookstove System Tested

A cookstove system consists of the stove, cooking vessel, fuel, and operating procedure. The default operating procedure used for testing is the set of written instructions provided by the manufacturer, or operation as intended by the manufacturer. Actual performance of a cookstove used in the field may vary if the system is not operated as intended, or if the stove is used with a different type of fuel or cooking vessel.

Development and dissemination. Nancy Hughes and a team of volunteers from the Eugene Southtowne Rotary Club, Oregon, USA, developed the Ecocina cookstove. Stoves are produced in factories with all local materials in El Salvador, Guatemala, Honduras, and Mexico.

Type of stove. The StoveTeam Ecocina Stove is a natural-draft rocket-type of cookstove designed for wood fuel. Electrical power is not required for natural-draft stoves (power is required for some forced-draft stoves). As shown in Figure 1, the stove may be used with a cooking pot or comal (a griddle, also known as a plancha) for making tortillas or frying foods. For cooking with a pot, the comal may be removed to expose the pot directly to flames and hot combustion gases for improved efficiency. A rocket-type combustion chamber is located under the cooking pot or comal. An adjustable pot skirt enhances heat transfer to the sides, as well as the bottom, of the pot. The stove is designed to burn sticks of fuel wood or other biomass (e.g., corn cobs) that are manually fed into an opening in the lower front of the stove. Cooking power is controlled by the amount of fuel fed into the combustion chamber. The stove is designed to be manufactured in a small factory.



Credit: StoveTeam International

Figure 1. *Ecocina components: 1 Pot, 2 Pot Skirt, 3 Comal, 4 Pot Supports, 5 Body, 6 Wood Support.*

Construction materials. The Ecocina stove body is made of ferro-cement (steel-reinforced concrete), and the internal combustion chamber is made of low-fired tile surrounded by insulating pumice. Pot supports, wood support, comal, and a rim around the upper body are made of steel, and the pot skirt is made of galvanized steel. Weight of the stove is 38 kg with pot supports and wood supports, but without the comal, pot, or skirt.

Dimensions.
Stove height: 36 cm
Stove lower body diameter: 36 cm
Stove upper body diameter: 48.5 cm
Combustion chamber internal width: 12 cm
Combustion chamber internal depth: 14 cm
Combustion chamber internal height: 14 cm
Fuel/air opening: 13 cm x 13 cm
Height of fuel/air opening from bottom: 4 cm

Figure 2. *Ecocina stove with pot skirt*

Accessories. The stove was supplied with the following removable parts: adjustable pot skirt, comal, pot support, and wood support. A pot was not supplied with the stove.

Cooking vessel. A default standard flat-bottomed pot was used for the tests. This pot has a weight of approximately 815 grams. Full capacity is approximately 7 liters, and the pot is used with 5 liters of

water for the tests. Material is stainless steel. Outside diameter of the rolled edge at the top of the pot is 257 mm, and inside diameter of the pot at the top is 244 mm. Outside diameter at the bottom is 243 mm. Height (not including handles) is 162 mm. The pot was obtained from the CICCI Company (Copenhagen, Denmark) that provides supplies for emergency relief and development projects around the world.

Fuel. A hardwood, Red Oak (*Quercus rubra*), was obtained from a local supplier in Raleigh, NC. Bark was removed, and the wood was saw-cut to dimensions of 2 cm x 2 cm x 36 cm long for low-moisture fuel and dimensions of 1 cm x 2 cm x 36 cm long for high-moisture fuel. Wood was air dried, and high-moisture fuel was preserved in air-sealed containers in a freezer. Moisture content on a wet basis is reported in Tables 1-3 for low-moisture fuel and in Tables 7-9 for high-moisture fuel.

Operating procedure. Operating instructions were supplied with the stove, and the instructions were followed during testing.

Cost. According to StoveTeam information, in 2011, approximate production cost was US$35, wholesale cost was US$44, and retail cost was US$50.

Quantity disseminated. As of May 2016, factories produced and sold more than 56,334 stoves, according to StoveTeam International (12).

Lifetime. Estimated typical lifetime is approximately five years, but lifetime may vary depending on hours of use, fuel quality, environmental conditions, and other factors. In the future, a durability testing protocol may be developed through ISO TC 285, and durability testing may provide more comparable and quantitative results than estimated lifetime.

Test Protocol

The cookstove system was tested using the Water Boiling Test (WBT) Version 4.2.3 (8) and following the ISO International Workshop Agreement Guidelines for Evaluating Cookstove Performance (9) (10). Further development of testing protocols and standards is underway through ISO Technical Committee 285 (3). For measuring air pollutant emissions, the “total capture” method (also known as the “hood” method) was used, as described on Pages 60-61 of the WBT protocol (8) and similar to EPA Method 5G (11). Emissions were captured in a fume hood and were drawn under negative pressure through a primary dilution tunnel and then through a secondary tunnel with additional HEPA (high-efficiency particulate air)-filtered dilution air. Gaseous air pollutants were sampled from the primary dilution tunnel, and particulate pollutants were sampled from the secondary dilution tunnel for testing of this stove/fuel. Indoor emissions results were determined from total emissions for the Ecocina cookstove without a chimney. The WBT protocol specifies that the stove be tested at high power (cold- and hot-start phases) and low power (simmer phase). The cold-start phase begins with the stove at ambient temperature, and the hot-start phase begins with the stove at operating temperature. During both phases, the stove is operated at high power to heat water in the cooking vessel from ambient to boiling temperature. During the simmer phase, the stove is operated at low power to maintain the target water temperature at 3°C below the boiling point. Fuel burning rates determine the power levels. During testing, variation in fuel burning rates between test replications is minimized. Actual

performance of a cookstove used in the field may vary if the stove is operated at different fuel burning rates and hence at different power levels.

During each of the three separate phases of the test protocol, $PM_{2.5}$ (particulate matter with an aerodynamic diameter ≤ 2.5 micrometers) was isokinetically sampled and collected on PTFE (polytretrafluoroethylene)-membrane filters for gravimetric analysis and on quartz-fiber filters for OC (organic carbon) and EC (elemental carbon) analyses. Gravimetric analysis was performed with a microbalance in a temperature- and humidity-controlled room. OC and EC analyses were performed using NIOSH (National Institute for Occupational Safety and Health) Method 5040 (13), including analysis of gas-phase samples collected on quartz fiber filters downstream of PTFE membrane filters to account for the gas-phase absorption artifact (14). BC (black carbon) concentrations were measured in real-time with a microAeth® Model AE51 (AethLabs, San Francisco, CA, USA) aethalometer. Gaseous pollutant concentrations were measured in real-time with continuous emission monitors. CO (carbon monoxide) and CO_2 (carbon dioxide) were measured with non-dispersive infrared analyzers, THC (total hydrocarbons) and CH_4 (methane) were measured with flame-ionization detection analyzers, and nitrogen oxides (NO_X) were measured with a chemiluminescence analyzer.

Fuel moisture content was measured using the oven-drying method (15), and fuel heat of combustion was measured using the calorimeter method (16).

The cookstove was also tested with its optional griddle (comal), as shown in Figure 1, following guidelines (17) developed by an ad-hoc group of stove testing experts from Latin America at the Plancha Stove Testing Protocol Workshop at Zamorano University in Honduras on October 29-31, 2013. WBT Version 4.2.3 was followed, except the pot was replaced with the comal, and a flexible cooking vessel constructed from polyester film (0.13 mm thick) was used to hold water for the test. The flexible cooking vessel conformed to the surface of the griddle and covered 60 percent of the surface area, per the plancha stove testing guidelines (17).

Test Results

A summary of results is presented in accordance with ISO IWA 11:2012 (9) on Page iv of this report. IWA tier ratings are based on the performance of the stove system operated as intended with low-moisture wood fuel.

Ecocina test results are compared with previously published results (18) in Figures 3-9. Key indicators of performance shown in the figures are described in Jetter et al. 2012 (18). Error bars on the data points for the Ecocina stove indicate standard deviations or 95% confidence intervals (using the t-distribution), as specified in the figures. For reference, data points for the 3-stone fire are indicated by red-colored X markers. Two data points are shown on each graph for a carefully-tended and a minimally-tended 3-stone fire. The carefully-tended fire performed better than the minimally-tended fire in all measures (18). Data points (blue diamonds indicated by the letter “P”) are indicated for comparison with the Philips Model HD4012 – a well-known and relatively high-performing forced-draft solid-fuel household stove. Data points for other stoves with previously published results are not identified in Figures 3-9, but stoves are identified in the journal article (18). All data shown in the figures are for stoves tested with low-moisture solid fuels, as described in the published results (18).

Cooking power versus fire power (in measurement units of Watts) data are shown in Figure 3 for high-power (average of cold-start and hot-start phases of the WBT). Cooking power is the rate of useful energy delivered to the contents of the cooking vessel, while fire power is the rate of fuel energy used. Adequate cooking power is important for user acceptability, and cooking power is correlated with "time-to-boil" (18). The ratio of cooking power to fire power is thermal efficiency – shown in Figure 4.

Specific energy use during low-power (simmer phase of the WBT) **versus thermal efficiency during high-power** (average of cold-start and hot-start phases of the WBT) data are shown in Figure 4. These metrics are used to determine IWA Tier ratings, and the IWA Sub-Tiers are indicated in the figure.

Low-power versus high-power MCE (modified combustion efficiency) data are shown in Figure 5. MCE is defined as $[CO_2/(CO_2 + CO)]$ on a molar basis and is considered a reasonable proxy for true combustion efficiency. MCE is not used to determine IWA Tier ratings, but stoves with higher MCEs tend to have lower emissions of air pollutants. Best performance is indicated in the upper right corner of the graph.

CO versus $PM_{2.5}$ emissions per useful energy delivered ($MJ_{delivered}$) to the water in the cooking vessel during high-power phases of the WBT data are shown in Figure 6. Pollutant emissions per useful energy delivered and thermal efficiency are key IWA metrics because they are based on the fundamental desired output – cooking energy – that enables valid comparisons between all stoves and fuels.

CO versus $PM_{2.5}$ emissions per minute per liter of water simmered during the low-power phase of the WBT data are shown in Figure 7. Useful cooking energy is not accurately measured during the low-power test phase of the WBT (18), therefore the specific emission rate is used as the metric, per the IWA.

CO versus $PM_{2.5}$ indoor emission rates during high-power phases of the WBT data are shown in Figure 8.

CO versus $PM_{2.5}$ indoor emission rates during low-power data are shown in Figure 9.

Tabulated data for the Ecocina with low-moisture wood fuel, including data for test replicates, are shown in Tables 1-3 for parameters of the Water Boiling Test (8) and emissions of $PM_{2.5}$ and gaseous air pollutants, as described in Jetter et al. 2012 (18). Test Numbers shown in the column headings may not be sequential, because some tests were rejected for the reasons given in footnotes to the tables. The number of accepted test replicates performed was seven for low-power, seven for high-power hot-start, and nine for high-power cold-start test phases. A sufficient number of replicates was performed to reduce 95% confidence intervals for ISO IWA tier ratings (Figures 4 and 6-9).

OC and EC particulate emissions data are reported for low-moisture fuel in Table 4. Mass fractions of organic and elemental carbon to total carbon in particulate matter are reported in Table 5.

BC emissions data are reported for low-moisture fuel in Table 6.

Test Results for High-Moisture Fuel

Tabulated data for the Ecocina stove with high-moisture fuel are shown in Tables 7-12 in the same format as Tables 1-6, as described in the previous section for low-moisture fuel. Three test replicates were performed to enable the calculation of standard deviations as an indicator of test variability. Moisture content was approximately 30 percent (wet basis) for high-moisture wood fuel, but some low-moisture fuel was required for starting the fire and maintaining combustion. Fuel moisture content is reported as the average (on a mass basis) of low- and high-moisture fuels, as described in Jetter et al. – see Supporting Information (18).

Test Results for Stove Use with Griddle (Comal)

Tabulated data for the Ecocina stove with its optional griddle (comal) are shown in Tables 13-18 in the same format as Tables 1-6, as described above. The number of acceptable test replicates performed was seven for low-power, eight for high-power hot-start, and eight for high-power cold-start test phases. Tests with the griddle were performed with low-moisture wood fuel.

A side-by-side comparison of results with pot/griddle and low-/high-moisture is provided in Tables 19-22. Results for high-moisture “green” wood fuel are indicated by the green background color in the tables, results for low-moisture (dry) fuel are indicated by the tan color, and results for the griddle are indicated by the blue color.

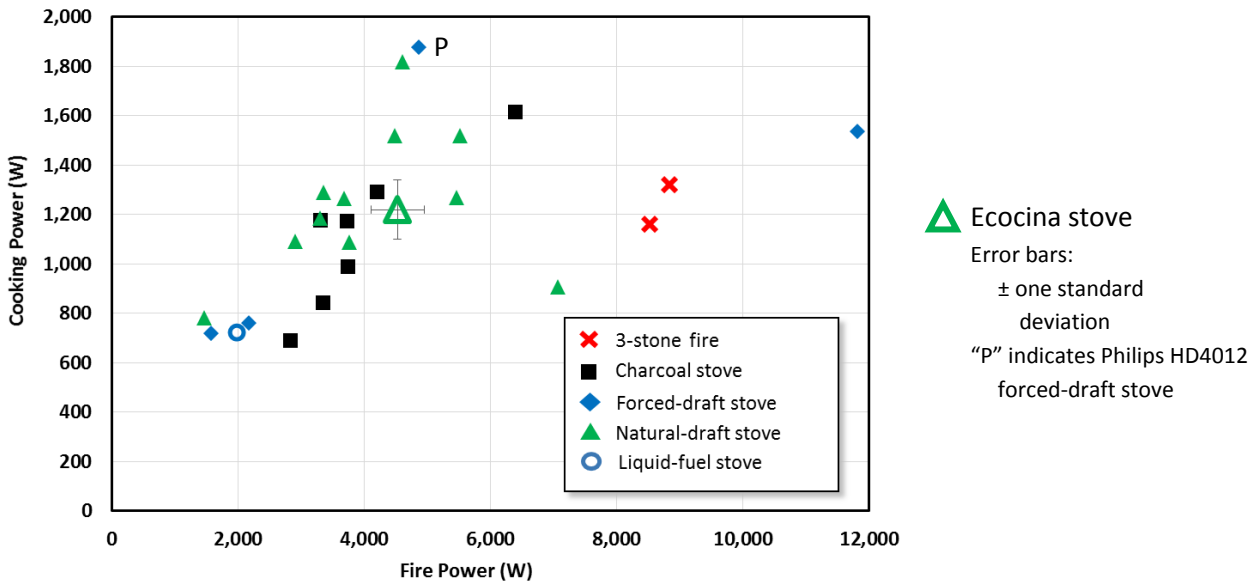


Figure 3. *Cooking power versus fire power during high-power*

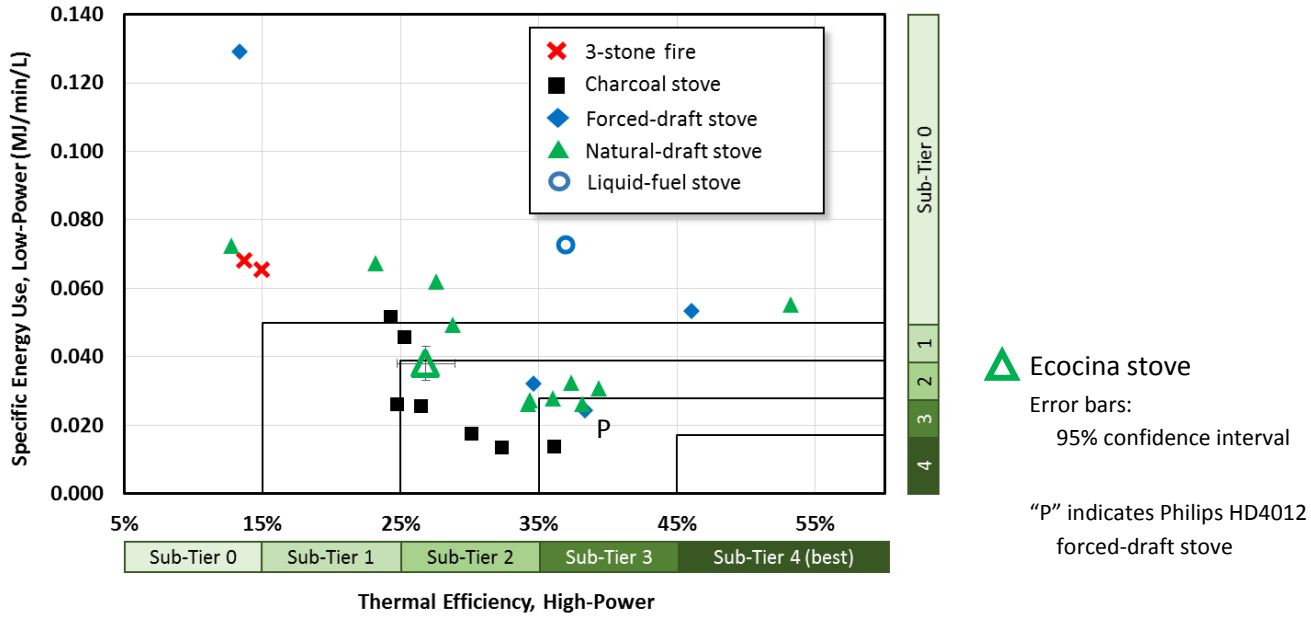


Figure 4. *Specific energy consumption during low-power versus thermal efficiency during high-power*

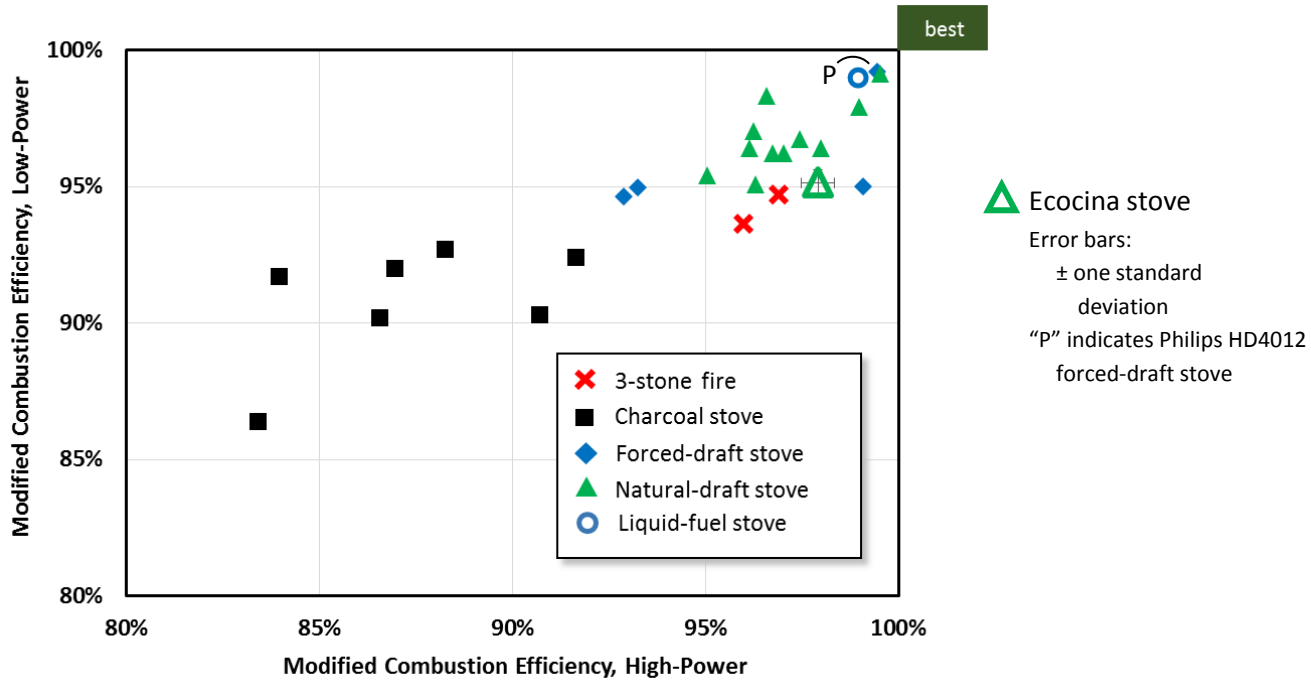


Figure 5. *Modified combustion efficiency, low-power versus high-power*

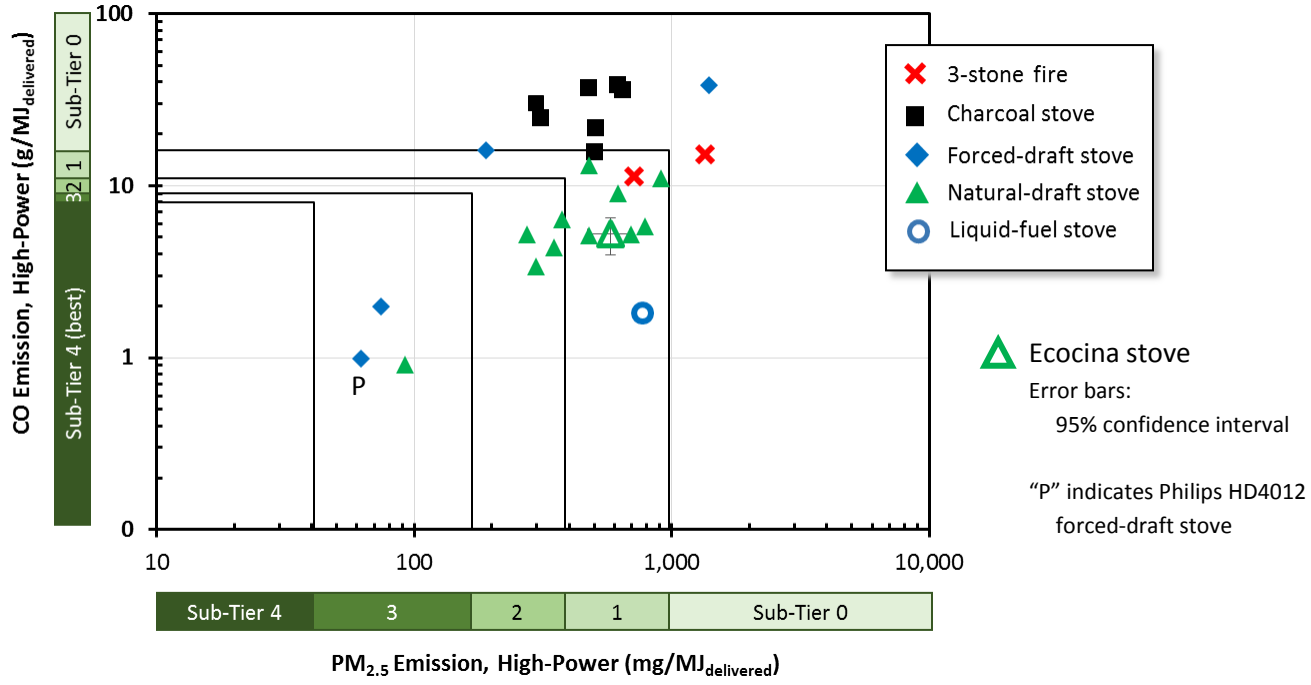


Figure 6. *CO versus $PM_{2.5}$ emissions per useful energy delivered to water in the cooking vessel during high-power*

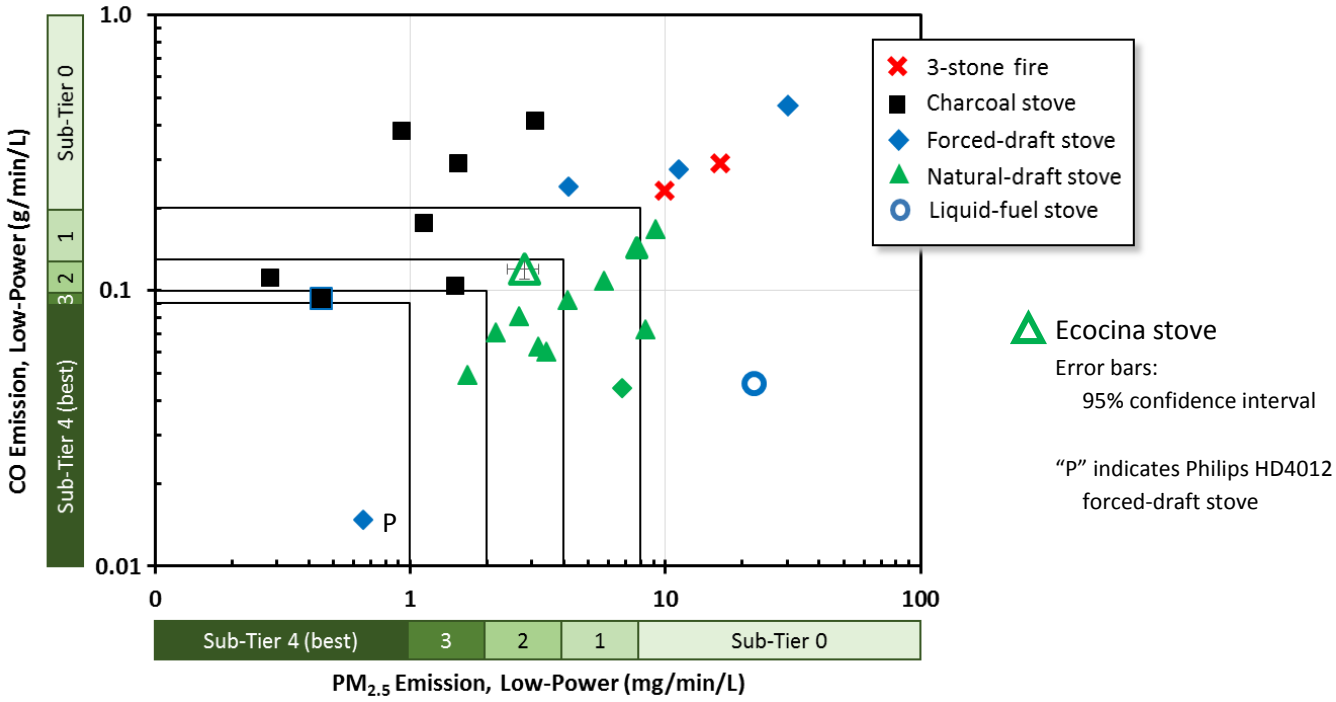


Figure 7. *CO versus $PM_{2.5}$ emissions per liter of water simmered per minute during low-power*

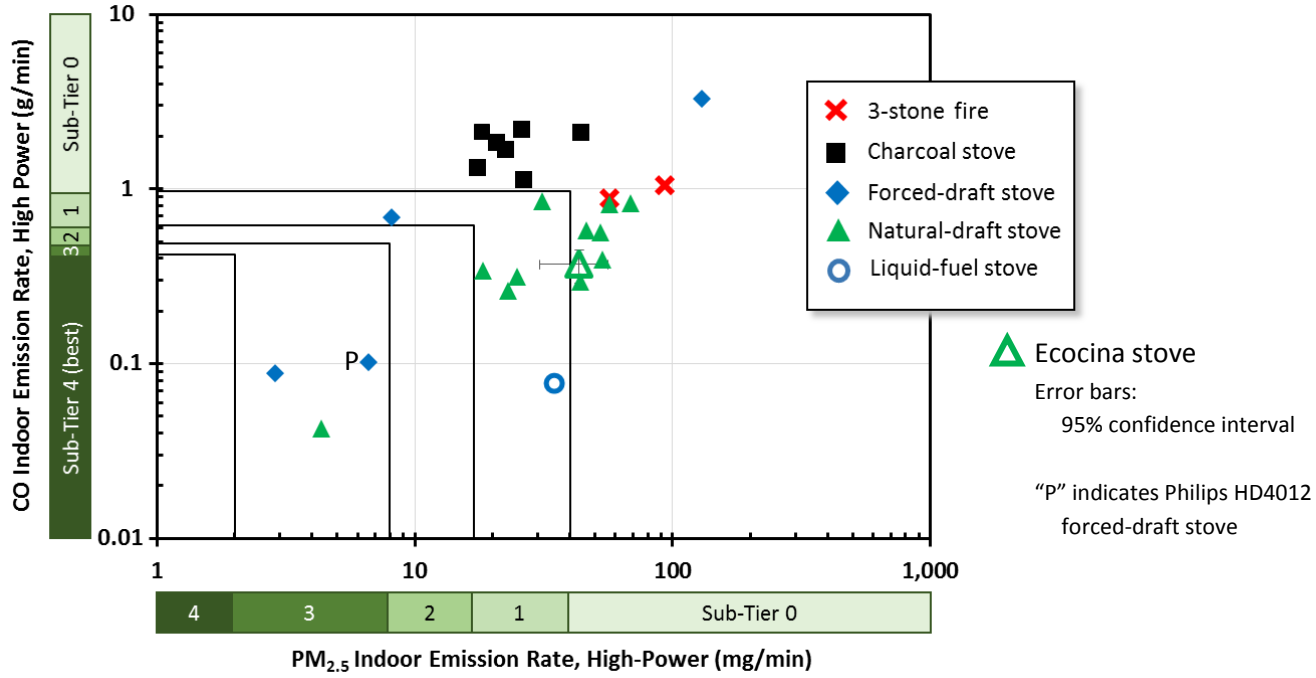


Figure 8. *CO versus $PM_{2.5}$ indoor emission rates during high-power*

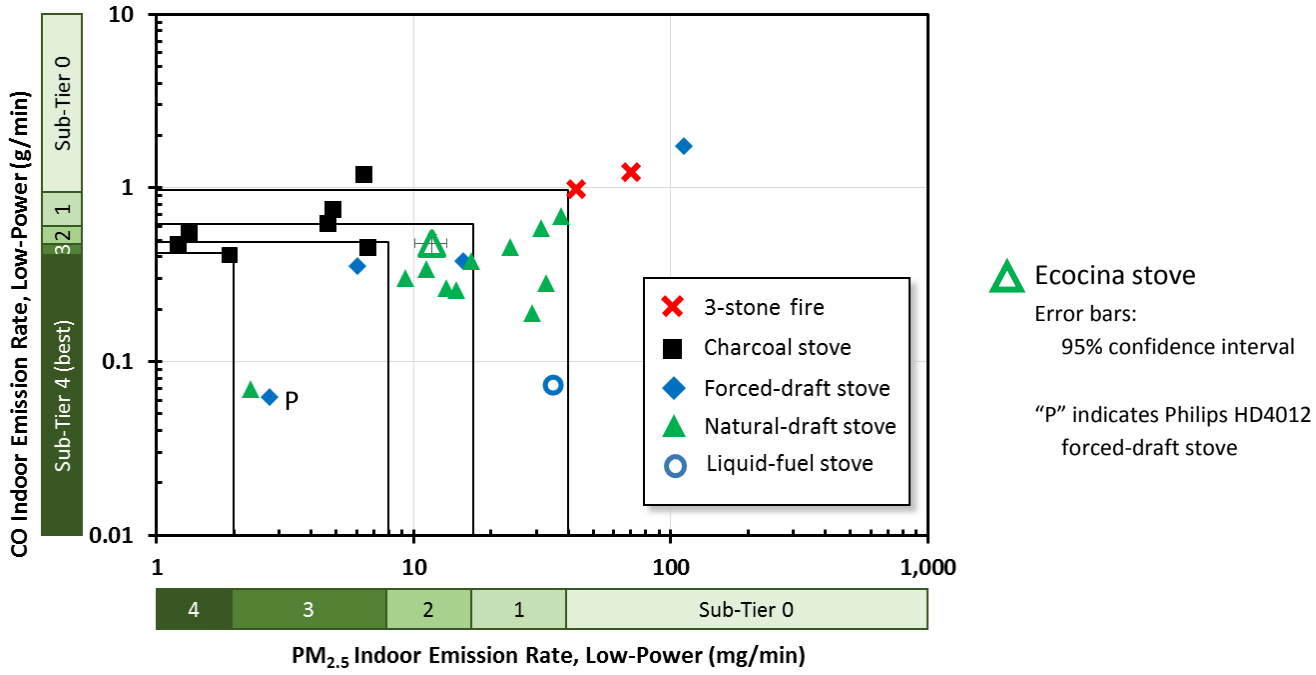


Figure 9. *CO versus $PM_{2.5}$ indoor emission rates during low-power*

Discussion of Results and Observations

As shown in the Results Summary on Page iv, the Ecocina's cooking power was approximately 1.2 kW (average of cold-start and hot-start test phases of the WBT). Average cooking power was greater during the hot-start phase because more heat was absorbed by the stove's thermal mass during the cold-start (see Tables 1 and 2). As shown in Figure 3, average cooking power for the Ecocina was similar to that for the 3-stone fire, but fire power for the Ecocina was lower due to its better thermal efficiency. The Ecocina is rated at Tier 2 for Efficiency/Fuel Use, as shown in Figure 4. MCE was greater during high-power than during low-power, as shown in Figure 5.

The Ecocina is rated at Tier 1 for Total Emissions, as shown in the Results Summary. High-power CO emissions are rated at Sub-Tier 4, and low-power emissions of both CO and $PM_{2.5}$ are rated at Sub-Tier 2, but high-power $PM_{2.5}$ emissions are rated at Sub-Tier 1. The overall Tier rating is based on the lowest Sub-Tier rating, per the IWA. As shown in Figures 6 and 7, most previously tested natural-draft stoves were rated in Sub-Tiers 1 and 2 for Emissions.

As shown in the Results Summary, the Ecocina is rated at Tier 0 for Indoor Emissions. High-power CO emissions are rated at Sub-Tier 4, and low-power emissions of CO and $PM_{2.5}$ are rated at Sub-Tiers 3 and 2, respectively, but high-power $PM_{2.5}$ emissions are rated at Sub-Tier 0. Indoor Emissions Tiers are based on emission rates (pollutant mass per time) into the household space, as shown in Figures 8 and 9. A stove with an effective chimney could have relatively high Total Emissions (low Tier rating) but low Indoor Emissions (high Tier rating). The Ecocina does not have a chimney, although an attachment for a chimney has been demonstrated at the Ecocomal Factory near Antigua, Guatemala. The stove with attachment and chimney has not been tested by EPA.

The fraction of organic to total carbon in $PM_{2.5}$ was similar at low- and high-power, as shown in Table 5. Elemental carbon is generally considered a reasonable proxy for black carbon, but black carbon is not yet scientifically well defined. Black carbon emissions can be operationally defined by an aethalometer instrument, as presented in Table 6. Discrepancies in mass between EC and BC and between TC and $PM_{2.5}$ may sometimes be observed due to the different methods and measurement uncertainties.

As expected, performance was generally better with low-moisture fuel than with high-moisture fuel, as shown in Table 19. With low-moisture fuel, fuel consumption was lower, thermal efficiency was higher, cooking power was higher, and air pollutant emissions based on useful energy delivered were mostly lower, except $PM_{2.5}$ emissions were higher during the hot-start test phase. Cooking power was greater during the hot-start test phase than during the cold-start phase for both low- and high-moisture fuels, because the stove's thermal mass absorbs more heat during the cold-start. Emissions of particle-phase organic carbon were lower with low-moisture fuel for low-power and high-power cold-start test phases, but emissions were lower with high-moisture fuel for the high-power hot-start phase, as shown in Table 20. Emissions of elemental and black carbon were lower with low-moisture fuel for the low-power test phase, but emissions were lower with high-moisture fuel for the high-power phases, as shown in Tables 20-21.

Thermal efficiency was better with the pot than with the griddle, as shown in Table 19. The plancha (griddle) testing protocol (17) was developed to evaluate thermal efficiency based on the measurement of heat transfer directly to the surface of the griddle – water in direct contact with the griddle simulates food (e.g., tortillas and meat) cooked directly on the griddle. If a pot is heated on top of a griddle, thermal efficiency is typically relatively low due to the limited contact area for the conduction of heat from the griddle to the pot and due to the conduction of heat away from the pot by the griddle (18). Stoves with fixed griddles typically have relatively low thermal efficiency for cooking with pots (18) (19), but the Ecocina has a removable griddle (comal – Figure 1) that enables relatively high thermal efficiency with the use of a pot and pot skirt.

Real-time data for a typical test sequence are shown in Figure 10. Data are shown for pollutant concentrations measured in the dilution tunnel, and pot water temperature indicates the three phases of WBT test sequence. Concentrations fluctuated over time as fuel was fed into the stove. CO_2 concentration indicates the rate of fuel consumption. THC concentrations were reported as C_3H_8 (propane). Concentrations of THC, CH_4, and NO_X were relatively low, but clearly above background levels.

The Ecocina performed without any problems during testing. The Ecocina is simple to operate – similar to typical rocket stoves. The Ecocina is portable, but with a mass of 38 kg, it is heavier than typical metal stoves. Stoves are manufactured in small factories [see Ecocina web site (12)], and the Ecocina seems solidly made.

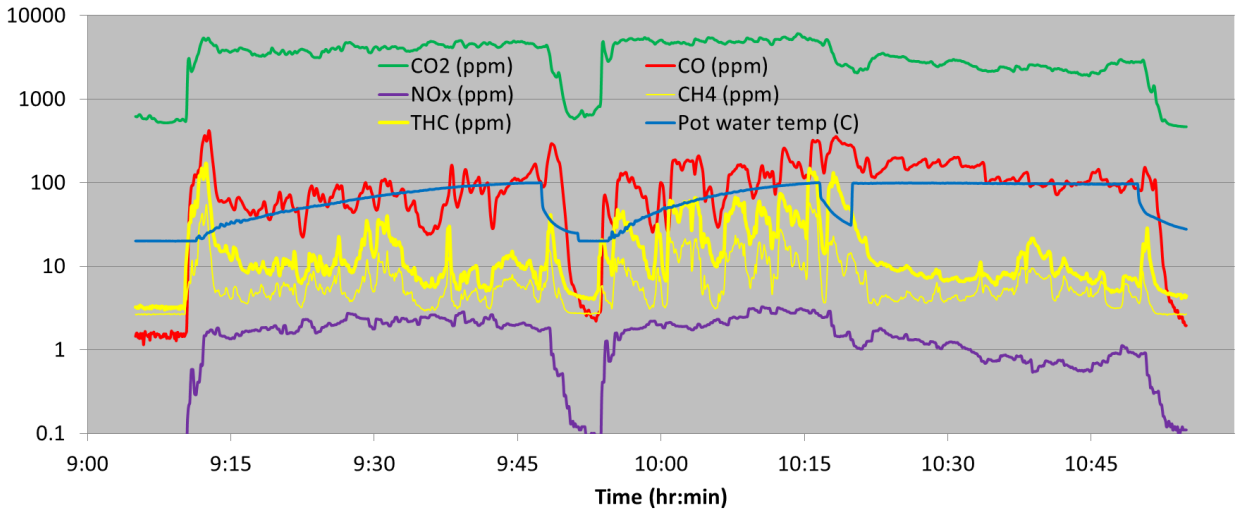


Figure 10. *Real-time data for a typical test sequence*

Quality Assurance/Quality Control

A Quality Assurance Project Plan (QAPP) meeting EPA requirements (20) was prepared and was reviewed by an EPA Quality Manager. Specifically, work was in compliance with Category II Quality Assurance Project Plan requirements "…for important, highly visible Agency projects involving areas such as supporting the development of environmental regulations and standards" (21).

In February 2014, EPA QA staff conducted a technical systems audit (TSA) of this project. The purpose of this TSA was to conduct an independent and objective assessment of on-site activities through an in-depth evaluation of technical system documents, on-site laboratory work, equipment, procedures, and record keeping activities to ensure (1) that environmental data collection activities and the resulting data comply with the project's QAPP; (2) that these activities are implemented effectively; and (3) that these activities are suitable to achieve the project's data quality goals.

The TSA was conducted in accordance with principles described in *Guidance on Technical Audits and Related Assessments for Environmental Data Operations* (22). The technical basis of the TSA was the QAPP entitled *Cookstove Testing for Air Pollutant Emissions, Energy Efficiency, and Fuel Use, Revision 1*, September 2013.

In general, the audit findings were positive in nature and indicated that the project was implemented as described in the QAPP. Note that the term "findings" as used in this document was consistent with the QA/G-7 definition and does not necessarily imply non-conformance. There were no findings that indicated a quality problem requiring corrective action. All phases of the implementation were found to be acceptable and to be performed in a manner consistent with the QAPP and with EPA quality assurance requirements.

In May 2016, EPA QA staff conducted an ADQ (audit of data quality) of the test results being reported in this publication. The ADQ was conducted in accordance with *Guidance on Technical Audits and Related Assessments for Environmental Data Operations* (22). It examined the results after they had been collected and verified by project personnel. It determined how well the measurement system performed

with respect to the performance goals specified in the QAPP and whether the data were accumulated, transferred, reduced, calculated, summarized, and reported correctly. It documented and evaluated the methods by which decisions were made during treatment of the data. It found that there is sufficient documentation of all procedures used in the data collection effort and that the data were collected according to these procedures. Enough information is provided to allow a potential user to determine the quality and limitations of the data and whether the intended use of the data is appropriate. The data are of sufficient quality with respect to measurement quality objectives and other performance criteria for their intended use.

An important indicator of overall data quality for cookstove performance testing is the carbon mass balance. Carbon measured in the emissions is compared with carbon measured in the fuel consumed. A percent difference based on carbon in the fuel is calculated for each test phase. A positive result indicates that more carbon was measured in the fuel than in the emissions, and a negative result indicates that less carbon was measured in fuel than in emissions. The absolute value of the percent difference is used as a quality indicator and is considered to be excellent when ≤ 10%, good when ≤ 15%, acceptable when ≤ 20%, and unacceptable when > 20%. A continuous improvement process is used in pursuit of excellent results, and tests are rejected when the carbon balance is > 20%. Carbon-balance results are shown in Table 22. Measurement uncertainties for both emissions and fuel are reflected in the carbon-balance results. Negative values in Table 17 indicate potential positive bias for carbon measured in emissions and/or negative bias for carbon measured in fuel. Test replicates were rejected if the carbon balance was unacceptable, and data were rejected if measurement quality objectives (described below) were unacceptable.

The carbon balance is an overall indicator of many of the critical measurements included as measurement quality objectives listed in Table 23. Test results included in this report were based on measurements that met or exceeded these quality objectives. Data were rejected if measurements did not meet acceptance criteria.

Tables

Following are tabulated data and information, as described above.

Table 1. *Low-moisture fuel, high-power cold-start – WBT, $PM_{2.5}$, and gaseous pollutant parameters*

Parameter	Units	Average	SD	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
Fuel moisture (wet basis)	%	7.7	1.0	9.4	9.4	7.2	7.1	7.7	7.7	6.6	7.1	7.2
Fuel consumed (raw)	g	700	86	819	731	790	703	564	711	585	654	743
Equivalent dry fuel consumed	g	554	73	650	562	647	576	431	540	468	527	589
Time to boil 5 liters of water, 25 to 100°C	min	40.45	7.46	51.62	45.67	42.83	37.45	27.28	42.08	33.13	37.33	46.68
Thermal efficiency	%	24.0	2.8	21.3	22.2	20.3	21.2	27.9	26.3	26.9	25.5	24.4
Fuel burning rate, equivalent dry fuel basis	g/min	13.9	1.3	12.6	12.3	15.1	15.4	15.8	12.8	14.1	14.1	12.6
Temperature-corrected specific fuel consumption	g/liter	112	17	137	114	132	110	85	112	90	105	122
Temperature-corrected specific energy use	kJ/liter	2011	336	2513	2090	2414	2016	1497	1977	1592	1855	2146
Fire power	W	4149	410	3841	3758	4611	4695	4649	3772	4152	4151	3709
Cooking power	W	994	149	817	834	938	995	1295	993	1115	1057	904
Modified combustion efficiency	%	97.9	0.5	96.8	98.0	98.2	98.2	97.3	98.2	98.2	97.9	98.1
$PM_{2.5}$ temperature-corrected total mass	mg	1149	175	1300	846	1390	1075	1336	1215	1113	1044	1026
mass per effective volume of water boiled	mg/liter	246	38	284	180	299	225	277	267	233	222	223
mass per fuel mass (raw)	mg/kg	1769	365	1643	1213	1860	1678	2499	1807	2064	1703	1454
mass per equivalent dry fuel mass	mg/kg	2238	484	2071	1577	2270	2046	3267	2379	2579	2114	1836
mass per fuel energy	mg/MJ	125	28	113	86	124	112	185	135	146	120	104
mass per useful energy delivered (to water in pot)	mg/MJ	519	85	532	388	609	527	665	512	544	470	427
mass per time	mg/hour	1885	556	1564	1165	2058	1888	3099	1831	2185	1790	1389
CO temperature-corrected total mass	g	13.3	4.8	25.4	13.2	12.7	10.5	13.3	10.9	9.0	11.9	12.5
mass per effective volume of water boiled	g/liter	2.84	1.06	5.54	2.80	2.73	2.20	2.75	2.39	1.89	2.53	2.71
mass per fuel mass (raw)	g/kg	19.9	5.3	32.1	18.9	17.0	16.4	24.8	16.2	16.7	19.4	17.6
mass per equivalent dry fuel mass	g/kg	25.2	6.8	40.4	24.5	20.7	20.0	32.4	21.3	20.9	24.1	22.3
mass per fuel energy	g/MJ	1.40	0.37	2.21	1.34	1.13	1.09	1.84	1.21	1.18	1.37	1.26
mass per useful energy delivered (to water in pot)	g/MJ	5.92	1.80	10.37	6.03	5.57	5.16	6.59	4.59	4.41	5.36	5.18
mass per time	g/hour	20.9	5.6	30.5	18.1	18.8	18.5	30.7	16.4	17.7	20.4	16.9
CO_2 temperature-corrected total mass	g	942	151	1218	1027	1059	893	742	932	763	853	992
mass per effective volume of water boiled	g/liter	202	35	266	218	228	187	154	205	160	182	216
mass per fuel mass (raw)	g/kg	1423	51	1539	1472	1418	1394	1387	1387	1415	1392	1405
mass per equivalent dry fuel mass	g/kg	1799	83	1940	1913	1730	1699	1814	1826	1769	1727	1775
mass per fuel energy	g/MJ	100	5	106	104	95	93	103	104	100	98	101
mass per useful energy delivered (to water in pot)	g/MJ	423	47	498	471	465	438	369	393	373	384	413
mass per time	g/hour	1494	113	1465	1413	1569	1568	1721	1405	1498	1463	1343
THC (as C_3H_8) temperature-corrected total mass	g	1.40	0.67	2.96	1.47	1.55	1.04	1.72	1.09	0.83	1.10	0.83
mass per effective volume of water boiled	g/liter	0.30	0.15	0.65	0.31	0.33	0.22	0.36	0.24	0.17	0.23	0.18
mass per fuel mass (raw)	g/kg	2.10	0.84	3.74	2.11	2.08	1.62	3.21	1.62	1.54	1.79	1.17
mass per equivalent dry fuel mass	g/kg	2.66	1.09	4.72	2.75	2.53	1.98	4.20	2.13	1.93	2.22	1.48
mass per fuel energy	g/MJ	0.15	0.06	0.26	0.15	0.14	0.11	0.24	0.12	0.11	0.13	0.08
mass per useful energy delivered (to water in pot)	g/MJ	0.63	0.27	1.21	0.68	0.68	0.51	0.85	0.46	0.41	0.49	0.34

mass per time	g/hour	2.22	0.94	3.56	2.03	2.30	1.83	3.99	1.64	1.63	1.88	1.12
CH_4 temperature-corrected total mass	g	0.40	0.17	0.78	0.45	0.31	0.20	0.53	0.35	0.28	0.35	0.33
mass per effective volume of water boiled	g/liter	0.08	0.04	0.17	0.10	0.07	0.04	0.11	0.08	0.06	0.07	0.07
mass per fuel mass (raw)	g/kg	0.60	0.24	0.98	0.65	0.41	0.31	1.00	0.52	0.51	0.57	0.46
mass per equivalent dry fuel mass	g/kg	0.76	0.32	1.24	0.84	0.50	0.37	1.31	0.69	0.64	0.71	0.59
mass per fuel energy	g/MJ	0.04	0.02	0.07	0.05	0.03	0.02	0.07	0.04	0.04	0.04	0.03
mass per useful energy delivered (to water in pot)	g/MJ	0.18	0.07	0.32	0.21	0.13	0.10	0.27	0.15	0.14	0.16	0.14
mass per time	g/hour	0.63	0.28	0.93	0.62	0.45	0.34	1.24	0.53	0.54	0.60	0.44
NO_X temperature-corrected total mass	g	0.37	0.12	n.a.[1]	0.41	0.62	0.43	0.25	0.32	0.24	0.30	0.38
mass per effective volume of water boiled	g/liter	0.08	0.03	n.a.[1]	0.09	0.13	0.09	0.05	0.07	0.05	0.06	0.08
mass per fuel mass (raw)	g/kg	0.56	0.13	n.a.[1]	0.59	0.83	0.66	0.47	0.48	0.45	0.49	0.54
mass per equivalent dry fuel mass	g/kg	0.71	0.15	n.a.[1]	0.77	1.02	0.81	0.61	0.63	0.56	0.61	0.69
mass per fuel energy	g/MJ	0.04	0.01	n.a.[1]	0.04	0.06	0.04	0.03	0.04	0.03	0.03	0.04
mass per useful energy delivered (to water in pot)	g/MJ	0.17	0.05	n.a.[1]	0.19	0.27	0.21	0.12	0.14	0.12	0.14	0.16
mass per time	g/hour	0.60	0.16	n.a.[1]	0.57	0.92	0.75	0.58	0.49	0.47	0.51	0.52

[1] NO_X concentration measurement failed acceptance criteria

Table 2. *Low-moisture fuel, high-power hot-start – WBT, $PM_{2.5}$, and gaseous pollutant parameters*

Parameter	Units	Average	SD	Test 1	Test 4[1]	Test 5	Test 6	Test 7	Test 8	Test 9
Fuel moisture (wet basis)	%	7.6	0.9	9.4	7.1	7.7	7.7	6.6	7.1	7.2
Fuel consumed (raw)	g	549	46	601	616	520	524	536	560	489
Equivalent dry fuel consumed	g	417	51	454	497	391	366	422	438	351
Time to boil 5 liters of water, 25 to 100°C	min	25.46	3.73	32.25	28.67	21.23	24.38	24.50	23.17	24.03
Thermal efficiency	%	29.6	3.3	27.6	26.2	29.3	33.8	28.4	27.5	34.6
Fuel burning rate, equivalent dry fuel basis	g/min	16.5	1.9	14.1	17.3	18.4	15.0	17.2	18.9	14.6
Temperature-corrected specific fuel consumption	g/liter	82.5	10.5	93.9	97.7	76.6	73.4	80.9	85.6	69.2
Temperature-corrected specific energy use	kJ/liter	1473	214	1719	1789	1351	1295	1428	1511	1222
Fire power	W	4905	555	4296	5285	5410	4418	5064	5566	4293
Cooking power	W	1444	130	1187	1383	1583	1494	1440	1533	1485
Modified combustion efficiency	%	98.0	0.5	97.4	97.9	97.8	98.3	98.5	97.4	98.5
$PM_{2.5}$ temperature-corrected total mass	mg	1302	255	1101	1315	1759	1255	1346	n.a.[2]	1034
mass per effective volume of water boiled	mg/liter	273	51	236	280	363	266	279	n.a.[2]	216
mass per fuel mass (raw)	mg/kg	2543	571	1897	2313	3562	2534	2715	n.a.[2]	2235
mass per equivalent dry fuel mass	mg/kg	3386	776	2510	2871	4743	3626	3449	n.a.[2]	3116
mass per fuel energy	mg/MJ	190	46	137	157	269	206	195	n.a.[2]	177
mass per useful energy delivered (to water in pot)	mg/MJ	637	155	496	599	918	608	687	n.a.[2]	511
mass per time	mg/hour	3317	1061	2120	2984	5235	3269	3563	n.a.[2]	2729
CO temperature-corrected total mass	g	9.4	3.2	14.7	11.2	9.4	7.2	6.3	11.3	5.9
mass per effective volume of water boiled	g/liter	1.98	0.69	3.14	2.39	1.93	1.52	1.30	2.36	1.22
mass per fuel mass (raw)	g/kg	17.9	4.8	25.3	19.7	19.0	14.5	12.7	21.6	12.7
mass per equivalent dry fuel mass	g/kg	23.6	6.0	33.4	24.5	25.2	20.8	16.1	27.5	17.7
mass per fuel energy	g/MJ	1.32	0.32	1.83	1.34	1.43	1.18	0.91	1.56	1.00
mass per useful energy delivered (to water in pot)	g/MJ	4.55	1.39	6.60	5.11	4.89	3.48	3.21	5.66	2.90
mass per time	g/hour	23.4	6.3	28.2	25.4	27.9	18.7	16.7	31.3	15.5
CO_2 temperature-corrected total mass	g	703	93	858	815	648	663	654	662	624
mass per effective volume of water boiled	g/liter	148	21	184	174	134	141	136	138	130
mass per fuel mass (raw)	g/kg	1356	75	1478	1434	1312	1339	1320	1261	1350
mass per equivalent dry fuel mass	g/kg	1795	129	1957	1779	1747	1916	1677	1609	1882
mass per fuel energy	g/MJ	101	7	107	97	99	109	95	91	107
mass per useful energy delivered (to water in pot)	g/MJ	342	28	387	372	338	321	334	331	308
mass per time	g/hour	1766	105	1653	1849	1928	1727	1732	1828	1648
THC (as C_3H_8) temperature-corrected total mass	g	1.10	0.59	1.87	1.05	1.48	0.63	0.68	1.68	0.31
mass per effective volume of water boiled	g/liter	0.23	0.12	0.40	0.22	0.31	0.13	0.14	0.35	0.06
mass per fuel mass (raw)	g/kg	2.08	1.05	3.23	1.84	3.00	1.28	1.38	3.19	0.67
mass per equivalent dry fuel mass	g/kg	2.73	1.35	4.27	2.29	3.99	1.83	1.75	4.08	0.94
mass per fuel energy	g/MJ	0.15	0.08	0.23	0.12	0.23	0.10	0.10	0.23	0.05
mass per useful energy delivered (to water in pot)	g/MJ	0.53	0.28	0.84	0.48	0.77	0.31	0.35	0.84	0.15

mass per time	g/hour	2.76	1.47	3.61	2.38	4.40	1.65	1.81	4.63	0.82
CH_4 temperature-corrected total mass	g	0.32	0.17	0.50	0.22	0.46	0.20	0.23	0.52	0.12
mass per effective volume of water boiled	g/liter	0.07	0.03	0.11	0.05	0.09	0.04	0.05	0.11	0.02
mass per fuel mass (raw)	g/kg	0.61	0.30	0.85	0.38	0.93	0.40	0.46	0.98	0.25
mass per equivalent dry fuel mass	g/kg	0.80	0.39	1.13	0.47	1.24	0.57	0.58	1.25	0.35
mass per fuel energy	g/MJ	0.04	0.02	0.06	0.03	0.07	0.03	0.03	0.07	0.02
mass per useful energy delivered (to water in pot)	g/MJ	0.16	0.08	0.22	0.10	0.24	0.10	0.12	0.26	0.06
mass per time	g/hour	0.81	0.45	0.95	0.49	1.37	0.51	0.60	1.42	0.31
NO_X temperature-corrected total mass	g	0.25	0.06	n.a.[3]	0.37	0.20	0.28	0.22	0.22	0.23
mass per effective volume of water boiled	g/liter	0.05	0.01	n.a.[3]	0.08	0.04	0.06	0.05	0.05	0.05
mass per fuel mass (raw)	g/kg	0.50	0.09	n.a.[3]	0.65	0.41	0.56	0.44	0.42	0.50
mass per equivalent dry fuel mass	g/kg	0.66	0.13	n.a.[3]	0.81	0.55	0.80	0.56	0.53	0.70
mass per fuel energy	g/MJ	0.04	0.01	n.a.[3]	0.04	0.03	0.05	0.03	0.03	0.04
mass per useful energy delivered (to water in pot)	g/MJ	0.12	0.02	n.a.[3]	0.17	0.11	0.13	0.11	0.11	0.12
mass per time	g/hour	0.66	0.10	n.a.[3]	0.84	0.61	0.72	0.58	0.60	0.62

[1] Test 2 rejected due to fuel burning rate too low, Test 3 rejected due to fuel burning rate too high

[2] $PM_{2.5}$ outlier rejected

[3] NO_X concentration measurement failed acceptance criteria

Table 3. *Low-moisture fuel, low-power (30-min simmer) – WBT and pollutant emission parameters*

Parameter	Units	Average	SD	Test 1	Test 2	Test 5[1]	Test 6	Test 7	Test 8	Test 9
Fuel moisture (wet basis)	%	7.9	1.1	9.4	9.4	7.7	7.7	6.6	7.1	7.2
Fuel consumed (raw)	g	248	36	277	311	260	229	212	226	221
Equivalent dry fuel consumed	g	270	27	285	312	285	272	232	252	255
Fuel burning rate, equivalent dry fuel basis	g/min	9.0	0.9	9.5	10.4	9.5	9.1	7.7	8.4	8.5
Specific fuel consumption	g/liter	64.4	7.4	68.5	77.1	66.6	64.7	54.4	59.6	60.0
Specific energy use	kJ/liter	1150	150	1254	1412	1175	1142	959	1052	1059
Fire power	W	2680	302	2887	3178	2793	2663	2276	2468	2497
Modified combustion efficiency	%	95.1	0.5	95.4	95.7	95.1	95.2	94.7	94.2	95.5
$PM_{2.5}$ total mass	mg	355	47	n.a.[2]	418	404	318	347	345	298
mass per volume of water remaining	mg/liter	84.4	12.2	n.a.[2]	103.2	94.5	75.9	81.2	81.7	70.2
mass per fuel mass (raw)	mg/kg	1467	123	n.a.[2]	1344	1552	1390	1636	1530	1347
mass per equivalent dry fuel mass	mg/kg	1327	132	n.a.[2]	1338	1418	1172	1493	1371	1170
mass per fuel energy	mg/MJ	74.7	7.5	n.a.[2]	73.1	80.4	66.4	84.6	77.7	66.3
mass per time	mg/hour	710	94	n.a.[2]	836	808	637	693	690	596
CO total mass	g	14.6	1.8	16.0	14.6	15.6	13.3	13.9	17.0	11.5
mass per volume of water remaining	g/liter	3.46	0.45	3.86	3.60	3.65	3.17	3.25	4.02	2.71
mass per fuel mass (raw)	g/kg	59.4	9.2	57.9	46.9	60.0	58.1	65.5	75.2	51.9
mass per equivalent dry fuel mass	g/kg	54.1	7.9	56.3	46.6	54.8	49.0	59.8	67.4	45.1
mass per fuel energy	g/MJ	3.04	0.46	3.08	2.55	3.11	2.77	3.39	3.82	2.56
mass per time	g/hour	29.1	3.7	32.0	29.1	31.3	26.6	27.8	33.9	23.0
CO_2 total mass	g	448	56	522	507	479	419	390	436	381
mass per volume of water remaining	g/liter	107	15	126	125	112	100	91	103	90
mass per fuel mass (raw)	g/kg	1812	103	1886	1631	1841	1828	1842	1934	1721
mass per equivalent dry fuel mass	g/kg	1655	115	1834	1623	1682	1541	1681	1733	1495
mass per fuel energy	g/MJ	93	6	100	89	95	87	95	98	85
mass per time	g/hour	895	111	1041	1014	959	837	781	872	762
THC (as C_3H_8) total mass	g	0.59	0.32	1.23	0.78	0.44	0.35	0.33	0.41	0.56
mass per volume of water remaining	g/liter	0.14	0.08	0.30	0.19	0.10	0.08	0.08	0.10	0.13
mass per fuel mass (raw)	g/kg	2.30	1.04	4.46	2.50	1.70	1.53	1.56	1.84	2.53
mass per equivalent dry fuel mass	g/kg	2.13	1.06	4.33	2.49	1.55	1.29	1.42	1.65	2.20
mass per fuel energy	g/MJ	0.12	0.06	0.24	0.14	0.09	0.07	0.08	0.09	0.12
mass per time	g/hour	1.17	0.64	2.46	1.55	0.88	0.70	0.66	0.83	1.12
CH_4 total mass	g	0.26	0.08	0.41	0.31	0.24	0.20	0.20	0.18	0.31
mass per volume of water remaining	g/liter	0.06	0.02	0.10	0.08	0.06	0.05	0.05	0.04	0.07
mass per fuel mass (raw)	g/kg	1.06	0.27	1.47	1.01	0.94	0.86	0.93	0.78	1.41
mass per equivalent dry fuel mass	g/kg	0.97	0.27	1.43	1.00	0.86	0.73	0.85	0.70	1.22
mass per fuel energy	g/MJ	0.05	0.01	0.08	0.05	0.05	0.04	0.05	0.04	0.07
mass per time	g/hour	0.53	0.17	0.81	0.63	0.49	0.40	0.39	0.35	0.62

NO_X total mass	g	0.13	0.03	n.a.[3]	0.19	0.13	0.12	0.11	0.13	0.10
mass per volume of water remaining	g/liter	0.03	0.01	n.a.[3]	0.05	0.03	0.03	0.02	0.03	0.02
mass per fuel mass (raw)	g/kg	0.53	0.06	n.a.[3]	0.60	0.49	0.53	0.50	0.59	0.45
mass per equivalent dry fuel mass	g/kg	0.48	0.07	n.a.[3]	0.60	0.45	0.45	0.46	0.52	0.39
mass per fuel energy	g/MJ	0.03	0.00	n.a.[3]	0.03	0.03	0.03	0.03	0.03	0.02
mass per time	g/hour	0.26	0.06	n.a.[3]	0.38	0.26	0.24	0.21	0.26	0.20

[1] Tests 3 and 4 rejected due to fuel burning rates too high

[2] $PM_{2.5}$ outlier rejected

[3] NO_X concentration measurement failed acceptance criteria

Table 4. *Low-moisture fuel – emissions of OC (organic carbon) and EC (elemental carbon) in $PM_{2.5}$*

Parameter	Units	Average	SD	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
High-power cold-start												
OC temperature-corrected total mass	mg	262	72	409	227	207	212	354	274	237	229	210
mass per effective volume of water boiled	mg/liter	56.0	15.6	89.3	48.4	44.6	44.4	73.3	60.0	49.6	48.8	45.6
mass per fuel mass (raw)	mg/kg	403	122	516	326	278	330	661	407	440	374	297
mass per equivalent dry fuel mass	mg/kg	512	164	651	424	339	403	865	536	550	464	375
mass per fuel energy	mg/MJ	28.6	9.4	35.5	23.1	18.5	22.0	49.0	30.4	31.2	26.3	21.3
mass per useful energy delivered (to water in pot)	mg/MJ	118	32	167	104	91	104	176	115	116	103	87
mass per time	mg/hour	429	163	491	313	307	372	820	412	466	393	284
EC temperature-corrected total mass	mg	786	148	670	530	1020	798	938	853	836	690	741
mass per effective volume of water boiled	mg/liter	168	31	147	113	220	167	195	187	175	147	161
mass per fuel mass (raw)	mg/kg	1219	318	847	760	1366	1245	1755	1270	1550	1126	1050
mass per equivalent dry fuel mass	mg/kg	1541	412	1068	988	1667	1518	2295	1672	1937	1397	1326
mass per fuel energy	mg/MJ	86.1	23.9	58.3	54.0	91.0	82.9	130.0	94.7	109.8	79.2	75.1
mass per useful energy delivered (to water in pot)	mg/MJ	357	78	274	243	447	391	467	360	409	311	308
mass per time	mg/hour	1304	449	806	730	1511	1401	2176	1286	1641	1183	1003
High-power hot-start												
OC temperature-corrected total mass	mg	291	205	210	n.a.[1]	n.a.[2]	231	700	239	245	n.a.[2]	121
mass per effective volume of water boiled	mg/liter	60.9	42.1	44.9	n.a.[1]	n.a.[2]	49.3	144.5	50.8	50.8	n.a.[2]	25.3
mass per fuel mass (raw)	mg/kg	571	423	361	n.a.[1]	n.a.[2]	407	1417	484	494	n.a.[2]	262
mass per equivalent dry fuel mass	mg/kg	759	564	478	n.a.[1]	n.a.[2]	505	1887	692	627	n.a.[2]	366
mass per fuel energy	mg/MJ	42.7	32.2	26.1	n.a.[1]	n.a.[2]	27.6	107.0	39.2	35.6	n.a.[2]	20.7
mass per useful energy delivered (to water in pot)	mg/MJ	144	111	94	n.a.[1]	n.a.[2]	105	365	116	125	n.a.[2]	60
mass per time	mg/hour	767	657	404	n.a.[1]	n.a.[2]	525	2083	624	648	n.a.[2]	320
EC temperature-corrected total mass	mg	970	82	871	n.a.[1]	n.a.[2]	992	1022	993	1071	n.a.[2]	871
mass per effective volume of water boiled	mg/liter	204	16	186	n.a.[1]	n.a.[2]	212	211	211	222	n.a.[2]	182
mass per fuel mass (raw)	mg/kg	1894	242	1500	n.a.[1]	n.a.[2]	1746	2069	2007	2160	n.a.[2]	1882
mass per equivalent dry fuel mass	mg/kg	2524	361	1985	n.a.[1]	n.a.[2]	2167	2755	2871	2745	n.a.[2]	2624
mass per fuel energy	mg/MJ	142	23	108	n.a.[1]	n.a.[2]	118	156	163	156	n.a.[2]	149
mass per useful energy delivered (to water in pot)	mg/MJ	473	60	392	n.a.[1]	n.a.[2]	452	534	481	547	n.a.[2]	430
mass per time	mg/hour	2448	485	1676	n.a.[1]	n.a.[2]	2252	3041	2588	2835	n.a.[2]	2298
Low-power (30-minute simmer)												
OC total mass	mg	60.3	18.0	n.a.[3]	68.7	n.a.[2]	n.a.[2]	59.2	43.0	55.5	44.0	91.3
mass per volume of water remaining	mg/liter	14.3	4.3	n.a.[3]	16.9	n.a.[2]	n.a.[2]	13.8	10.2	13.0	10.4	21.5
mass per fuel mass (raw)	mg/kg	251	84	n.a.[3]	221	n.a.[2]	n.a.[2]	227	188	262	195	413
mass per equivalent dry fuel mass	mg/kg	226	71	n.a.[3]	220	n.a.[2]	n.a.[2]	208	158	239	175	359
mass per fuel energy	mg/MJ	12.8	4.0	n.a.[3]	12.0	n.a.[2]	n.a.[2]	11.8	9.0	13.6	9.9	20.3
mass per time	mg/hour	121	36	n.a.[3]	137	n.a.[2]	n.a.[2]	118	86	111	88	183
EC total mass	mg	224	53	n.a.[3]	271	n.a.[2]	n.a.[2]	276	205	215	243	134

mass per volume of water remaining	mg/liter	53.2	12.9	n.a.[3]	66.8	n.a.[2]	n.a.[2]	64.5	48.7	50.4	57.4	31.5
mass per fuel mass (raw)	mg/kg	920	177	n.a.[3]	871	n.a.[2]	n.a.[2]	1061	893	1015	1075	604
mass per equivalent dry fuel mass	mg/kg	834	171	n.a.[3]	867	n.a.[2]	n.a.[2]	969	753	926	963	525
mass per fuel energy	mg/MJ	47.0	9.7	n.a.[3]	47.3	n.a.[2]	n.a.[2]	54.9	42.7	52.5	54.6	29.7
mass per time	mg/hour	448	105	n.a.[3]	542	n.a.[2]	n.a.[2]	552	409	430	485	267

[1] Test rejected due to fuel burning rate too low

[2] Test rejected due to fuel burning rate too high

[3] OC/EC outliers rejected

Table 5. *Low-moisture fuel – $PM_{2.5}$ mass fractions of organic carbon to total carbon (OC/TC) and elemental carbon to total carbon (EC/TC)*

	High-Power Cold-Start	High-Power Hot-Start	Low-Power (Simmer)
Mass fraction of OC/TC	0.250	0.231	0.212
Mass fraction of EC/TC	0.750	0.769	0.788

Table 6. *Low-moisture fuel – emissions of BC (black carbon) measured with aethalometer*

Parameter	Units	Average	SD	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
High-power cold-start												
BC temperature-corrected total mass	mg	760	144	676	596	1055	858	860	741	738	617	699
mass per effective volume of water boiled	mg/liter	162	30	148	127	227	180	178	163	154	131	152
mass per fuel mass (raw)	mg/kg	1171	269	854	855	1412	1339	1608	1103	1369	1006	991
mass per equivalent dry fuel mass	mg/kg	1479	341	1077	1111	1723	1632	2102	1452	1711	1249	1251
mass per fuel energy	mg/MJ	82.5	19.5	58.8	60.7	94.1	89.1	119.1	82.3	97.0	70.8	70.9
mass per useful energy delivered (to water in pot)	mg/MJ	345	75	276	273	463	421	428	312	361	278	291
mass per time	mg/hour	1252	400	813	821	1562	1507	1994	1117	1449	1057	947
High-power hot-start												
BC temperature-corrected total mass	mg	705	98	590	n.a.[1]	n.a.[2]	n.a.[3]	852	648	704	n.a.[3]	729
mass per effective volume of water boiled	mg/liter	148	19	126	n.a.[1]	n.a.[2]	n.a.[3]	176	137	146	n.a.[3]	152
mass per fuel mass (raw)	mg/kg	1409	270	1016	n.a.[1]	n.a.[2]	n.a.[3]	1725	1309	1421	n.a.[3]	1576
mass per equivalent dry fuel mass	mg/kg	1904	376	1345	n.a.[1]	n.a.[2]	n.a.[3]	2297	1873	1805	n.a.[3]	2198
mass per fuel energy	mg/MJ	107	22	73	n.a.[1]	n.a.[2]	n.a.[3]	130	106	102	n.a.[3]	125
mass per useful energy delivered (to water in pot)	mg/MJ	349	66	266	n.a.[1]	n.a.[2]	n.a.[3]	445	314	360	n.a.[3]	360
mass per time	mg/hour	1830	503	1136	n.a.[1]	n.a.[2]	n.a.[3]	2536	1688	1865	n.a.[3]	1925
Low-power (30-minute simmer)												
BC total mass	mg	128	37	180	167	n.a.[2]	n.a.[2]	123	97	104	n.a.[3]	98
mass per volume of water remaining	mg/liter	31	9	43	41	n.a.[2]	n.a.[2]	29	23	24	n.a.[3]	23
mass per fuel mass (raw)	mg/kg	503	83	651	538	n.a.[2]	n.a.[2]	472	423	491	n.a.[3]	444
mass per equivalent dry fuel mass	mg/kg	465	103	633	535	n.a.[2]	n.a.[2]	432	356	448	n.a.[3]	386
mass per fuel energy	mg/MJ	26.0	5.2	34.6	29.2	n.a.[2]	n.a.[2]	24.5	20.2	25.4	n.a.[3]	21.9
mass per time	mg/hour	256	73	359	335	n.a.[2]	n.a.[2]	246	194	208	n.a.[3]	197

[1] Test rejected due to fuel burning rate too low

[2] Test rejected due to fuel burning rate too high

[3] BC aethalometer attenuation exceeded limit

Table 7. *High-moisture fuel, high-power cold-start – WBT, $PM_{2.5}$, and gaseous pollutant parameters*

Parameter	Units	Average	SD	Test 2[1]	Test 4	Test 5
Fuel moisture (wet basis)	%	16.7	0.8	16.7	15.9	17.5
Fuel consumed (raw)	g	887	99	777	970	913
Equivalent dry fuel consumed	g	649	66	577	707	664
Time to boil 5 liters of water, 25 to 100°C	min	50.31	7.81	42.17	57.75	51.00
Thermal efficiency	%	20.5	0.3	20.2	20.4	20.7
Fuel burning rate, equivalent dry fuel basis	g/min	13.0	0.7	13.7	12.2	13.0
Temperature-corrected specific fuel consumption	g/liter	133	17	113	145	140
Temperature-corrected specific energy use	kJ/liter	2428	312	2072	2654	2559
Fire power	W	3964	220	4179	3739	3974
Cooking power	W	811	43	846	762	824
Modified combustion efficiency	%	97.1	0.3	97.1	97.3	96.8
$PM_{2.5}$ temperature-corrected total mass	mg	1328	92	1222	1377	1385
mass per effective volume of water boiled	mg/liter	286	27	255	302	302
mass per fuel mass (raw)	mg/kg	1589	78	1674	1519	1574
mass per equivalent dry fuel mass	mg/kg	2167	84	2252	2084	2164
mass per fuel energy	mg/MJ	118	5	123	114	118
mass per useful energy delivered (to water in pot)	mg/MJ	578	26	607	558	570
mass per time	mg/hour	1691	159	1850	1531	1690
CO temperature-corrected total mass	g	20	2	18	19	23
mass per effective volume of water boiled	g/liter	4.31	0.60	3.84	4.10	4.98
mass per fuel mass (raw)	g/kg	23.9	2.9	25.2	20.6	25.9
mass per equivalent dry fuel mass	g/kg	32.6	3.8	33.9	28.3	35.6
mass per fuel energy	g/MJ	1.78	0.21	1.85	1.54	1.94
mass per useful energy delivered (to water in pot)	g/MJ	8.70	0.98	9.15	7.57	9.38
mass per time	g/hour	25.5	4.1	27.9	20.8	27.8
CO_2 temperature-corrected total mass	g	1032	64	958	1068	1070
mass per effective volume of water boiled	g/liter	222	20	200	234	233
mass per fuel mass (raw)	g/kg	1235	69	1312	1178	1216
mass per equivalent dry fuel mass	g/kg	1684	76	1766	1616	1672
mass per fuel energy	g/MJ	92	4	96	88	91
mass per useful energy delivered (to water in pot)	g/MJ	450	23	476	433	440
mass per time	g/hour	1314	131	1450	1188	1306
THC (as C_3H_8) temperature-corrected total mass	g	2.43	0.24	2.70	2.33	2.26
mass per effective volume of water boiled	g/liter	0.52	0.04	0.56	0.51	0.49
mass per fuel mass (raw)	g/kg	2.94	0.65	3.70	2.57	2.56
mass per equivalent dry fuel mass	g/kg	4.01	0.84	4.97	3.53	3.52
mass per fuel energy	g/MJ	0.22	0.05	0.27	0.19	0.19
mass per useful energy delivered (to water in pot)	g/MJ	1.07	0.23	1.34	0.94	0.93
mass per time	g/hour	3.14	0.82	4.09	2.59	2.75
CH_4 temperature-corrected total mass	g	0.48	0.05	0.42	0.50	0.50
mass per effective volume of water boiled	g/liter	0.10	0.01	0.09	0.11	0.11
mass per fuel mass (raw)	g/kg	0.57	0.01	0.58	0.55	0.57
mass per equivalent dry fuel mass	g/kg	0.77	0.01	0.78	0.76	0.78
mass per fuel energy	g/MJ	0.042	0.001	0.043	0.041	0.043
mass per useful energy delivered (to water in pot)	g/MJ	0.207	0.003	0.210	0.203	0.206
mass per time	g/hour	0.60	0.04	0.64	0.56	0.61
NO_X temperature-corrected total mass	g	0.46	0.05	0.40	0.48	0.49
mass per effective volume of water boiled	g/liter	0.10	0.01	0.08	0.11	0.11
mass per fuel mass (raw)	g/kg	0.55	0.01	0.55	0.53	0.56
mass per equivalent dry fuel mass	g/kg	0.75	0.02	0.74	0.73	0.77
mass per fuel energy	g/MJ	0.041	0.001	0.041	0.040	0.042
mass per useful energy delivered (to water in pot)	g/MJ	0.199	0.004	0.201	0.195	0.202
mass per time	g/hour	0.58	0.04	0.61	0.53	0.60

[1] Tests 1 and 3 not included due to testing errors

Table 8. *High-moisture fuel, high-power hot-start – WBT, $PM_{2.5}$, and gaseous pollutant parameters*

Parameter	Units	Average	SD	Test 1	Test 2	Test 3
Fuel moisture (wet basis)	%	16.7	0.5	16.4	16.5	17.3
Fuel consumed (raw)	g	666	48	719	651	627
Equivalent dry fuel consumed	g	477	21	499	477	456
Time to boil 5 liters of water, 25 to 100°C	min	24.81	1.29	26.25	23.75	24.42
Thermal efficiency	%	24.1	0.7	23.5	23.9	24.8
Fuel burning rate, equivalent dry fuel basis	g/min	19.2	0.7	19.0	20.1	18.7
Temperature-corrected specific fuel consumption	g/liter	93.3	4.5	98.0	92.6	89.1
Temperature-corrected specific energy use	kJ/liter	1708	82	1796	1697	1632
Fire power	W	5875	223	5798	6127	5700
Cooking power	W	1413	52	1360	1464	1414
Modified combustion efficiency	%	98.0	0.3	98.3	97.6	98.1
$PM_{2.5}$ temperature-corrected total mass	mg	927	187	726	1095	960
mass per effective volume of water boiled	mg/liter	192	38	151	227	199
mass per fuel mass (raw)	mg/kg	1496	378	1070	1791	1626
mass per equivalent dry fuel mass	mg/kg	2075	473	1543	2448	2236
mass per fuel energy	mg/MJ	113	26	84	134	122
mass per useful energy delivered (to water in pot)	mg/MJ	470	102	359	559	492
mass per time	mg/hour	2403	601	1758	2947	2505
CO temperature-corrected total mass	g	9.53	1.92	8.61	11.73	8.25
mass per effective volume of water boiled	g/liter	1.98	0.39	1.79	2.43	1.71
mass per fuel mass (raw)	g/kg	15.3	3.5	12.7	19.2	14.0
mass per equivalent dry fuel mass	g/kg	21.2	4.3	18.3	26.2	19.2
mass per fuel energy	g/MJ	1.16	0.24	1.00	1.43	1.05
mass per useful energy delivered (to water in pot)	g/MJ	4.82	1.01	4.25	5.99	4.22
mass per time	g/hour	24.6	6.0	20.8	31.6	21.5
CO_2 temperature-corrected total mass	g	734	51	768	759	675
mass per effective volume of water boiled	g/liter	152	11	160	157	140
mass per fuel mass (raw)	g/kg	1172	61	1131	1242	1143
mass per equivalent dry fuel mass	g/kg	1633	63	1631	1697	1571
mass per fuel energy	g/MJ	89	3	89	93	86
mass per useful energy delivered (to water in pot)	g/MJ	371	22	380	388	346
mass per time	g/hour	1887	143	1858	2043	1761
THC (as C_3H_8) temperature-corrected total mass	g	1.30	0.73	0.69	2.12	1.10
mass per effective volume of water boiled	g/liter	0.27	0.15	0.14	0.44	0.23
mass per fuel mass (raw)	g/kg	2.12	1.24	1.02	3.46	1.86
mass per equivalent dry fuel mass	g/kg	2.92	1.66	1.47	4.73	2.56
mass per fuel energy	g/MJ	0.16	0.09	0.08	0.26	0.14
mass per useful energy delivered (to water in pot)	g/MJ	0.66	0.38	0.34	1.08	0.56
mass per time	g/hour	3.42	2.07	1.68	5.70	2.87
CH_4 temperature-corrected total mass	g	0.19	0.13	0.09	0.34	0.15
mass per effective volume of water boiled	g/liter	0.04	0.03	0.02	0.07	0.03
mass per fuel mass (raw)	g/kg	0.31	0.22	0.13	0.56	0.25
mass per equivalent dry fuel mass	g/kg	0.43	0.30	0.18	0.76	0.34
mass per fuel energy	g/MJ	0.02	0.02	0.01	0.04	0.02
mass per useful energy delivered (to water in pot)	g/MJ	0.10	0.07	0.04	0.17	0.08
mass per time	g/hour	0.50	0.37	0.21	0.92	0.38
NO_X temperature-corrected total mass	g	0.30	0.03	0.33	0.29	0.27
mass per effective volume of water boiled	g/liter	0.06	0.01	0.07	0.06	0.06
mass per fuel mass (raw)	g/kg	0.47	0.02	0.49	0.48	0.45
mass per equivalent dry fuel mass	g/kg	0.66	0.05	0.71	0.65	0.62
mass per fuel energy	g/MJ	0.036	0.002	0.039	0.035	0.034
mass per useful energy delivered (to water in pot)	g/MJ	0.15	0.01	0.16	0.15	0.14
mass per time	g/hour	0.76	0.06	0.81	0.78	0.69

Table 9. *High-moisture fuel, low-power (30-min simmer) – WBT and pollutant emission parameters*

Parameter	Units	Average	SD	Test 1	Test 2	Test 3
Fuel moisture (wet basis)	%	18.0	4.4	14.2	16.8	22.8
Fuel consumed (raw)	g	350	47	297	388	364
Equivalent dry fuel consumed	g	306	31	302	338	276
Fuel burning rate, equivalent dry fuel basis	g/min	10.2	1.0	10.0	11.2	9.2
Specific fuel consumption	g/liter	73.2	7.9	72.4	81.5	65.7
Specific energy use	kJ/liter	1341	145	1327	1493	1203
Fire power	W	3101	307	3064	3424	2813
Modified combustion efficiency	%	95.9	0.8	95.6	95.2	96.8
$PM_{2.5}$ total mass	mg	568	144	465	733	506
mass per volume of water remaining	mg/liter	136	35	111	177	120
mass per fuel mass (raw)	mg/kg	1615	255	1564	1891	1390
mass per equivalent dry fuel mass	mg/kg	1846	315	1538	2167	1831
mass per fuel energy	mg/MJ	101	17	84	118	100
mass per time	mg/hour	1132	286	927	1459	1012
CO total mass	g	15.4	4.3	16.1	19.2	10.8
mass per volume of water remaining	g/liter	3.68	1.05	3.86	4.63	2.56
mass per fuel mass (raw)	g/kg	44.5	13.1	54.2	49.6	29.6
mass per equivalent dry fuel mass	g/kg	49.7	9.5	53.3	56.8	39.0
mass per fuel energy	g/MJ	2.71	0.52	2.91	3.10	2.12
mass per time	g/hour	30.6	8.5	32.1	38.2	21.5
CO_2 total mass	g	554	43	556	596	509
mass per volume of water remaining	g/liter	133	11	133	144	121
mass per fuel mass (raw)	g/kg	1602	242	1870	1537	1399
mass per equivalent dry fuel mass	g/kg	1815	46	1840	1761	1843
mass per fuel energy	g/MJ	99	3	100	96	101
mass per time	g/hour	1104	83	1108	1185	1019
THC (as C_3H_8) total mass	g	0.80	0.15	0.93	0.85	0.63
mass per volume of water remaining	g/liter	0.19	0.04	0.22	0.21	0.15
mass per fuel mass (raw)	g/kg	2.35	0.71	3.12	2.20	1.73
mass per equivalent dry fuel mass	g/kg	2.62	0.40	3.06	2.53	2.28
mass per fuel energy	g/MJ	0.14	0.02	0.17	0.14	0.12
mass per time	g/hour	1.60	0.31	1.85	1.70	1.26
CH_4 total mass	g	0.15	0.05	0.20	0.17	0.09
mass per volume of water remaining	g/liter	0.04	0.01	0.05	0.04	0.02
mass per fuel mass (raw)	g/kg	0.45	0.21	0.66	0.43	0.25
mass per equivalent dry fuel mass	g/kg	0.49	0.16	0.65	0.50	0.33
mass per fuel energy	g/MJ	0.03	0.01	0.04	0.03	0.02
mass per time	g/hour	0.30	0.11	0.39	0.33	0.18
NO_X total mass	g	0.22	0.01	0.22	0.22	0.20
mass per volume of water remaining	g/liter	0.052	0.003	0.054	0.053	0.048
mass per fuel mass (raw)	g/kg	0.63	0.11	0.75	0.57	0.55
mass per equivalent dry fuel mass	g/kg	0.71	0.05	0.74	0.65	0.73
mass per fuel energy	g/MJ	0.039	0.003	0.040	0.036	0.040
mass per time	g/hour	0.43	0.02	0.45	0.44	0.40

Table 10. *High-moisture fuel – emissions of $PM_{2.5}$ OC (organic carbon) and EC (elemental carbon)*

Parameter	Units	Average	SD	Test 1	Test 2	Test 3	Test 4	Test 5
High-power cold-start								
OC temperature-corrected total mass	mg	501	98	n.a.[1]	410	n.a.[1]	604	488
mass per effective volume of water boiled	mg/liter	108	24	n.a.[1]	86	n.a.[1]	133	107
mass per fuel mass (raw)	mg/kg	595	63	n.a.[1]	562	n.a.[1]	667	555
mass per equivalent dry fuel mass	mg/kg	811	90	n.a.[1]	756	n.a.[1]	915	763
mass per fuel energy	mg/MJ	44.3	4.9	n.a.[1]	41.3	n.a.[1]	49.9	41.6
mass per useful energy delivered (to water in pot)	mg/MJ	217	25	n.a.[1]	204	n.a.[1]	245	201
mass per time	mg/hour	630	39	n.a.[1]	621	n.a.[1]	672	596
EC temperature-corrected total mass	mg	489	85	n.a.[1]	519	n.a.[1]	393	555
mass per effective volume of water boiled	mg/liter	105	18	n.a.[1]	108	n.a.[1]	86	121
mass per fuel mass (raw)	mg/kg	592	143	n.a.[1]	711	n.a.[1]	434	631
mass per equivalent dry fuel mass	mg/kg	807	188	n.a.[1]	957	n.a.[1]	595	868
mass per fuel energy	mg/MJ	44.0	10.3	n.a.[1]	52.2	n.a.[1]	32.5	47.3
mass per useful energy delivered (to water in pot)	mg/MJ	215	51	n.a.[1]	258	n.a.[1]	159	228
mass per time	mg/hour	634	178	n.a.[1]	786	n.a.[1]	438	678
High-power hot-start								
OC temperature-corrected total mass	mg	205	113	97	323	194	n.a.[2]	n.a.[2]
mass per effective volume of water boiled	mg/liter	42.4	23.4	20.1	66.8	40.3	n.a.[2]	n.a.[2]
mass per fuel mass (raw)	mg/kg	333	193	143	528	329	n.a.[2]	n.a.[2]
mass per equivalent dry fuel mass	mg/kg	460	258	205	722	453	n.a.[2]	n.a.[2]
mass per fuel energy	mg/MJ	25.1	14.1	11.2	39.4	24.7	n.a.[2]	n.a.[2]
mass per useful energy delivered (to water in pot)	mg/MJ	104	59	48	165	100	n.a.[2]	n.a.[2]
mass per time	mg/hour	537	318	234	869	507	n.a.[2]	n.a.[2]
EC temperature-corrected total mass	mg	639	81	552	714	652	n.a.[2]	n.a.[2]
mass per effective volume of water boiled	mg/liter	133	17	115	148	135	n.a.[2]	n.a.[2]
mass per fuel mass (raw)	mg/kg	1028	189	814	1167	1104	n.a.[2]	n.a.[2]
mass per equivalent dry fuel mass	mg/kg	1429	225	1173	1595	1517	n.a.[2]	n.a.[2]
mass per fuel energy	mg/MJ	77.9	12.3	64.0	87.0	82.8	n.a.[2]	n.a.[2]
mass per useful energy delivered (to water in pot)	mg/MJ	324	47	273	364	334	n.a.[2]	n.a.[2]
mass per time	mg/hour	1652	295	1337	1921	1700	n.a.[2]	n.a.[2]
Low-power (30-minute simmer)								
OC total mass	mg	156	47	161	200	107	n.a.[2]	n.a.[2]
mass per volume of water remaining	mg/liter	37.5	11.4	38.6	48.3	25.5	n.a.[2]	n.a.[2]
mass per fuel mass (raw)	mg/kg	452	136	542	517	295	n.a.[2]	n.a.[2]
mass per equivalent dry fuel mass	mg/kg	505	105	534	593	389	n.a.[2]	n.a.[2]
mass per fuel energy	mg/MJ	27.5	5.7	29.1	32.3	21.2	n.a.[2]	n.a.[2]
mass per time	mg/hour	312	92	321	399	215	n.a.[2]	n.a.[2]
EC total mass	mg	269	61	206	329	271	n.a.[2]	n.a.[2]
mass per volume of water remaining	mg/liter	64.4	14.9	49.5	79.3	64.5	n.a.[2]	n.a.[2]
mass per fuel mass (raw)	mg/kg	763	78	695	849	746	n.a.[2]	n.a.[2]
mass per equivalent dry fuel mass	mg/kg	879	170	684	972	982	n.a.[2]	n.a.[2]
mass per fuel energy	mg/MJ	48.0	9.2	37.3	53.0	53.6	n.a.[2]	n.a.[2]
mass per time	mg/hour	536	121	412	654	543	n.a.[2]	n.a.[2]

[1] Tests 1 and 3 not included due to testing errors

[2] Tests 4 and 5 high-power cold-start test phase only

Table 11. *High-moisture fuel – $PM_{2.5}$ mass fractions of organic carbon to total carbon (OC/TC) and elemental carbon to total carbon (EC/TC)*

	High-Power Cold-Start	High-Power Hot-Start	Low-Power (Simmer)
Mass fraction of OC/TC	0.709	0.341	0.747
Mass fraction of EC/TC	0.291	0.659	0.253

Table 12. *High-moisture fuel – emissions of BC (black carbon) measured with aethalometer*

Parameter	Units	Average	SD	Test 1	Test 2	Test 3	Test 4	Test 5
High-power cold-start								
BC temperature-corrected total mass	mg	575	57	n.a.[1]	571	n.a.[1]	520	634
mass per effective volume of water boiled	mg/liter	124	13	n.a.[1]	119	n.a.[1]	114	138
mass per fuel mass (raw)	mg/kg	692	107	n.a.[1]	782	n.a.[1]	574	721
mass per equivalent dry fuel mass	mg/kg	944	139	n.a.[1]	1052	n.a.[1]	788	991
mass per fuel energy	mg/MJ	51.5	7.6	n.a.[1]	57.4	n.a.[1]	43.0	54.1
mass per useful energy delivered (to water in pot)	mg/MJ	252	37	n.a.[1]	284	n.a.[1]	211	261
mass per time	mg/hour	739	146	n.a.[1]	864	n.a.[1]	579	774
High-power hot-start								
BC temperature-corrected total mass	mg	616	37	575	647	625	n.a.[2]	n.a.[2]
mass per effective volume of water boiled	mg/liter	128	7	120	134	130	n.a.[2]	n.a.[2]
mass per fuel mass (raw)	mg/kg	988	122	847	1058	1058	n.a.[2]	n.a.[2]
mass per equivalent dry fuel mass	mg/kg	1374	132	1222	1446	1455	n.a.[2]	n.a.[2]
mass per fuel energy	mg/MJ	75.0	7.2	66.6	78.9	79.4	n.a.[2]	n.a.[2]
mass per useful energy delivered (to water in pot)	mg/MJ	312	24	284	330	320	n.a.[2]	n.a.[2]
mass per time	mg/hour	1588	178	1392	1741	1630	n.a.[2]	n.a.[2]
Low-power (30-minute simmer)								
BC total mass	mg	244	67	187	226	318	n.a.[2]	n.a.[2]
mass per volume of water remaining	mg/liter	58.3	15.7	44.8	54.5	75.5	n.a.[2]	n.a.[2]
mass per fuel mass (raw)	mg/kg	695	156	628	584	873	n.a.[2]	n.a.[2]
mass per equivalent dry fuel mass	mg/kg	813	293	618	669	1150	n.a.[2]	n.a.[2]
mass per fuel energy	mg/MJ	44.3	16.0	33.7	36.5	62.7	n.a.[2]	n.a.[2]
mass per time	mg/hour	486	135	372	450	636	n.a.[2]	n.a.[2]

[1] Tests 1 and 3 not included due to testing errors

[2] Tests 4 and 5 high-power cold-start test phase only

Table 13. *Tests with griddle, low-moisture fuel, high-power cold-start – WBT, $PM_{2.5}$, and gaseous pollutant parameters*

Parameter	Units	Average	SD	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 8[1]	Test 9
Fuel moisture (wet basis)	%	7.8	0.9	6.5	6.6	6.9	8.4	8.4	8.4	8.4	8.4
Fuel consumed (raw)	g	965	57	931	909	1047	926	951	1025	908	1024
Equivalent dry fuel consumed	g	758	39	754	737	810	713	735	773	722	818
Time to boil 5 liters of water, 25 to 100°C	min	44.31	3.20	46.67	43.22	44.80	41.48	39.70	43.12	45.47	50.02
Thermal efficiency	%	16.4	0.4	16.1	16.1	17.1	16.4	16.7	16.8	15.8	16.2
Fuel burning rate, equivalent dry fuel basis	g/min	17.1	1.0	16.1	17.0	18.1	17.2	18.5	17.9	15.9	16.4
Temperature-corrected specific fuel consumption	g/liter	265	27	248	239	253	238	263	274	312	296
Temperature-corrected specific energy use	kJ/liter	4819	489	4499	4345	4597	4320	4775	4980	5668	5370
Fire power	W	5186	293	4886	5158	5470	5196	5601	5424	4807	4949
Cooking power	W	851	69	786	830	933	853	936	912	759	803
Modified combustion efficiency	%	98.0	0.3	97.8	97.9	98.4	98.1	98.4	98.3	97.4	97.8
$PM_{2.5}$ temperature-corrected total mass	mg	2083	115	1927	2138	2001	2008	2143	2174	2002	2268
mass per effective volume of water boiled	mg/liter	593	47	533	587	541	553	614	629	630	657
mass per fuel mass (raw)	mg/kg	1760	114	1741	1988	1655	1786	1804	1728	1605	1776
mass per equivalent dry fuel mass	mg/kg	2241	137	2150	2453	2138	2322	2335	2292	2018	2222
mass per fuel energy	mg/MJ	123	8	118	135	118	128	129	126	111	122
mass per useful energy delivered (to water in pot)	mg/MJ	753	46	736	840	690	778	769	751	704	754
mass per time	mg/hour	2309	229	2084	2509	2319	2393	2593	2465	1924	2181
CO temperature-corrected total mass	g	23	5	24	23	18	20	18	19	32	29
mass per effective volume of water boiled	g/liter	6.54	1.79	6.66	6.18	4.92	5.54	5.08	5.50	10.01	8.41
mass per fuel mass (raw)	g/kg	19.2	4.1	21.8	20.9	15.0	17.9	14.9	15.1	25.5	22.7
mass per equivalent dry fuel mass	g/kg	24.4	4.7	26.9	25.8	19.4	23.3	19.3	20.0	32.1	28.4
mass per fuel energy	g/MJ	1.34	0.26	1.48	1.42	1.07	1.28	1.06	1.10	1.77	1.57
mass per useful energy delivered (to water in pot)	g/MJ	8.24	1.79	9.19	8.84	6.28	7.81	6.36	6.57	11.19	9.65
mass per time	g/hour	24.9	3.4	26.0	26.4	21.1	24.0	21.4	21.6	30.6	27.9
CO_2 temperature-corrected total mass	g	1749	127	1689	1635	1743	1653	1669	1711	1907	1982
mass per effective volume of water boiled	g/liter	499	57	467	449	472	455	478	495	600	575
mass per fuel mass (raw)	g/kg	1476	69	1527	1520	1441	1470	1405	1360	1529	1553
mass per equivalent dry fuel mass	g/kg	1878	49	1885	1876	1862	1911	1818	1804	1922	1942
mass per fuel energy	g/MJ	103	3	104	103	103	105	100	99	106	107
mass per useful energy delivered (to water in pot)	g/MJ	631	30	645	642	601	641	599	591	670	659
mass per time	g/hour	1929	74	1827	1919	2020	1970	2020	1941	1832	1906
THC (as C_3H_8) temperature-corrected total mass	g	2.08	0.23	2.30	1.79	2.07	2.06	1.76	2.36	2.00	2.29
mass per effective volume of water boiled	g/liter	0.59	0.07	0.64	0.49	0.56	0.57	0.50	0.68	0.63	0.66
mass per fuel mass (raw)	g/kg	1.76	0.18	2.08	1.66	1.71	1.83	1.48	1.88	1.61	1.79
mass per equivalent dry fuel mass	g/kg	2.23	0.23	2.57	2.05	2.21	2.38	1.92	2.49	2.02	2.24
mass per fuel energy	g/MJ	0.12	0.01	0.14	0.11	0.12	0.13	0.11	0.14	0.11	0.12
mass per useful energy delivered (to water in pot)	g/MJ	0.75	0.08	0.88	0.70	0.71	0.80	0.63	0.82	0.70	0.76

mass per time	g/hour	2.30	0.25	2.49	2.10	2.40	2.45	2.13	2.68	1.93	2.20
CH_4 temperature-corrected total mass	g	0.46	0.07	0.55	0.37	0.45	0.38	0.38	0.53	0.46	0.53
mass per effective volume of water boiled	g/liter	0.13	0.02	0.15	0.10	0.12	0.10	0.11	0.15	0.14	0.15
mass per fuel mass (raw)	g/kg	0.38	0.06	0.50	0.35	0.37	0.34	0.32	0.42	0.37	0.42
mass per equivalent dry fuel mass	g/kg	0.49	0.07	0.61	0.43	0.48	0.44	0.42	0.56	0.46	0.52
mass per fuel energy	g/MJ	0.027	0.004	0.034	0.024	0.026	0.024	0.023	0.031	0.025	0.029
mass per useful energy delivered (to water in pot)	g/MJ	0.16	0.02	0.21	0.15	0.15	0.15	0.14	0.18	0.16	0.18
mass per time	g/hour	0.50	0.07	0.59	0.44	0.52	0.45	0.46	0.61	0.44	0.51
NO_X temperature-corrected total mass	g	0.88	0.07	0.84	0.79	0.88	0.82	0.83	0.89	0.99	0.96
mass per effective volume of water boiled	g/liter	0.25	0.03	0.23	0.22	0.24	0.22	0.24	0.26	0.31	0.28
mass per fuel mass (raw)	g/kg	0.74	0.03	0.76	0.74	0.73	0.73	0.70	0.71	0.79	0.76
mass per equivalent dry fuel mass	g/kg	0.94	0.03	0.94	0.91	0.94	0.94	0.91	0.94	0.99	0.94
mass per fuel energy	g/MJ	0.052	0.001	0.052	0.050	0.052	0.052	0.050	0.052	0.055	0.052
mass per useful energy delivered (to water in pot)	g/MJ	0.32	0.01	0.32	0.31	0.30	0.32	0.03	0.31	0.35	0.32
mass per time	g/hour	0.96	0.04	0.91	0.93	1.02	0.97	1.01	1.01	0.95	0.93

[1] Test 7 rejected due to carbon balance out of limits

Table 14. *Tests with griddle, low-moisture fuel, high-power hot-start – WBT, $PM_{2.5}$, and gaseous pollutant parameters*

Parameter	Units	Average	SD	Test 2[1]	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
Fuel moisture (wet basis)	%	8.0	0.8	6.6	6.9	8.4	8.4	8.4	8.4	8.4	8.4
Fuel consumed (raw)	g	750	64	835	748	721	786	800	650	785	674
Equivalent dry fuel consumed	g	557	64	667	532	525	584	567	470	610	499
Time to boil 5 liters of water, 25 to 100°C	min	28.36	2.23	30.70	27.75	27.07	29.05	29.57	24.57	31.32	26.85
Thermal efficiency	%	19.8	1.2	18.9	21.7	19.9	19.6	20.9	20.3	17.7	19.6
Fuel burning rate, equivalent dry fuel basis	g/min	19.6	1.0	21.7	19.2	19.4	20.1	19.2	19.1	19.5	18.6
Temperature-corrected specific fuel consumption	g/liter	201	27	169	171	186	218	227	194	247	198
Temperature-corrected specific energy use	kJ/liter	3653	493	3076	3108	3378	3953	4115	3528	4475	3588
Fire power	W	5931	290	6576	5805	5871	6082	5803	5793	5894	5628
Cooking power	W	1174	71	1244	1258	1166	1190	1213	1178	1046	1102
Modified combustion efficiency	%	97.9	0.4	98.1	97.7	97.7	98.4	98.4	98.2	97.3	97.5
$PM_{2.5}$ temperature-corrected total mass	mg	1987	252	1959	2230	2101	2145	2005	1895	2138	1426
mass per effective volume of water boiled	mg/liter	552	77	465	581	580	609	593	552	631	408
mass per fuel mass (raw)	mg/kg	2048	272	2194	2416	2268	2078	1854	2054	1991	1528
mass per equivalent dry fuel mass	mg/kg	2766	393	2744	3395	3114	2795	2615	2838	2561	2063
mass per fuel energy	mg/MJ	152	22	151	187	172	154	144	156	141	114
mass per useful energy delivered (to water in pot)	mg/MJ	768	94	799	863	864	787	689	769	795	581
mass per time	mg/hour	3256	495	3578	3908	3626	3372	3010	3260	2994	2302
CO temperature-corrected total mass	g	18.0	4.6	14.7	19.4	18.8	13.7	14.7	14.0	26.9	21.3
mass per effective volume of water boiled	g/liter	5.01	1.45	3.48	5.06	5.19	3.90	4.34	4.08	7.95	6.10
mass per fuel mass (raw)	g/kg	18.5	4.4	16.4	21.0	20.3	13.3	13.6	15.2	25.1	22.9
mass per equivalent dry fuel mass	g/kg	24.9	5.8	20.5	29.6	27.9	17.9	19.1	21.0	32.2	30.9
mass per fuel energy	g/MJ	1.37	0.32	1.13	1.63	1.54	0.99	1.05	1.16	1.78	1.70
mass per useful energy delivered (to water in pot)	g/MJ	6.96	1.82	5.98	7.52	7.74	5.04	5.05	5.69	10.01	8.69
mass per time	g/hour	29.2	6.3	26.8	34.0	32.5	21.6	22.0	24.1	37.7	34.5
CO_2 temperature-corrected total mass	g	1317	115	1176	1294	1239	1344	1405	1234	1541	1305
mass per effective volume of water boiled	g/liter	368	53	279	337	342	381	415	359	455	373
mass per fuel mass (raw)	g/kg	1354	51	1317	1402	1337	1302	1299	1338	1435	1399
mass per equivalent dry fuel mass	g/kg	1827	95	1647	1970	1836	1751	1832	1848	1846	1888
mass per fuel energy	g/MJ	101	5	91	109	101	96	101	102	102	104
mass per useful energy delivered (to water in pot)	g/MJ	509	31	480	501	509	493	483	501	573	531
mass per time	g/hour	2145	53	2148	2268	2138	2112	2108	2124	2158	2107
THC (as C_3H_8) temperature-corrected total mass	g	1.92	0.53	1.53	2.28	2.89	1.74	1.25	1.80	2.31	1.56
mass per effective volume of water boiled	g/liter	0.53	0.15	0.36	0.59	0.80	0.49	0.37	0.52	0.68	0.45
mass per fuel mass (raw)	g/kg	1.99	0.60	1.71	2.47	3.12	1.68	1.16	1.95	2.15	1.67
mass per equivalent dry fuel mass	g/kg	2.69	0.84	2.14	3.46	4.29	2.27	1.63	2.69	2.77	2.25
mass per fuel energy	g/MJ	0.15	0.05	0.12	0.19	0.24	0.12	0.09	0.15	0.15	0.12
mass per useful energy delivered (to water in pot)	g/MJ	0.75	0.23	0.62	0.88	1.19	0.64	0.43	0.73	0.86	0.63

mass per time	g/hour	3.15	0.96	2.79	3.99	4.99	2.73	1.88	3.09	3.23	2.52
CH_4 temperature-corrected total mass	g	0.42	0.12	0.36	0.52	0.63	0.37	0.25	0.41	0.49	0.34
mass per effective volume of water boiled	g/liter	0.12	0.03	0.09	0.14	0.17	0.11	0.08	0.12	0.15	0.10
mass per fuel mass (raw)	g/kg	0.44	0.14	0.41	0.56	0.68	0.36	0.24	0.45	0.46	0.36
mass per equivalent dry fuel mass	g/kg	0.59	0.19	0.51	0.79	0.93	0.48	0.33	0.62	0.59	0.49
mass per fuel energy	g/MJ	0.03	0.01	0.03	0.04	0.05	0.03	0.02	0.03	0.03	0.03
mass per useful energy delivered (to water in pot)	g/MJ	0.17	0.05	0.15	0.20	0.26	0.14	0.09	0.17	0.18	0.14
mass per time	g/hour	0.70	0.22	0.66	0.91	1.09	0.58	0.38	0.71	0.69	0.55
NO_X temperature-corrected total mass	g	0.67	0.06	0.59	0.66	0.62	0.70	0.73	0.61	0.78	0.67
mass per effective volume of water boiled	g/liter	0.19	0.03	0.14	0.17	0.17	0.20	0.22	0.18	0.23	0.19
mass per fuel mass (raw)	g/kg	0.69	0.03	0.66	0.72	0.67	0.68	0.67	0.67	0.73	0.71
mass per equivalent dry fuel mass	g/kg	0.93	0.05	0.83	1.01	0.92	0.91	0.95	0.92	0.93	0.96
mass per fuel energy	g/MJ	0.051	0.003	0.046	0.056	0.051	0.050	0.052	0.051	0.051	0.053
mass per useful energy delivered (to water in pot)	g/MJ	0.26	0.02	0.24	0.26	0.26	0.26	0.25	0.25	0.29	0.27
mass per time	g/hour	1.09	0.03	1.08	1.16	1.07	1.10	1.10	1.06	1.09	1.07

[1] Test 1 high-power cold-start test phase only

Table 15. *Tests with griddle, low-moisture fuel, low-power (30-min simmer) – WBT and pollutant emission parameters*

Parameter	Units	Average	SD	Test 2[1]	Test 4[2]	Test 5	Test 6	Test 7	Test 8	Test 9
Fuel moisture (wet basis)	%	8.2	0.7	6.6	8.4	8.4	8.4	8.4	8.4	8.4
Fuel consumed (raw)	g	411	40	375	426	472	450	393	359	405
Equivalent dry fuel consumed	g	407	36	382	401	440	463	384	359	418
Fuel burning rate, equivalent dry fuel basis	g/min	13.6	1.2	12.7	13.4	14.7	15.4	12.8	12.0	13.9
Specific fuel consumption	g/liter	105	12	98	101	117	124	97	90	104
Specific energy use	kJ/liter	1900	218	1788	1839	2129	2258	1755	1640	1893
Fire power	W	4102	365	3851	4045	4438	4672	3872	3624	4212
Modified combustion efficiency	%	97.0	0.8	95.4	97.7	97.6	97.0	97.4	96.9	96.7
$PM_{2.5}$ total mass	mg	567	125	537	581	715	719	426	404	586
mass per volume of water remaining	mg/liter	146	36	138	147	191	193	107	102	146
mass per fuel mass (raw)	mg/kg	1367	193	1431	1365	1515	1598	1084	1125	1448
mass per equivalent dry fuel mass	mg/kg	1382	198	1406	1449	1625	1553	1108	1126	1404
mass per fuel energy	mg/MJ	76.1	10.9	77.5	79.8	89.5	85.5	61.1	62.0	77.3
mass per time	mg/hour	1134	249	1074	1163	1430	1439	851	809	1173
CO total mass	g	13.2	3.0	18.8	9.9	11.6	13.8	11.1	12.3	14.9
mass per volume of water remaining	g/liter	3.39	0.78	4.84	2.51	3.08	3.70	2.79	3.10	3.72
mass per fuel mass (raw)	g/kg	32.5	9.1	50.0	23.4	24.5	30.6	28.2	34.3	36.8
mass per equivalent dry fuel mass	g/kg	32.7	8.2	49.1	24.8	26.3	29.8	28.8	34.3	35.7
mass per fuel energy	g/MJ	1.80	0.45	2.71	1.37	1.45	1.64	1.59	1.89	1.97
mass per time	g/hour	26.4	5.9	37.5	19.9	23.1	27.6	22.1	24.6	29.8
CO_2 total mass	g	667	48	613	673	737	703	663	600	684
mass per volume of water remaining	g/liter	172	16	158	170	196	189	167	151	171
mass per fuel mass (raw)	g/kg	1626	58	1633	1581	1560	1562	1688	1668	1689
mass per equivalent dry fuel mass	g/kg	1644	67	1605	1679	1674	1517	1726	1669	1638
mass per fuel energy	g/MJ	91	4	88	92	92	84	95	92	90
mass per time	g/hour	1335	96	1226	1347	1473	1406	1326	1199	1368
THC (as C_3H_8) total mass	g	0.38	0.11	0.60	0.33	0.31	0.30	0.31	0.47	0.37
mass per volume of water remaining	g/liter	0.10	0.03	0.16	0.08	0.08	0.08	0.08	0.12	0.09
mass per fuel mass (raw)	g/kg	0.96	0.36	1.60	0.77	0.65	0.66	0.79	1.31	0.91
mass per equivalent dry fuel mass	g/kg	0.96	0.35	1.57	0.82	0.70	0.65	0.81	1.31	0.89
mass per fuel energy	g/MJ	0.05	0.02	0.09	0.04	0.04	0.04	0.04	0.07	0.05
mass per time	g/hour	0.77	0.23	1.20	0.65	0.62	0.60	0.62	0.94	0.74
CH_4 total mass	g	0.12	0.04	0.20	0.10	0.09	0.08	0.11	0.16	0.12
mass per volume of water remaining	g/liter	0.03	0.01	0.05	0.02	0.03	0.02	0.03	0.04	0.03
mass per fuel mass (raw)	g/kg	0.31	0.13	0.53	0.23	0.20	0.18	0.28	0.43	0.30
mass per equivalent dry fuel mass	g/kg	0.31	0.12	0.52	0.24	0.21	0.18	0.29	0.43	0.29
mass per fuel energy	g/MJ	0.02	0.01	0.03	0.01	0.01	0.01	0.02	0.02	0.02
mass per time	g/hour	0.25	0.08	0.40	0.19	0.19	0.16	0.22	0.31	0.25

NO_X total mass	g	0.34	0.04	0.31	0.34	0.38	0.39	0.37	0.28	0.32
mass per volume of water remaining	g/liter	0.09	0.01	0.08	0.09	0.10	0.10	0.09	0.07	0.08
mass per fuel mass (raw)	g/kg	0.83	0.05	0.83	0.80	0.80	0.86	0.93	0.77	0.79
mass per equivalent dry fuel mass	g/kg	0.84	0.06	0.81	0.85	0.86	0.83	0.95	0.77	0.76
mass per fuel energy	g/MJ	0.046	0.004	0.045	0.047	0.048	0.046	0.052	0.042	0.042
mass per time	g/hour	0.68	0.08	0.62	0.68	0.76	0.77	0.73	0.55	0.64

[1] Test 1 high-power cold-start test phase only

[2] Test 3 rejected due to carbon balance out of limits

Table 16. *Tests with griddle, low-moisture fuel – emissions of OC (organic carbon) and EC (elemental carbon) in $PM_{2.5}$*

Parameter	Units	Average	SD	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
High-power cold-start												
OC temperature-corrected total mass	mg	418	93	526	570	313	385	303	436	NA	414	397
mass per effective volume of water boiled	mg/liter	119	26	145	157	85	106	87	126	NA	130	115
mass per fuel mass (raw)	mg/kg	356	98	475	530	259	342	255	347	NA	332	311
mass per equivalent dry fuel mass	mg/kg	452	115	587	654	335	445	330	460	NA	418	389
mass per fuel energy	mg/MJ	24.9	6.3	32.3	36.1	18.4	24.5	18.2	25.3	NA	23.0	21.4
mass per useful energy delivered (to water in pot)	mg/MJ	152	41	201	224	108	149	109	151	NA	146	132
mass per time	mg/hour	463	110	568	669	363	458	367	495	NA	398	382
EC temperature-corrected total mass	mg	1364	158	1053	1324	1383	1321	1580	1480	NA	1304	1468
mass per effective volume of water boiled	mg/liter	389	51	291	364	374	363	453	428	NA	411	426
mass per fuel mass (raw)	mg/kg	1150	114	951	1231	1143	1174	1330	1176	NA	1046	1150
mass per equivalent dry fuel mass	mg/kg	1467	164	1175	1519	1477	1527	1721	1560	NA	1315	1439
mass per fuel energy	mg/MJ	80.8	9.0	64.7	83.7	81.4	84.1	94.8	85.9	NA	72.4	79.3
mass per useful energy delivered (to water in pot)	mg/MJ	492	49	402	520	477	512	567	511	NA	459	488
mass per time	mg/hour	1515	244	1138	1554	1603	1573	1911	1678	NA	1254	1412
High-power hot-start												
OC temperature-corrected total mass	mg	387	105	NA	577	377	494	335	402	304	360	249
mass per effective volume of water boiled	mg/liter	106	23	NA	137	98	136	95	119	88	106	71
mass per fuel mass (raw)	mg/kg	402	126	NA	646	409	533	325	372	329	336	266
mass per equivalent dry fuel mass	mg/kg	540	157	NA	807	575	732	437	525	455	432	359
mass per fuel energy	mg/MJ	29.8	8.6	NA	44.5	31.7	40.3	24.1	28.9	25.0	23.8	19.8
mass per useful energy delivered (to water in pot)	mg/MJ	150	45	NA	235	146	203	123	138	123	134	101
mass per time	mg/hour	641	214	NA	1053	662	852	527	604	522	505	401
EC temperature-corrected total mass	mg	1352	243	NA	1098	1654	1326	1597	1319	1370	1508	940
mass per effective volume of water boiled	mg/liter	377	75	NA	261	431	366	453	390	399	445	269
mass per fuel mass (raw)	mg/kg	1390	239	NA	1229	1793	1431	1548	1220	1486	1404	1008
mass per equivalent dry fuel mass	mg/kg	1880	359	NA	1537	2519	1965	2082	1721	2052	1806	1360
mass per fuel energy	mg/MJ	104	20	NA	85	139	108	115	95	113	100	75
mass per useful energy delivered (to water in pot)	mg/MJ	522	85	NA	448	640	545	586	454	556	561	383
mass per time	mg/hour	2209	410	NA	2005	2900	2288	2511	1980	2358	2112	1518
Low-power (30-minute simmer)												
OC total mass	mg	86.9	24.4	NA	124.1	NA	52.9	80.4	105.7	64.4	97.3	83.1
mass per volume of water remaining	mg/liter	22.4	6.5	NA	32.0	NA	13.4	21.4	28.4	16.2	24.5	20.8
mass per fuel mass (raw)	mg/kg	214	70	NA	331	NA	124	170	235	164	271	205
mass per equivalent dry fuel mass	mg/kg	215	66	NA	325	NA	132	183	228	168	271	199
mass per fuel energy	mg/MJ	11.8	3.6	NA	17.9	NA	7.3	10.1	12.6	9.2	14.9	11.0
mass per time	mg/hour	174	49	NA	248	NA	106	161	211	129	195	166
EC total mass	mg	376	121	NA	231	NA	459	514	496	304	232	396

mass per volume of water remaining	mg/liter	97.1	33.1	NA	59.7	NA	115.9	137.1	133.2	76.6	58.3	98.9
mass per fuel mass (raw)	mg/kg	898	214	NA	616	NA	1077	1090	1102	775	645	978
mass per equivalent dry fuel mass	mg/kg	911	233	NA	606	NA	1143	1169	1071	792	645	948
mass per fuel energy	mg/MJ	50.2	12.8	NA	33.4	NA	63.0	64.4	59.0	43.6	35.5	52.2
mass per time	mg/hour	752	242	NA	463	NA	917	1029	992	608	463	792

[1] Rejected due to carbon balance out of limits

[2] Test 1 high-power cold-start test phase only

Table 17. *Tests with griddle, low-moisture fuel – $PM_{2.5}$ mass fractions of organic carbon to total carbon (OC/TC) and elemental carbon to total carbon (EC/TC)*

	High-Power Cold-Start	High-Power Hot-Start	Low-Power (Simmer)
Mass fraction of OC/TC	0.235	0.223	0.188
Mass fraction of EC/TC	0.765	0.777	0.812

Table 18. *Tests with griddle, low-moisture fuel – emissions of BC (black carbon) measured with aethalometer*

Parameter	Units	Average	SD	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
High-power cold-start												
BC temperature-corrected total mass	mg	1279	87	1167	1325	1221	1151	1382	1344	n.a.[1]	1310	1331
mass per effective volume of water boiled	mg/liter	365	37	323	364	330	317	396	389	n.a.[1]	412	386
mass per fuel mass (raw)	mg/kg	1081	77	1054	1232	1010	1024	1163	1068	n.a.[1]	1050	1043
mass per equivalent dry fuel mass	mg/kg	1376	93	1302	1521	1304	1331	1505	1417	n.a.[1]	1320	1304
mass per fuel energy	mg/MJ	75.8	5.1	71.7	83.8	71.9	73.3	82.9	78.0	n.a.[1]	72.7	71.9
mass per useful energy delivered (to water in pot)	mg/MJ	462	32	446	521	421	446	496	464	n.a.[1]	461	443
mass per time	mg/hour	1417	154	1262	1556	1415	1372	1672	1524	n.a.[1]	1259	1280
High-power hot-start												
BC temperature-corrected total mass	mg	1269	138	n.a.[2]	1224	1410	1262	1383	1290	1293	1328	964
mass per effective volume of water boiled	mg/liter	353	46	n.a.[2]	291	368	348	393	381	376	392	276
mass per fuel mass (raw)	mg/kg	1308	151	n.a.[2]	1371	1528	1362	1340	1193	1402	1237	1033
mass per equivalent dry fuel mass	mg/kg	1767	228	n.a.[2]	1714	2147	1870	1802	1683	1936	1591	1395
mass per fuel energy	mg/MJ	97.4	12.6	n.a.[2]	94.5	118.3	103.0	99.3	92.7	106.7	87.7	76.8
mass per useful energy delivered (to water in pot)	mg/MJ	491	50	n.a.[2]	499	546	519	508	444	525	494	392
mass per time	mg/hour	2080	283	n.a.[2]	2236	2472	2178	2174	1936	2224	1860	1556
Low-power (30-minute simmer)												
BC total mass	mg	372	108	n.a.[2]	244	n.a.[1]	419	498	499	314	246	387
mass per volume of water remaining	mg/liter	96.1	30.1	n.a.[2]	62.8	n.a.[1]	105.8	132.8	133.9	79.0	61.8	96.6
mass per fuel mass (raw)	mg/kg	891	181	n.a.[2]	649	n.a.[1]	983	1056	1108	799	684	956
mass per equivalent dry fuel mass	mg/kg	903	195	n.a.[2]	638	n.a.[1]	1044	1133	1077	817	684	927
mass per fuel energy	mg/MJ	49.7	10.8	n.a.[2]	35.1	n.a.[1]	57.5	62.4	59.3	45.0	37.7	51.0
mass per time	mg/hour	745	216	n.a.[2]	487	n.a.[1]	837	997	998	628	492	774

[1] Rejected due to carbon balance out of limits

[2] Test 1 high-power cold-start test phase only

Table 19. *Comparison of results with pot/griddle and low-/high-moisture fuel – WBT, $PM_{2.5}$ and gaseous pollutant parameters*

Parameter	Units	High-power cold-start			High-power hot-start			Low-power 30-minute simmer		
Cooking vessel	n.a.	pot	pot	griddle	pot	pot	griddle	pot	pot	griddle
Fuel moisture (wet basis)	%	7.7	16.7	7.8	7.6	16.7	8.0	7.9	18.0	8.2
Fuel consumed (raw)	g	700	887	965	549	666	750	248	350	411
Equivalent dry fuel consumed	g	554	649	758	417	477	557	270	306	407
Time to boil 5 liters of water, 25 to 100°C	min	40.45	50.31	44.31	25.46	24.81	28.36	n.a.[1]	n.a.[1]	n.a.[1]
Thermal efficiency	%	24.0	20.5	16.4	29.6	24.1	19.8	n.a.[1]	n.a.[1]	n.a.[1]
Fuel burning rate, equivalent dry fuel basis	g/min	13.9	13.0	17.1	16.5	19.2	19.6	9.0	10.2	13.6
Temperature-corrected specific fuel consumption	g/liter	112	133	265	82.5	93.3	201	64.4	73.2	105
Temperature-corrected specific energy use	kJ/liter	2011	2428	4819	1473	1708	3653	1150	1341	1900
Fire power	W	4149	3964	5186	4905	5875	5931	2680	3101	4102
Cooking power	W	994	811	851	1444	1413	1174	n.a.[1]	n.a.[1]	n.a.[1]
Modified combustion efficiency	%	97.9	97.1	98.0	98.0	98.0	97.9	95.1	95.9	97.0
$PM_{2.5}$ temperature-corrected total mass	mg	1149	1328	2083	1302	927	1987	355	568	567
mass per effective volume of water	mg/liter	246	286	593	273	192	552	84.4	136	146
mass per fuel mass (raw)	mg/kg	1769	1589	1760	2543	1496	2048	1467	1615	1367
mass per equivalent dry fuel mass	mg/kg	2238	2167	2241	3386	2075	2766	1327	1846	1382
mass per fuel energy	mg/MJ	125	118	123	190	113	152	74.7	101	76.1
mass per useful energy delivered (to water in pot)	mg/MJ	519	578	753	637	470	768	n.a.[1]	n.a.[1]	n.a.[1]
mass per time	mg/hour	1885	1691	2309	3317	2403	3256	710	1132	1134
CO temperature-corrected total mass	g	13.3	20	23	9.4	9.53	18.0	14.6	15.4	13.2
mass per effective volume of water	g/liter	2.84	4.31	6.54	1.98	1.98	5.01	3.46	3.68	3.39
mass per fuel mass (raw)	g/kg	19.9	23.9	19.2	17.9	15.3	18.5	59.4	44.5	32.5
mass per equivalent dry fuel mass	g/kg	25.2	32.6	24.4	23.6	21.2	24.9	54.1	49.7	32.7
mass per fuel energy	g/MJ	1.40	1.78	1.34	1.32	1.16	1.37	3.04	2.71	1.80
mass per useful energy delivered (to water in pot)	g/MJ	5.92	8.70	8.24	4.55	4.82	6.96	n.a.[1]	n.a.[1]	n.a.[1]
mass per time	g/hour	20.9	25.5	24.9	23.4	24.6	29.2	29.1	30.6	26.4
CO_2 temperature-corrected total mass	g	942	1032	1749	703	734	1317	448	554	667
mass per effective volume of water	g/liter	202	222	499	148	152	368	107	133	172
mass per fuel mass (raw)	g/kg	1423	1235	1476	1356	1172	1354	1812	1602	1626
mass per equivalent dry fuel mass	g/kg	1799	1684	1878	1795	1633	1827	1655	1815	1644
mass per fuel energy	g/MJ	100	92	103	101	89	101	93	99	91
mass per useful energy delivered (to water in pot)	g/MJ	423	450	631	342	371	509	n.a.[1]	n.a.[1]	n.a.[1]
mass per time	g/hour	1494	1314	1929	1766	1887	2145	895	1104	1335
THC (as C_3H_8) temperature-corrected total mass	g	1.40	2.43	2.08	1.10	1.30	1.92	0.59	0.80	0.38
mass per effective volume of water	g/liter	0.30	0.52	0.59	0.23	0.27	0.53	0.14	0.19	0.10
mass per fuel mass (raw)	g/kg	2.10	2.94	1.76	2.08	2.12	1.99	2.30	2.35	0.96
mass per equivalent dry fuel mass	g/kg	2.66	4.01	2.23	2.73	2.92	2.69	2.13	2.62	0.96

mass per fuel energy	g/MJ	0.15	0.22	0.12	0.15	0.16	0.15	0.12	0.14	0.05
mass per useful energy delivered (to water in pot)	g/MJ	0.63	1.07	0.75	0.53	0.66	0.75	n.a.[1]	n.a.[1]	n.a.[1]
mass per time	g/hour	2.22	3.14	2.30	2.76	3.42	3.15	1.17	1.60	0.77
CH_4 temperature-corrected total mass	g	0.40	0.48	0.46	0.32	0.19	0.42	0.26	0.15	0.12
mass per effective volume of water	g/liter	0.08	0.10	0.13	0.07	0.04	0.12	0.06	0.04	0.03
mass per fuel mass (raw)	g/kg	0.60	0.57	0.38	0.61	0.31	0.44	1.06	0.45	0.31
mass per equivalent dry fuel mass	g/kg	0.76	0.77	0.49	0.80	0.43	0.59	0.97	0.49	0.31
mass per fuel energy	g/MJ	0.04	0.04	0.03	0.04	0.02	0.03	0.05	0.03	0.02
mass per useful energy delivered (to water in pot)	g/MJ	0.18	0.21	0.16	0.16	0.10	0.17	n.a.[1]	n.a.[1]	n.a.[1]
mass per time	g/hour	0.63	0.60	0.50	0.81	0.50	0.70	0.53	0.30	0.25
NO_X temperature-corrected total mass	g	0.37	0.46	0.88	0.25	0.30	0.67	0.13	0.22	0.34
mass per effective volume of water	g/liter	0.08	0.10	0.25	0.05	0.06	0.19	0.03	0.052	0.09
mass per fuel mass (raw)	g/kg	0.56	0.55	0.74	0.50	0.47	0.69	0.53	0.63	0.83
mass per equivalent dry fuel mass	g/kg	0.71	0.75	0.94	0.66	0.66	0.93	0.48	0.71	0.84
mass per fuel energy	g/MJ	0.04	0.04	0.05	0.04	0.04	0.051	0.03	0.04	0.046
mass per useful energy delivered (to water in pot)	g/MJ	0.17	0.20	0.32	0.12	0.15	0.26	n.a.[1]	n.a.[1]	n.a.[1]
mass per time	g/hour	0.60	0.58	0.96	0.66	0.76	1.09	0.26	0.43	0.68

[1] Not applicable to the low-power 30-minute simmer phase

Table 20. *Comparison of results with pot/griddle and low-/high-moisture fuel – emissions of OC (organic carbon) and EC (elemental carbon) in $PM_{2.5}$*

Parameter	Units	High-power cold-start			High-power hot-start			Low-power 30-minute simmer		
Cooking vessel	n.a.	pot	pot	griddle	pot	pot	griddle	pot	pot	griddle
Fuel moisture (wet basis)	%	7.7	16.7	7.8	7.6	16.7	8.0	7.9	18.0	8.2
OC temperature-corrected total mass	mg	262	501	418	291	205	387	60.3	156	86.9
mass per effective volume of water	mg/liter	56.0	108	119	60.9	42.4	106	14.3	37.5	22.4
mass per fuel mass (raw)	mg/kg	403	595	356	571	333	402	251	452	214
mass per equivalent dry fuel mass	mg/kg	512	811	452	759	460	540	226	505	215
mass per fuel energy	mg/MJ	28.6	44.3	24.9	42.7	25.1	29.8	12.8	27.5	11.8
mass per useful energy delivered	mg/MJ	118	217	152	144	104	150	n.a.[1]	n.a.[1]	n.a.[1]
mass per time	mg/hour	429	630	463	767	537	641	121	312	174
EC temperature-corrected total mass	mg	786	489	1364	970	639	1352	224	269	376
mass per effective volume of water	mg/liter	168	105	389	204	133	377	53.2	64.4	97.1
mass per fuel mass (raw)	mg/kg	1219	592	1150	1894	1028	1390	920	763	898
mass per equivalent dry fuel mass	mg/kg	1541	807	1467	2524	1429	1880	834	879	911
mass per fuel energy	mg/MJ	86.1	44.0	80.8	142	77.9	104	47.0	48.0	50.2
mass per useful energy delivered	mg/MJ	357	215	492	473	324	522	n.a.[1]	n.a.[1]	n.a.[1]
mass per time	mg/hour	1304	634	1515	2448	1652	2209	448	536	752
Mass fraction of OC/TC	-	0.250	0.709	0.235	0.231	0.341	0.223	0.212	0.747	0.188
Mass fraction of EC/TC	-	0.750	0.291	0.765	0.769	0.659	0.777	0.788	0.253	0.812

[1] Not applicable to the low-power 30-minute simmer phase

Table 21. *Comparison of low- and high-moisture fuel – emissions of BC (black carbon) measured with aethalometer*

Parameter	Units	High-power cold-start			High-power hot-start			Low-power 30-minute simmer		
Cooking vessel	n.a.	pot	pot	griddle	pot	pot	griddle	pot	pot	griddle
Fuel moisture (wet basis)	%	7.7	16.7	7.8	7.6	16.7	8.0	7.9	18.0	8.2
BC temperature-corrected total mass	mg	760	575	1279	705	616	1269	128	244	372
mass per effective volume of water	mg/liter	162	124	365	148	128	353	31	58.3	96.1
mass per fuel mass (raw)	mg/kg	1171	692	1081	1409	988	1308	503	695	891
mass per equivalent dry fuel mass	mg/kg	1479	944	1376	1904	1374	1767	465	813	903
mass per fuel energy	mg/MJ	82.5	51.5	75.8	107	75.0	97.4	26.0	44.3	49.7
mass per useful energy delivered	mg/MJ	345	252	462	349	312	491	n.a.[1]	n.a.[1]	n.a.
mass per time	mg/hour	1252	739	1417	1830	1588	2080	256	486	745

[1] Not applicable to the low-power 30-minute simmer phase

Table 22. *Carbon balance, percent difference based on fuel carbon*

Fuel Moisture	Test phase	Units	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
Tested with cooking pot			09/21/2012	09/25/2012	03/10/2014	03/17/2014	01/23/2015	01/26/2015	01/28/2015	01/29/2015	01/30/2015
Low	High-power cold-start	%	-10.5	-7.3	2.6	4.4	-2.4	-1.6	1.3	3.4	1.2
	High-power hot-start	%	-11.0	Rejected[1]	Rejected[2]	-0.6	1.6	-6.4	6.6	8.4	-4.2
	Low-power (simmer)	%	-5.4	7.3	Rejected[2]	Rejected[2]	3.2	11.3	2.7	-0.8	14.0
Tested with cooking pot			03/06/2014	03/14/2014	03/19/2014	04/08/2014	04/09/2014	---	---	---	---
High	High-power cold-start	%	Rejected[3]	1.3	Rejected[3]	9.9	6.6	---	---	---	---
	High-power hot-start	%	10.3	5.5	13.4	---	---	---	---	---	---
	Low-power (simmer)	%	-4.2	0.2	-1.2	---	---	---	---	---	---
Tested with cooking griddle			02/17/16	02/18/16	02/23/16	02/25/16	02/26/16	03/01/16	03/02/16	03/03/16	03/08/16
Low	High-power cold-start	%	-7.6	-6.8	-5.7	-8.4	-2.8	-2.2	Rejected[4]	-9.6	-10.4
	High-power hot-start	%	n.a.[5]	6.3	-13.1	-5.1	0.9	-3.8	-5.0	-5.6	-7.9
	Low-power (simmer)	%	n.a.[5]	6.9	Rejected[4]	5.2	5.3	13.9	2.3	5.0	6.7

[1] Rejected due to fuel burning rate too low

[2] Rejected due to fuel burning rate too high

[3] Rejected due to testing error

[4] Rejected due to carbon balance out of limits

[5] High-power cold-start test phase only

Table 23. *Measurement quality objectives for critical measurements.*
All data included in this report were based on measurements that met or exceeded these objectives.

Measurement	Reference	Indicators	Acceptance Criteria
Water and Fuel Mass, Electronic Balance	EPA RTP Met Lab SOP, MS-0501.0	Accuracy Precision	± 1 g ± 1 g
Water Temperature, Thermocouple	EPA RTP Met Lab SOP, TH-0301.0	Accuracy Precision	± 0.5 ˚C ± 0.5 ˚C
Fuel Heat of Combustion	ASTM D5865-04	Accuracy Precision	± 0.5% ± 0.5%
Fuel Moisture Content Mass, Electronic Balance	ASTM D4442-07	Accuracy Precision	± 1g ± 0.5g
$PM_{2.5}$ Mass, Microbalance	EPA Method 5	Accuracy Precision	± 0.01 mg ± 0.01 mg
$PM_{2.5}$ Mass, Sampling Air Flow	EPA RTP Met Lab SOP FV-0237.1	Accuracy Precision	± 1 Lpm ± 1 Lpm
PM OC/EC Mass	NIOSH Method 5040	Accuracy Precision	± 16.7% ± 10%
THC Concentration CH_4 Concentration	EPA Method 25A	Calibration linearity Zero bias Span bias Zero drift Span drift	± 2% of scale ± 5% of scale ± 5% of scale ± 3% of scale ± 3% of scale
CO Concentration	EPA Method 10		
CO_2 Concentration	EPA Method 3A		
NO_X Concentration	EPA Method 7E		
Duct Gas Velocity	EPA Methods 1 & 2	Accuracy Precision	± 5% of reading ± 5% of reading
Duct Gas Temperature Thermocouple	EPA RTP Met Lab SOP, TH-0301.0	Accuracy Precision	± 1 ˚C ± 1 ˚C

Acknowledgments

(Alphabetical Order)

Joan Bursey, EPA SEE (Senior Environmental Program) Quality Assurance

Dale Greenwell, EPA Instrumentation

Jerroll Faircloth, ARCADIS Instrumentation and Stove Operation

Michael Hays, EPA OC/EC Analysis

Amara Holder, EPA Aerosol Instrumentation

Laura Nessley, ARCADIS Quality Assurance

Bakul Patel, EPA OC/EC Analysis

Chris Pressley, EPA Electronics Shop

Michael Tufts, ARCADIS Metrology Laboratory

Richard Valentine, EPA Facilities

Craig Williams, ARCADIS Project Lead

Robert Wright, EPA Quality Assurance

References

1. ***Partnership for Clean Indoor Air.*** **[Online] 2012. [Cited: March 12, 2014.] http://www.pciaonline.org/.**

2. The United States' Commitment to the Global Alliance for Clean Cookstoves: Year Three Progress Report. *U.S. Department of State.* [Online] September 26, 2013. [Cited: March 12, 2014.] http://www.state.gov/r/pa/prs/ps/2013/09/214799.htm.

3. ISO/TC 285 Clean cookstoves and clean cooking solutions. *International Organization for Standardization.* [Online] 2014. [Cited: March 12, 2014.] http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=4857971.

4. Chiang, Ranyee. EPA Stove Testing Training Workshop. *Global Alliance for Clean Cookstoves.* [Online] February 28, 2013. [Cited: May 25, 2015.] http://community.cleancookstoves.org/about/news/02-28-2013-bonding-over-barbeque-bluegrass-music-and-best-practices-for-quality-testing.html.

5. *A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010.* Lim et al. Pp.2224-60, Elsevier : Lancet, 2012, Vol. 380.

6. *Bounding the role of black carbon in the climate system: A scientific assessment.* Bond et al. Pp. 5380-5552, American Geophysical Union : Journal of Geophysical Research, 2013, Vol. 118.

7. Standards & Testing. *Global Alliance for Clean Cookstoves.* [Online] 2014. [Cited: March 12, 2014.] http://www.cleancookstoves.org/our-work/standards-and-testing/.

8. The Water Boiling Test Version 4.2.3. *Global Alliance for Clean Cookstoves.* [Online] March 19, 2014. [Cited: September 26, 2014.] http://www.cleancookstoves.org/our-work/standards-and-testing/learn-about-testing-protocols/protocols/downloads/wbt-protocol.pdf.

9. International Workshop Agreement 11: 2012 Guidelines for Evaluating Cookstove Performance. *International Organization for Standardization.* [Online] 2012. [Cited: March 12, 2014.] http://www.iso.org/iso/catalogue_detail?csnumber=61975. IWA 11: 2012.

10. International Workshop Agreement 11: 2012 Guidelines for Evaluating Cookstove Performance. Final Draft. *Partnership for Clean Indoor Air.* [Online] 2012. [Cited: September 26, 2014.] http://www.pciaonline.org/files/ISO-IWA-Cookstoves.pdf.

11. Method 5G - Determination of Particulate Matter Emissions From Wood Heaters (Dilution Tunnel Sampling Location). *U.S. Environmental Protection Agency.* [Online] [Cited: October 06, 2015.] http://www3.epa.gov/ttnemc01/promgate/m-05g.pdf.

12. *StoveTeam International.* [Online] 2016. [Cited: May 30, 2016.] http://www.stoveteam.org/home.

13. NIOSH Method 5040, Diesel Particulate Matter. Atlanta, GA, USA : National Institute for Occupational Safety and Health, 2003.

14. *Measuring and simulating particulate organics in the atmosphere: problems and prospects.* Turpin, BJ, Saxena, P and Andrews, E. Elsevier : Atmospheric Environment, 2000, Vol. 34.

15. *Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials.* West Conshohocken, PA : ASTM International, 2007. ASTM D4442 - 07.

16. *Standard Test Method for Gross Calorific Value of Coal and Coke.* West Conshohocken, PA : ASTM International, 2013. ASTM D5865-13.

17. Longwell, Timothy. Desarrollo de la Propuesta del Protocolo Para la Evaluacion de Estufas con Plancha. San Antonio de Oriente, Francisco Morazan, Honduras : Zamorano University, October 31, 2013.

18. *Pollutant Emissions and Energy Efficiency under Controlled Conditions for Household Biomass Cookstoves and Implications for Metrics Useful in Setting International Test Standards - Also see Supplemental Information.* Jetter, J; Zhao, Y; Smith, K R; Khan, B; Yelverton, T; DeCarlo, P; Hays, M D. ACS Publications : Environmental Science & Technology, 2012, Vols. 46, Iss. 19., Pp. 10827-10834. [Cited: January 5, 2016]. http://www.kirkrsmith.org/publications/2012/11/04/pollutant-emissions-and-energy-efficiency-under-controlled-conditions-for-household-biomass-cookstoves-and-implications-for-metrics-useful-in-setting-international-test-standards.

19. *Solid-fuel household cook stoves: Characterization of performance and emissions.* Jetter, JJ and Kariher, P. Elsevier : Biomass and Bioenergy, 2009, Vols. 33, Iss. 2, Pp 294-305.

20. EPA QA/R-5, EPA Requirements for Quality Assurance Project Plans. *U.S. Environmental Protection Agency.* [Online] March 2001. [Cited: February 16, 2016.] http://www.epa.gov/quality/epa-qar-5-epa-requirements-quality-assurance-project-plans. EPA/240/B-01/003.

21. *Quality System and Description.* Cincinnati, OH : U.S. Environmental Protection Agency, National Risk Management Research Laboratory, August 15, 2012. Chapter 2.

22. Guidance on Technical Audits and Related Assessments for Environmental Data Operations, EPA QA/G-7 from January 2000. *U.S. Environmental Protection Agency.* [Online] January 2000. [Cited: February 16, 2016.] http://www.epa.gov/quality/guidance-technical-audits-and-related-assessments-environmental-data-operations-epa-qag-7. EPA/600/R-99/080.

23. Quality System and Description. *U.S. Environmental Protection Agency.* [Online] August 15, 2012. [Cited: March 12, 2014.] http://www.epa.gov/nrmrl/qa/chapter2.html.

24. EPA Requirements for Quality Assurance Project Plans. *U.S. Environmental Protection Agency.* [Online] 2001. [Cited: September 26, 2014.] http://www.epa.gov/quality/qs-docs/r5-final.pdf.