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ISO 19867 Laboratory Testing of the Zhejiang Huiwenmei Stove Company (ZHSC) Jet-Flame Combustion Accessory in the C-Quest Capital (CQC) Rocket Stove

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Figure 1 The ZHSC Jet-Flame in the Clay/Sand 15 Brick CQC Rocket stove with pot skirt.



Figure 2 The ZHSC Jet-Flame Combustion Accessory

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Introduction

The C-Quest Capital stove was built at the Aprovecho laboratory in April, 2020 following the manufacturer's design specifications. The 34cm by 34cm by 30cm tall stove is constructed with four layers of high mass bricks made from clay, sand, and cement. The combustion chamber is 12cm by 12cm with a fuel opening that is 12cm wide by 15cm tall. A pot skirt with a channel gap of 6mm was used on the 24cm in diameter testing pot. The stove was evaluated for fuel use and emissions with the Zhejiang Huiwenmei Stove Company Jet-Flame combustion accessory installed. Standard laboratory tests were performed using the ARC Laboratory Emissions Monitoring System (LEMS) and the ISO 19867-1 Water Heating Test at three power levels. A brief description of the fine particulate matter (PM_{2.5}), CO (carbon monoxide), and CO₂ (carbon dioxide) emission quality control measures are given. Further records are available upon request.

Testing a cook stove system

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

Fuel

The stove was fed with sticks of Douglas Fir that were cut to a particular cross section. A cross section of 2x1 cm is the standard lab wood used by the Aprovecho lab in the absence of other field-based specifications. The test results were optimized by using wood of different cross sections for each power level. During the high power test, the cross section was 7.6x8.9 cm constructed from two 3.8 x8.9 cm sticks. The wide end of one stick was laid against the floor of the stove. The wide end of the second piece was laid flat against the first piece, and the second piece cantilevered off the first piece by 2.5 cm. During the medium power test, the cross section of the sticks was 1x3.75cm. During the low power test, 3.8x3.8 cm sticks were used. The 7.6x8.9 cm and the 3.8x3.8 cm sticks had several 2.5 cm deep cuts put in the end of the sticks.

The moisture content of the wood was found to be 11.4% after repeated weighing of the wood as it was drying in a convection oven set to 75 C. Although the ISO protocol specifies an oven set to 103 C, the 75 C set point achieves the same outcome over a longer period of time due to the physical principal of evaporation in an unconfined space.

Stove and operating procedures

The CQC Rocket is a continuous feed wood burning Rocket stove. Control of firepower is achieved by changing the number of sticks present in the combustion chamber, and by controlling the rate that they are fed into the fire. The Jet-Flame with Power Control was fitted into the combustion chamber. The Jet-Flame is a combustion enhancing device that uses a fan to blow 30 jets of air into the bottom of the fire. The Jet-Flame with Power Control has a control switch that allows the fan to deliver a variable amount of air to the fire. While the firepower is still controlled by the feed rate, changing the amount of air supplied to the bottom of the stove influences the emissions. As the firepower is reduced the amount of air needed for the reduction of CO and PM_{2.5} is also decreased.

High power was achieved with a single 7.6x8.9 cm piece of Douglas Fir, constructed as described above, and with a feed rate that kept a steady flame size with the Jet-Flame on high. Medium power was achieved with two 1x3.75cm sticks laid flat and a steady flame size with the Jet-Flame also on high. Low power was achieved using two 3.8x3.8 cm sticks with the Jet-Flame on low. For low power the flame size was kept below 8 cm (as determined by visual estimate). During high and medium power the full flame was not visible, but care was taken to ensure that it filled the visible portion of the combustion chamber. The operating power levels were chosen to show the stove system at optimum performance.

Starting sequence

The tests were started with 10 cm long 1.8x1cm Douglas Fire sticks, char, and denatured (with methanol) alcohol. High power used four sticks, 20 g of char, and 1 tablespoon of alcohol. Both Medium and Low power used 5 sticks, 20 g of char and 2 tablespoons of alcohol.

The cooking vessel and water

A 24 cm diameter by 16 cm tall flat bottom pot was used. The pot is constructed of 20 gauge stainless steel. It was filled with 5 L of water. A pot skirt was used during the tests. The sheet metal pot skirt measured 10 cm high and there was an even gap of 6 mm between the skirt and the pot. The pot's mass was 0.824 kg. The water was heated to between 19 and 21 degrees C before the start of the stove test for consistency between test replicates.

Laboratory operational conditions

The environmental conditions of the laboratory were measured before and after each test. The air temperature was between 7 C and 20 C. The RH was between 40% and 50%. The atmospheric pressure was between 28.87 in Hg and 29.24 in Hg. The wind speed was not measured, but the tests were carried out indoors and the doors and windows were closed, so it was assumed to be nearly zero.

Testing Procedure

Standard ISO protocol

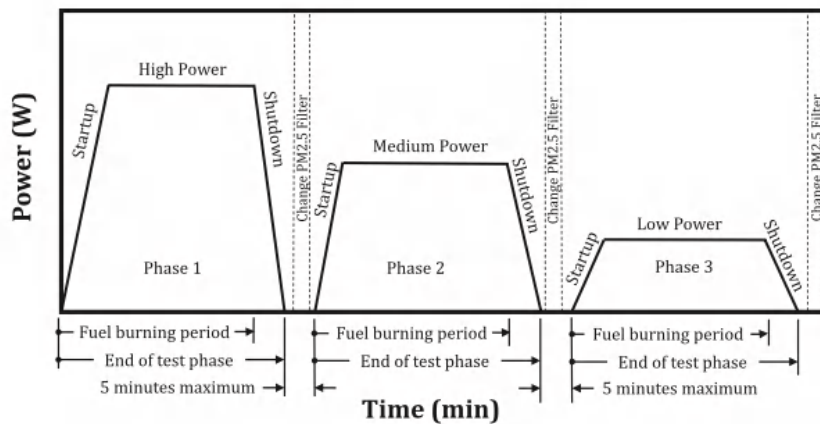


Figure 3 Diagram of the testing phases for a stove tested at three power levels (copied from the ISO standard).

ISO 19867 provides a laboratory test for cookstoves to be evaluated with performance metrics such as thermal efficiency and emissions released per unit energy delivered to the cooking pot. The procedure primarily involves heating or boiling and evaporating water, but each test phase is carried out for 30 minutes (plus shutdown time) at an attempted constant power level. The simulated cooking task for all three power levels is to heat water in a pot. Energy that goes into the pot is accounted for by measuring, over the test period, the temperature rise of the water and the amount of water that evaporates. The mass of emissions released by the stove is measured during the full combustion cycle, which includes the startup phase, the steady state phase, and the shutdown phase. The ISO protocol calls for each power level test to be carried out in sequence. The high power test is therefore done with the stove body at room temperature, and the medium and low power tests are therefore done with the stove body heated by the fire to well above ambient temperature. The heated condition is referred to as a hot start.

Deviations from the standard ISO protocol

This evaluation deviates from the standard protocol in that each of the power levels were tested independently and not in the sequence of high, medium, low power. Each 30-minute test of a power level was conducted using the sequence of pre-fire, hot start, hot start, and in some cases an additional hot start was added to the sequence. Cold start results were not reported. A cold start tends to produce more emissions and a lower thermal efficiency. The 5-minute interval between the

shutdown and startup period of the 30-minute tests, as shown in Figure 3, was maintained.

Performance metrics are presented for each power level independently, as is specified in the protocol. They are not averaged together to show overall metrics for the average of the three power levels because the tests were performed independently, the starting methods were different, and different fuel sizes were used for each power level.

Measurements Methods

Evaluation of a cookstove with ISO 19867 consists of measurements that are related to fuel use, emissions, safety, and durability. The instruments used to take the measurements are described in the following sections.

Fuel use

The direct measurements needed to evaluate the fuel use of a cookstove during the test are the mass of the water that was heated in the pot, the mass of water that was evaporated out of the pot, the mass of fuel used, and the temperature change of the water in the pot. The lower heating value and moisture content of the fuel are needed, as well as the water boiling temperature and the latent heat of evaporation. A balance with 1 g resolution is used to obtain the masses, a silicone shielded thermocouple is used to obtain the water temperature, a bomb calorimeter is used to measure the higher heating value of the fuel, and an elemental analyzer (CHN/O) is used to determine the lower heating value of the fuel.

Emissions

Emissions measurements are made with the ARC Laboratory Emissions Monitoring System (LEMS). The LEMS has been manufactured by ARC since 2009 and is in use in laboratories worldwide. The LEMS is a total capture dilution tunnel emissions sampling system with a gravimetric PM_{2.5} sampler and CO and CO₂ gas analyzers that are calibrated against reference gasses.

The gas analyzers and a real-time light scattering PM_{2.5} sensor report concentrations. The volumetric flow rate through the dilution tunnel is determined through a measurement of the gas temperature within the tunnel and the differential pressure across a Pitot static flow grid. The flow grid and its pressure transducer are calibrated against an inclined manometer. The temperature sensors are calibrated against the phase change temperatures of water.

The gravimetric PM_{2.5} sampler includes a rotameter to monitor the sample flow rate. It is calibrated against a bubble meter. The sample flow rate is controlled by a critical orifice. The pre and post-test masses of the 47 mm glass-fiber filters were measured with a 10 ug resolution balance at Aprovecho.

PM_{2.5} data quality

A reference weight was used to check the calibration of the balance before each weighing session. The filters were conditioned in a temperature and humidity-controlled chamber for 24 hours before weighing, and repeated measurements of the filter weight were taken at a frequency no faster than every 6 hours until the weight of two consecutive sets agreed within 0.05 mg. This method is described in the ISO protocol and ensures high quality PM_{2.5} data.

CO and CO₂ data quality

The gas sensors were calibrated in the middle of the testing series and the calibration constants were applied to all of the tests. This method does not follow the quality control procedure of the ISO protocol that specifies calibration checks at the beginning and end of a series of tests, but past ARC data is available to show that the calibration does hold over the period of these tests.

Test Metrics

The two primary performance metrics are thermal efficiency and emissions released per unit energy delivered to the cooking pot. Fugitive emissions are the emissions that would enter the room in an actual cooking event. These two metrics have been mapped against Voluntary Tiers of Performance by an ISO committee. The mapping is detailed in ISO Technical Report 19867-3 and is similar to the Tiers that were used in the ISO IWA (International Workshop Agreement) 11:2012. The maximum 19867-3 Tier score is 5 and the minimum score is 0. A Tier score of 0 indicates no improvement over the open fire. A Tier score of 5 for Thermal Efficiency means that the stove has the highest performance when compared against existing technology. A Tier of 5 for PM_{2.5} or CO means that almost all users would not face adverse health effects from the stove as tested. Actual field use is known to result in higher emissions for many stove and fuel types.

Thermal efficiency is defined as the quotient of energy delivered to the water over the energy expended by the fire. For wood burning stoves, thermal efficiency is presented with and without an energy credit given for the char that is produced by the stove.

These tests were started with a significant amount of charcoal in the combustion chamber in order to reduce startup emissions. Thermal efficiency with char was calculated following the ISO equation which accounted for the energy in the charcoal used to start the fire and the energy in the charcoal that was remaining.

Thermal efficiency without char was calculated accounting for the energy in the charcoal used to start the fire and not accounting for the energy in the charcoal that was remaining. The calculation of thermal efficiency without char followed ISO, but the stove was considered a multi-fuel stove since there was a significant amount of energy in the charcoal used to start the fire. Ignoring this startup energy could lead to misleading thermal efficiency results.

The amount of charcoal produced by wood burning stoves is quantified as “Char mass productivity” and “Char energy productivity”. Both metrics are expressed as percentages. Char mass productivity is the mass of charcoal created divided by the mass of the wood consumed. Char energy productivity is similarly defined, but on an energy basis. Char mass productivity is normally positive because wood burning stoves that lack sufficient air under the fire produce charcoal.

A strict interpretation of “Char mass productivity” as above would equate to a result of less than 1% for these tests because less than 3 g of charcoal was left in each test, and that would be considered the charcoal that was “produced”. Since the Jet-Flame typically consumes charcoal in the combustion chamber “Char mass productivity” was defined in these tests as the change in charcoal mass divided by the mass of wood consumed. This allowed the metric to go negative which illustrated the char consuming nature of the Jet-Flame.

Emissions per energy delivered to the cooking pot is a derived metric. It is calculated by dividing the mass of the emissions that were released by the stove by the amount of energy that the stove delivered to the cooking pot.

The firepower of the stove is presented because it often influences the emission rate. The firepower is the rate of energy released by the fire. The cooking power is also presented. The cooking power is the rate of energy that goes into the cooking pot.

The measured emissions rates are presented because they are specified as useful metrics in ISO 19867-1, and may be used to estimate room emissions concentrations using models such as the single-zone box model. An implementation of the box model is available at aprovecho.org under the “Project Planning” menu item.

The temperature corrected time to boil is included to give a measure of the usability of the stove. “Temperature corrected” means that the time to boil was normalized as if the change in water temperature was 75 C while in reality the change in water temperature during the tests at ARC was closer to 80 C.

The test duration is presented to make the tests easier to reproduce.

Voluntary Tiers of Performance

To better understand the results of this stove testing report the essential definitions of the Voluntary Tiers of Performance for emissions that are presented in ISO 19867-3 are shown here.

From ISO 19867-3, 6.3.2.1, Table 6:

“The highest tier for PM_{2,5} is the emission rate that, under the stated emission model assumptions, would result in kitchen indoor air quality that meets the WHO annual mean air quality guideline value of 10 µg/m³[6] for 90 % of homes. This is the level of PM_{2,5} associated with minimal adverse health risk, and has a relative risk for child acute lower respiratory infections (ALRI) of 1,0 in the integrated exposure response function (IER)[25].”

“Intermediate emission rate tiers have been set to achieve levels of indoor air quality that are equivalent to relative risks of 3,15 (Tier 1), 3,0 (Tier 2), 2,5 (Tier 3), and 1,5 (Tier 4), based on the IER for child ALRI. The value for Tier 1 was selected to be consistent with performance observed with simple cookstove technology improvements.”

For Tier 0:

“An emission rate higher than Tier 1, consistent with that observed with open fires and other simple solid fuel cookstove technologies.”

For CO, Refer to ISO 19867-3, 6.3.3.1, Table 10:

“The highest tier for CO is the emission rate that, under the stated emission model assumptions, would result in 90 % of homes having kitchen CO concentrations that meets the WHO 24 h mean air quality guideline value of 7 mg/m³.”

“The Tier 1 emission rate has been set so that 90 % of homes would have kitchen CO concentration at or below 230 mg/m³ during cooking events, a level associated with mild adverse acute symptoms from CO exposure (see empirical basis for tiers section, 6.3.3.2). The remaining intermediate emission rate tiers (2 to 4) represent equal mathematical divisions between Tiers 1 and 5 for the percentage of homes covered at 7 mg/m³ daily average CO concentration.”

For Tier 0: “An emission rate higher than Tier 1, and consistent with that observed with open fires and other simple solid fuel cookstove technologies.”

Statistical analysis and Aprovecho repeatability quality standard

For each metric the report includes the confidence interval of the average (labeled conservative bound and upper bound in the tables in the Results section). The

confidence interval was calculated using Student's t-distribution at a confidence level of 90%. The ISO 19867-3 Voluntary Tiers of Performance are calculated for the average and the confidence interval. The Tier associated with the upper bound of the confidence interval is labeled the High Tier Estimate. The Tier associated with the conservative bound is labeled the Low Tier Estimate.

At least 5 test replicates were conducted for each power level (high, medium, and low) per ISO 19867-1, Sec. 6.7.4: "A minimum of five replicate tests shall be performed for each cookstove/fuel combination, and the number of replicates shall be reported. If greater statistical confidence is desired to meet user needs (e.g. for rating against performance targets), then more than five replicate tests should be conducted." Additional tests were made until the range of the 90% confidence interval was less than 1/3 of the range of the Tier that contained the conservative bound of the confidence interval. In the tables below the range of the confidence interval is expressed as a fraction of the range of the Tier that contains the conservative bound of the confidence interval. That fraction is labeled Tier CI Range. When Tier CI Range is equal to or less than 0.33 the number of tests is deemed sufficient to meet the Aprovecho data repeatability quality standard (seven to nine tests each for high, medium, and low power were sufficient in this case).

The tables for this report were generated using an Excel spreadsheet that is available at aprovecho.org/software. The spreadsheet indicates whether or not the quality standard was met in the column that is labeled "CI < 1/3 of Tier". When the range of the 90% confidence interval is less than 0.33 of the range of the Tier that contains the conservative bound of the confidence interval for a given metric, the table displaces P > 90% to indicate that there is a greater than a 90% chance that the quality standard is met.

Interpretation of data and limitations

Testing a described stove system provides an overview of well-tended performance by trained professionals. When another stove is tested in the same manner statistically significant differences can be accurately compared. Analyzing stove performance and emissions at high, medium, and low power was not included in previous protocols and is an important improvement. The power level has a large influence on many factors.

Cooking in the field can be different in many ways. These test results and Tier ratings are "therefore not intended to serve as the sole basis for decisions about which technologies/fuels to promote for a given setting, since the performance of a given technology will likely differ under real-use conditions. The best way to assess real-world impacts of a stove intervention or program is through field studies, see ISO 19869, as well as other existing methods.

In addition to the limitations arising from differences from real-world performance, laboratory test metrics (efficiency, emissions, safety, and durability) do not inform other factors that are critical to the impacts a product, program, or intervention may achieve. These factors include, but are not limited to geographic/cultural suitability, price-affordability, acceptability to the target user group, and other socio-economic factors.”

Results

Stove type/model		CQC HotA 4.28.20	CQC HotB 4.28.20	CQC HotA 4.29.20	CQC HotB 4.29.20	CQC HotA 5.4.20	CQC HotB 5.4.20	CQC HotC 5.4.20	Average	n = Upper CI Bound 1 - P =	7 Conservative CI Bound 0.1	
Location		Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho				
Fuel species		DF	DF	DF	DF	DF	DF	DF	DF			
Date		4.28.20	4.28.20	4.29.20	4.29.20	5.4.20	5.4.20	5.4.20	4.28.20			
ISO Performance Metrics	units	Value	Value	Value	Value	Value	Value	Value		CI < 1/3 of Tier		
Thermal Efficiency With Char	%	42.8%	45.5%	41.7%	44.1%	42.6%	45.0%	45.6%	43.9%	45.0%	42.8%	P > 90%
Thermal Efficiency Without Char	%	42.8%	45.5%	41.7%	44.1%	42.6%	45.0%	45.6%	43.9%	45.0%	42.8%	P > 90%
CO per Energy Delivered to Cooking Pot g/MJ _d		1.10	0.79	1.89	1.40	0.89	1.15	0.53	1.11	0.78	1.43	P > 90%
PM per Energy Delivered to Cooking Pot mg/MJ _d		17.7	13.1	27.2	22.4	16.9	15.2	6.5	17.0	12.1	21.9	P > 90%
										High Tier Estimate	Low Tier Estimate	Tier CI Range
		Tier	Tier	Tier	Tier	Tier	Tier	Tier	Average			
Thermal Efficiency With Char		4.2	4.5	4.1	4.4	4.2	4.4	4.5	4.3	4.50	4.27	0.23
Thermal Efficiency Without Char		4.2	4.5	4.1	4.4	4.2	4.4	4.5	4.3	4.50	4.27	0.23
CO per Energy Delivered to Cooking Pot		5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.00	5.00	0.00
PM per Energy Delivered to Cooking Pot		4.7	4.8	4.6	4.6	4.7	4.8	4.9	4.7	4.87	4.70	0.17

Table 4 Results from testing the CQC Rocket Stove with Jet-Flame with Power Control at high power

Stove type/model		CQC HotA 4.28.20	CQC HotB 4.28.20	CQC HotA 4.29.20	CQC HotB 4.29.20	CQC HotA 5.4.20	CQC HotB 5.4.20	CQC HotC 5.4.20	Average	Upper CI Bound	Conservative CI Bound
Basic Operation	units										
HOT START- HIGH POWER											
Time to boil Pot #1	min	16	13	19	16	16	15	14	16	17	14
Temp-Corrected Time to Boil	min	15.5	12.5	17.6	15.4	15.1	13.6	13.4	14.7	16.0	13.5
Test duration	min	35	35	35	35	35	36	35	35	35	35
Firepower	watts	4,154	4,486	3,353	3,622	4,025	4,194	4,042	3,982	4,260	3,704
Average Cooking Power	kW	1,844	2,111	1,470	1,701	1,815	1,988	1,949	1,840	1,994	1,686
Char mass productivity	%	-3%	-3%	-4%	-4%	-4%	-4%	-4%	-3.7%	-3%	-4%
Measured Emissions Rate											
HOT START- HIGH POWER											
CO	gr/min	(cold start)	(cold start)	(cold start)	(cold start)	(cold start)	(cold start)	(cold start)			
CO ₂	gr/min	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
PM _{2.5}	mg/min	26	29	21	25	26	27	26	26	27	24
		2.0	1.7	2.4	2.3	1.8	1.8	0.8	1.8	2.2	1.4

Table 5 Operating conditions and measured emissions rates of the CQC Rocket Stove with Jet Flame with Power Control at high power

Stove type/model		CQC Hot.A 5.26.20	CQC Hot.B 5.26.20	CQC Hot.C 5.26.20	CQC Hot.A 5.27.20	CQC Hot.B 5.27.20	CQC Hot.C 5.27.20	Average	n = Upper CI Bound 1 - P =	6 Conservative CI Bound 0.1	
Location		Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho				
Fuel species		DF	DF	DF	DF	DF	DF				
Date		5.26.20	5.26.20	5.26.20	5.27.20	5.27.20	5.27.20	5.26.20			
ISO Performance Metrics	units	Value	Value	Value	Value	Value	Value				CI < 1/3 of Tier
Thermal Efficiency With Char	%	35.9%	36.8%	37.9%	38.0%	37.5%	39.0%	37.5%	38.4%	36.6%	P > 90%
Thermal Efficiency Without Char	%	35.6%	36.4%	37.4%	37.6%	37.2%	38.5%	37.1%	38.0%	36.3%	P > 90%
CO per Energy Delivered to Cooking Pot	g/MJ _d	4.79	4.55	4.11	4.80	4.63	3.75	4.44	4.09	4.78	P > 90%
PM per Energy Delivered to Cooking Pot	mg/MJ _d	44.3	37.4	33.5	38.7	39.1	13.7	34.4	25.6	43.3	P > 90%
								Average	High Tier Estimate	Low Tier Estimate	Tier CI Range
Thermal Efficiency With Char		Tier	Tier	Tier	Tier	Tier	Tier	3.7	3.84	3.66	0.18
Thermal Efficiency Without Char		3.5	3.6	3.7	3.7	3.7	3.8	3.7	3.79	3.62	0.17
CO per Energy Delivered to Cooking Pot		3.8	3.9	4.2	3.8	3.9	4.4	3.9	4.22	3.86	0.25
PM per Energy Delivered to Cooking Pot		4.3	4.4	4.5	4.4	4.4	4.8	4.4	4.63	4.32	0.31

Table 6 Results from testing the CQC Rocket Stove with Jet-Flame with Power Control at medium power.

		CQC Hot.A	CQC Hot.B	CQC Hot.C	CQC Hot.A	CQC Hot.B	CQC Hot.C		Upper CI	Conservative
Stove type/model		5.26.20	5.26.20	5.26.20	5.27.20	5.27.20	5.27.20	Average	Bound	CI Bound
Basic Operation		units								
HOT START- MED POWER										
Time to boil Pot # 1	min	24	24	22	23	22	21	23	24	22
Temp-Corrected Time to Boil	min	22.8	22.4	21.2	22.1	21.4	19.9	21.6	22.5	20.7
Test duration	min	35	35	35	35	35	35	35	35	35
Firepower	watts	3,321	3,292	3,378	3,215	3,296	3,545	3,341	3,434	3,249
Average Cooking Power	kW	1,294	1,313	1,382	1,328	1,346	1,487	1,358	1,416	1,301
Char mass productivity	%	-6%	-5%	-5%	-6%	-6%	-5%	-5%	-5%	-6%
Measured Emissions Rate										
HOT START- MEDIUM POWER										
CO	gr/min	0.4	0.4	0.3	0.4	0.4	0.3	0.4	0.4	0.3
CO2	gr/min	23	23	23	23	23	24	23	24	23
PM2.5	mg/min	3.4	2.9	2.8	3.1	3.2	1.2	2.8	3.4	2.1

Table 7 Operating conditions and measured emissions rates of the CQC Rocket Stove with Jet Flame with Power Control at medium power

		CQC HOT.A	CQC HOT.B	CQC HOT.C	CQC HOT.A	CQC HOT.B	CQC HOT.C	CQC HOT.D	CQC HOT.E	CQC HOT.F				
Stove type/model		6.29.20	6.29.20	6.29.20	6.30.20	6.30.20	6.30.20	6.30.20	6.30.20	6.30.20	Average	n =	9	
Location		Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho		Upper CI	Conservative	
Fuel species		DF	DF	DF	DF	DF	DF	DF	DF	DF		Bound	CI Bound	
Date		6.29.20	6.29.20	6.29.20	6.30.20	6.30.20	6.30.20	6.30.20	6.30.20	6.30.20		1 - P =	0.1	
ISO Performance Metrics	units	Value	Value	Value	Value	Value	Value	Value	Value	Value	CI < 1/3 of Tier			
Thermal Efficiency With Char	%	34.1%	36.7%	35.6%	37.3%	36.0%	37.6%	40.4%	39.8%	39.3%	37.4%	38.7%	36.1%	P > 90%
Thermal Efficiency Without Char	%	33.7%	36.5%	35.4%	36.7%	35.2%	37.1%	39.4%	39.1%	38.8%	36.9%	38.1%	35.7%	P > 90%
CO per Energy Delivered to Cooking Pot	g/MJ _s	7.26	8.32	7.06	7.88	6.30	6.42	6.25	6.67	5.35	6.83	6.27	7.40	P > 90%
PM per Energy Delivered to Cooking Pot	mg/MJ _s	124.7	92.7	94.0	108.8	89.9	71.3	72.5	78.3	56.4	87.6	74.7	100.5	P > 90%
		Tier	Tier	Tier	Tier	Tier	Tier	Tier	Tier	Tier	Average	High Tier	Low Tier	Tier CI Range
												Estimate	Estimate	
Thermal Efficiency With Char		3.4	3.6	3.5	3.7	3.5	3.7	4.0	3.9	3.9	3.7	3.87	3.61	0.26
Thermal Efficiency Without Char		3.3	3.6	3.5	3.6	3.5	3.7	3.9	3.9	3.8	3.6	3.81	3.57	0.24
CO per Energy Delivered to Cooking Pot		2.9	2.7	3.0	2.8	3.3	3.2	3.3	3.1	3.6	3.1	3.33	2.95	0.26
PM per Energy Delivered to Cooking Pot		3.5	3.8	3.7	3.7	3.8	3.9	3.9	3.8	4.0	3.8	3.91	3.75	0.16

Table 8 Results from testing the CQC Rocket Stove with Jet-Flame with Power Control at low power

Stove type/model		CQC HOT.A	CQC HOT.B	CQC HOT.C	CQC HOT.A	CQC HOT.B	CQC HOT.C	CQC HOT.D	CQC HOT.E	CQC HOT.F	Average	Upper CI	Conservative
		6.29.20	6.29.20	6.29.20	6.30.20	6.30.20	6.30.20	6.30.20	6.30.20	6.30.20		Bound	CI Bound
Basic Operation		units											
HOT START- LOW POWER													
Time to boil Pot # 1	min	No Boil	No Boil	No Boil	No Boil	No Boil	No Boil	No Boil	No Boil	No Boil			
Temp-Corrected Time to Boil	min												
Test duration	min	35	35	35	35	35	35	35	35	35	35	35	35
Firepower	watts	2,373	2,198	2,352	2,145	2,267	2,222	2,084	2,312	2,348	2,256	2,318	2,193
Average Cooking Power	kW	913	924	952	912	917	950	955	1,035	1,040	955	986	925
Char mass productivity	%	-8%	-9%	-8%	-9%	-8%	-8%	-8%	-8%	-8%	-8%	-8%	-9%
Measured Emissions Rate													
HOT START- LOW POWER													
CO	gr/min	0.4	0.5	0.4	0.4	0.3	0.4	0.4	0.4	0.3	0.4	0.4	0.4
CO2	gr/min	17	16	16	17	15	15	14	15	15	16	16	15
PM2.5	mg/min	6.8	5.1	5.4	6.0	4.9	4.1	4.2	4.9	3.5	5.0	5.6	4.4

Table 9 Operating conditions and measured emissions rates of the CQC Rocket Stove with Jet Flame with Power Control at low power