ASTM E3053 TEST METHOD STUDY

Prepared by NESCAUM

March 2022

ASTM E3053 Test Method Study

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Abstract

In 2018, the U.S. Environmental Protection Agency (US EPA) granted broadly applicable Alternate Test Method status to test methods Alt-125 and Alt-127 for use in certifying residential cordwood stoves as meeting New Source Performance Standards (NSPS) under the federal Clean Air Act. These methods are based on the ASTM E3053 cordwood test protocol, which guides the fueling and operational procedures used in the wood stove tests. Because of the widespread use of those alternative methods in certifying wood stoves, the New York State Energy Research and Development Authority (NYSERDA) funded the Northeast States for Coordinated Air Use Management (NESCAUM) to conduct replicate certification testing with the ASTM E3053-based cordwood stove test methods. The research focused on non-catalytic stoves because they represent the most common emission control technology.

In this report, NESCAUM presents results from testing seven non-catalytic cordwood stoves that were previously certified with the test methods based on ASTM E3053. This study focused on non-catalytic stoves because they represent approximately 80% of the cordwood stove market, and approximately 60% of non-catalytic wood stoves have used the method to certify emissions and efficiency performance under the Clean Air Act, based on US EPA data. NESCAUM contracted with a US EPA-approved, ISO-accredited lab to conduct the tests. The test lab followed the operation and fueling information contained in the stoves' certification test reports submitted to US EPA when demonstrating compliance with the NSPS to the extent that test conditions were clearly reported. The test lab also conducted additional tests on the seven wood stoves following instructions in the stove owner's manuals to assess the stoves' emissions performance when following manufacturer operating instructions to the end-user.

The lab results from this study found that, when the reported certification test procedures were followed, measured stove emission rates were 3 to 17 times higher than reported to US EPA in the certification tests. When the instructions given in the manufacturers' owner's manuals were followed, measured emission rates of the seven tested stoves ranged from 108% higher to 63% lower than the lab tests following the certification test method. The practice of differing instructions to the lab versus those in the owner's manual can raise questions about conformance to the NSPS requirements contained in 40 CFR §60.536(g)(1), which requires that instructions given to the lab for certification testing be consistent with the instructions included in the owner's manual.

As this work concluded, the US EPA withdrew approval of the use of Alt-125 and Alt-127 as Broadly Approved Alternate Test Methods for compliance testing of residential cordwood stoves. The study

results presented here provide additional support for the withdrawal of these methods for use in certification testing.

Keywords/Glossary

ASTM – ASTM International, an international standards organization formerly known as the American Society for Testing and Materials

ATM – Alternative Test Method

BA-ATM – Broadly Applicable Alternative Test Method

EPA – U.S. Environmental Protection Agency

FRM – federal reference method

g/h – grams per hour, which is an emission rate

g/kg – grams per kilogram, which is an emission factor

HHV – higher heating value, which refers to the heating value of a fuel with the water component of the fuel included.

ISO – International Organization of Standardization

kg/h – kilogram per hour, which is an appliance's burn rate

M28 – Refers to M28R, which is the federal reference method for crib wood testing that references ASTM 2780

NSPS – New Source Performance Standards

NYSERDA – New York State Energy Research and Development Authority

PM – particulate matter

RWH – residential wood heater

Acknowledgements

The Northeast States for Coordinated Air Use Management (NESCAUM) gratefully acknowledges the funding support provided by the New York State Energy Research and Development Authority (NYSERDA) under Agreement 123059. This report was published by NESCAUM, an association of the eight Northeast state air pollution control agencies. NESCAUM assists its member state agencies in implementing national environmental programs required under the Clean Air Act and other federal legislation. We would like to thank the Alaska Department of Environmental Conservation for its assistance with this research.

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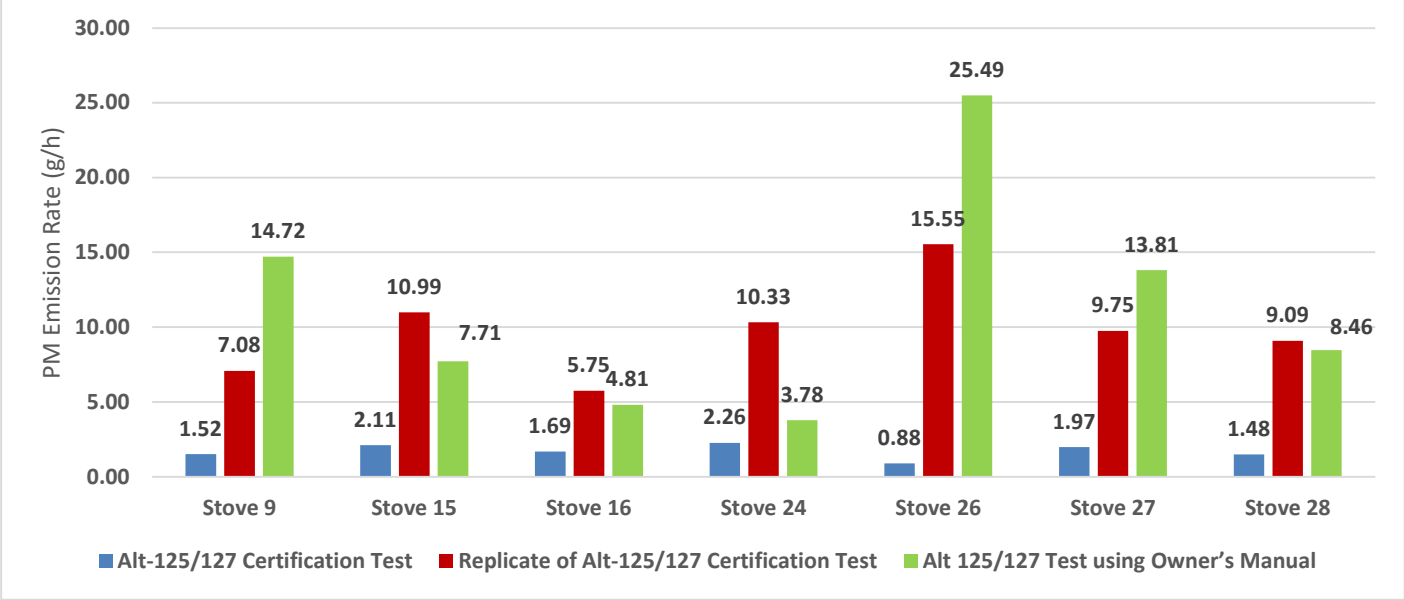
Executive Summary

Approximately 60 percent of all certified stoves, and more than 80 percent of cordwood stoves certified since EPA issued the broadly applicable status, used ASTM E3053-based test methods to determine compliance with EPA emission standards. There is little research data available, however, to assess the stringency, bias, reproducibility, or variability of the test methods. In order to investigate this data gap, NESCAUM identified seven non-catalytic cordwood stoves certified using ASTM E3053-based test methods to undergo emission testing assessment at an EPA-approved, ISO-accredited test laboratory. The seven stoves tested constitute about 10% of the non-catalytic stoves that have been certified as compliant with the Step 2 NSPS using the ASTM E3053-based method.

The test laboratory retained by NESCAUM performed a replicate test of the certification test for each of the seven stoves, following all instructions and information included in the stoves' certification test reports. The test laboratory was unable to replicate the emission rates submitted to US EPA using the information on test conditions provided in the test reports. The emissions rates measured in the replicate tests were 3.4 to 17.7 times higher than the certification values, as shown in Figure ES-1.

Figure ES-1. Comparison of All Weighted Average Emission Rates from Seven Stoves Study.



A second test was conducted on each stove following the operating instructions included in the manufacturer's owner's manual. This testing found that varying instructions had a significant impact on the emission outcomes when comparing results from following the test lab conditions and following the owner's manual instructions, from doubling emissions in one stove to reducing them by almost two thirds in another. The practice of differing instructions to the lab versus those in the owner's manual can raise questions about conformance to the NSPS requirements contained in 40 CFR §60.536(g)(1), which requires that instructions given to the lab for certification testing are consistent with the instructions included in the owner's manual.

As this work was concluding, EPA withdrew approval of the use of Alt-125 and Alt-127 as Broadly Approved Alternate Test Methods for compliance testing of residential cordwood stoves. The study results presented here provide additional support for the withdrawal of these methods for use in certification testing.

1 Introduction

In 2015, the U.S. Environmental Protection Agency (EPA) revised the New Source Performance Standards (NSPS) for Residential Wood Heaters (RWH), establishing two tiers of particulate matter (PM) emission limits for residential wood stoves.[1] The two tiers are Step 1 standards, which were in effect from May 2015 to May 2020, and more stringent Step 2 standards, which became effective in May 2020. A wood stove model line is certified as compliant with the NSPS requirements if emissions from a prototype appliance, as measured by an EPA-approved testing laboratory, conform with those limits. Compliance certificates are granted for five-year periods but typically are renewed every five years after the initial period without retesting unless the manufacturer has made significant stove design changes.

Certification tests for the RWH NSPS must be conducted according to EPA-approved test methods, including specifications concerning the fuel used and how it is configured in the firebox, the burn cycle, and emission measurement techniques. Method 28R (M28R) is the Federal Reference Method (FRM) for testing cordwood stoves. The method is a "hot-to-hot"[2] test using dimensional lumber as fuel in a single specified configuration (crib wood) and assesses performance over four prescribed burn rate categories. A form of this test method has been used to assess appliance performance in the federal program since the late 1980s and in state programs since the late 1970s.

As described in a 2016 EPA discussion paper "*Process for Developing Improved Cordwood Test Methods for Wood Heaters*," states, industry, and EPA participated in a discussion on changes in the RWH test methods to make the emission certification process more representative of in-use emissions, including a transition from crib-based to cordwood-based testing.[3] EPA's review of Alternative Test Method requests focuses on "a technical determination that the requested alternative test method will provide results adequate for the EPA Administrator's determination of compliance and that the proposed change in the test method will not negatively affect the stringency of the applicable regulation."[4]

General NSPS provisions allow EPA to consider case-by-case requests for the use of alternative test methods (ATMs) [40 CFR § 60.8(b)] and the preamble of the 2015 RWH NSPS anticipated the use of

[1] 80 Fed. Reg. 13672 (March 16, 2015).

[2] A "hot-to-hot" test means that emissions are measured starting when fuel is placed on a hot coal bed and the test is ended while the coal bed is still hot.

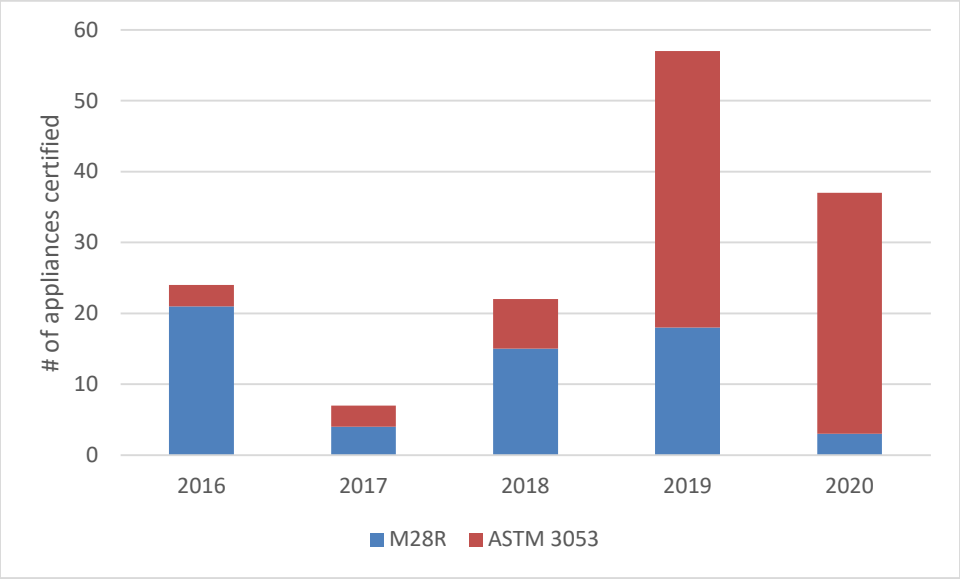
[3] US EPA (2016). Process for Developing Improved Cordwood Test Methods for Wood Heaters: Discussion Paper. Available at https://www.epa.gov/sites/default/files/2016-03/documents/discussion_paper_-_process_for_dev_imp_cwtm_030916.pdf. Accessed January 14, 2022.

[4] *Ibid.*, p. 23.

cordwood-based ATMs, stating that "(w)e will consider alternative cord wood test method requests on a case-by-case basis until we are convinced that improved test methods have been sufficiently demonstrated that they can be relied upon for regulatory purposes."[5] Requests to use an ATM to test an appliance are reviewed on a case-by-case basis, while methods that EPA designates as broadly applicable ATMs can be used without obtaining prior EPA approval.

In early 2018, EPA granted broadly applicable ATM status to two versions of the ASTM E3053[6] cordwood testing protocol. Those broadly applicable ATMs were designated as Alt-125, which uses ASTM E3053 in its entirety with additional requirements by EPA, and Alt-127, which is the same as Alt-125 but modifies the low burn rate requirement for large stoves. Manufacturers have embraced the use of Alt-125 and Alt-127 since they were granted the broadly applicable ATM designation. Of the 154 cordwood stoves currently certified by EPA as Step 2 devices, almost 60% were certified using the Alt-125 or Alt-127 methods,[7] including almost 90% of the stoves certified since those methods were designated as broadly applicable ATMs in 2018, as shown in Figure 1.

Figure 1. Comparison of Test Method Used for Wood Stove Certification Testing 2016-2020.[8]



[5] 80 Fed. Reg. 13672 (March 16, 2015), *see* p. 13678.

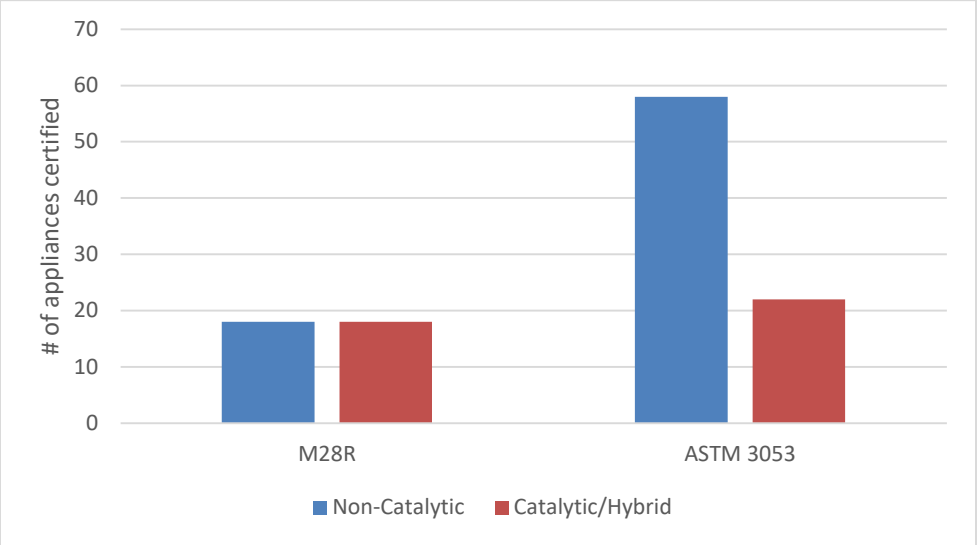
[6] ASTM International (2018). ASTM 3053-18 Standard Test Method for Determining Particulate Matter Emissions from Wood Heaters Using Cordwood Test Fuel. Available for purchase at https://www.astm.org/e3053-18.html.

[7] US EPA. Search Wood Stove Database (Room Heaters). Available at https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.search. Accessed December 28, 2021.

[8] Date of certification based on testing dates found in Alaska Department of Environmental Conservation, Division of Air Quality summary sheets available at https://dec.alaska.gov/air/burnwise/manufacturers-vendors/. Accessed December 21, 2021.

Data in the EPA's Wood Stove Database indicate that since granting broadly applicable ATM status to the ASTM E3053-based test methods, ASTM E3053-based test methods have been used more frequently with non-catalytic stoves than catalytic-equipped appliances, as shown in Figure 2. Note that hybrid appliances are equipped with both catalytic and non-catalytic controls and are included as catalytic devices in the figure.

Figure 2. Comparison of Emission Control Approach and Use of Certification Test Methods 2018-2020.[9]



Although the ASTM E3053-based test methods are cordwood tests, state regulatory agencies have raised concerns about using them for certification purposes.[10] The concerns include the lack of representativeness of testing conditions, e.g., emphasizing a single, large fuel configuration that is not typical of in-use fueling patterns, and the lack of specificity of many test parameters. The test method

[9] US EPA. Search Wood Stove Database (Room Heaters). Available at https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.search. Accessed December 21, 2021. Date of certification based on testing dates found in Alaska Department of Environmental Conservation, Division of Air Quality summary sheets available at https://dec.alaska.gov/air/burnwise/manufacturers-vendors/. Accessed December 21, 2021.

[10] NESCAUM (2019). Letter to Andrew Wheeler, Acting Administrator U.S. Environmental Protection Agency, Attention: Docket ID No. EPA-HQ-OAR-2018-0196, Re: Advanced Notice of Proposed Rulemaking for New Source Performance Standards for Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces, dated February 12, 2019, https://www.nescaum.org/documents/anprm-for-new-source-performance-standards-for-residential-wood-heaters-new-residential-hydronic-heaters-and-forced-air-furnaces/nescaum-wood-device-nsps-anprm-20190212-update.pdf.

itself states that it is impossible to assess the method's precision and that no information can be presented to determine method bias.[11]

In the spring of 2021, NESCAUM began testing cordwood stoves using the Alt-125/127 methodology. These tests were conducted by an ISO-accredited/EPA approved laboratory that is authorized to conduct EPA certification tests. Seven non-catalytic wood stoves that had been certified as Step 2 compliant using Alt-125/127 were included in the study. Those stoves constitute about 10% of the 65 non-catalytic stoves that meet those criteria, as listed in EPA's Wood Stove Database.

Two sets of ASTM E3053-based tests were conducted on each stove. The first was designed to replicate certification testing procedures as closely as possible. Those tests were used to evaluate the method's reproducibility and the study stove's ability to meet the NSPS limitations under the conditions specified in the manufacturer's instructions to the certification testing laboratory. The second set of tests was conducted using fueling and operating conditions recommended in the appliance owner's manual. Those tests were designed to reflect the performance of the appliances using the information given to users and to determine the impact of the lack of specificity of ASTM E3053-based test methods on the variability of test results. The results of these two sets of tests are presented in this report.

As this work was concluding, EPA withdrew approval of the use of Alt-125 and Alt-127 as broadly applicable Alternate Test Methods for compliance testing of residential cordwood stoves.[12]

[11] ASTM International (2018). ASTM E3053-18 –Standard Test Method for Determining Particulate Matter Emissions from Wood Heaters Using Cordwood Test Fuel. Section 11. Precision and Bias. Available for purchase at https://www.astm.org/e3053-18e01.html.

[12] 87 Fed. Reg. 3532 (January 24, 2022).

2 Replicate Testing

Between March and August of 2021, NESCAUM evaluated the emissions and performance of seven residential wood stoves equipped with non-catalytic control systems as part of a NYSERDA-funded RWH initiative. The ultimate goal of the initiative is to promote the design and manufacture of cleaner-burning and more efficient residential wood heaters.

2.1 Study Design

NESCAUM acquired seven non-catalytic cordwood stoves certified as Step 2 compliant using Alt-125 or Alt-127. Collectively, these stove models represent about 10% of the 65 stoves listed in EPA's Wood Stove Database as meeting Step 2 limits. Non-catalytic stoves were studied because, according to EPA estimates, 80% of wood stoves sold are non-catalytic.[13] In addition, previous research as part of the NYSERDA initiative indicated that non-catalytic stoves might not perform as well or as consistently as those with catalytic control systems.[14]

The seven stoves were shipped to an EPA-approved/ISO Accredited lab for testing in this study. ClearStak is an EPA-approved and ISO-accredited test lab for wood stoves. Three stoves in the study, identified as Stoves 9, 15, and 16, have been previously used in NESCAUM research testing. The other four units, Stoves 24, 26, 27, and 28, were purchased for this study and were conditioned before testing as specified by the Alt-125/127 test methods. The selection of study stoves strove to represent a range of firebox sizes, construction types, price points, certified particulate matter (PM) emission rates (ERs), heat outputs, and efficiencies.

2.1.1 Initial Inspection

As part of the initial inspection, the EPA-approved lab measured firebox volumes for all study stoves. Except for Stove 28, the EPA-approved/ISO Accredited lab replicate measurements did not match the measurements and firebox volumes specified in the stove certification reports and the EPA database. Firebox volume is important because that parameter is used to calculate the mass of the test fuel load, and load size can affect the length and performance of the test burn. As shown in Table 1, the largest differences, on a percentage basis, between the replicate measurements and certification report firebox volumes were with Stoves 26 and 9, with certification test volumes 10% and 9% higher, respectively,

[13] US EPA, Frequent Questions about Wood-Burning Appliances, https://www.epa.gov/burnwise/frequent-questions-about-wood-burning-appliances#:~:text=Non%2Dcatalytic%20or%20secondary%20combustion,range%20of%2060%2D80%25. Accessed February 2, 2022.

[14] Morin, B. and Rector, L. (2020). Reproducibility of Test Results in Step 2 Stoves. Available at https://www.nescaum.org/documents/nescaum-memo-audit-testing-step-2-stoves-20200904.pdf.

than those measured by replicate test, and Stove 27; the measurements of the production model for that stove was 8% lower than that listed in the certification report.

Table 1. Firebox Volumes (ft^3).

Stove	Certification Test Reported Firebox Volume	Study Measured Firebox Volume	Replicate of Alt 125/127 Certification Test	Alt 125/127 Test Following Owner's Manual Instructions	Notes
9	2.20	2.02	2.20	2.20	Dimensions not listed in the cert. test report. Firebox volume measured 10% less than in cert. test report.
15	0.82	0.79	0.82	0.82	Firebox volume not matched but difference is <5%.
16	2.02	2.14	2.02	2.40	The owner's manual states volume is 2.4. Multiple volumes reported and measured.
24	1.91	1.86	1.91	1.91	Firebox volume not matched but difference is <5%.
26	2.73	2.48	2.73	2.48	Volume given in cert. test report not consistent with firebox dimensions given in the owner's manual contained in the cert. test report. Firebox volume measured 10% less than in cert. test report.
27	2.92	3.17	2.92	3.17	Marketing materials say volume is 3.5; not consistent with lab measurements nor measurements in cert. test report. Firebox volume measured 9% greater than in cert. test report.
28	2.00	2.00	2.00	2.00	Firebox volume matched.

2.1.2 Testing Approach

The ISO-accredited/EPA approved laboratory conducted two complete Alt 125/127 tests on each stove. One set of the tests attempted to replicate the certification test; those tests were conducted according to the certification test's fueling and operational protocol information, matching the test conditions as

closely as possible to those in the manufacturer's instructions given to the certification testing laboratory. In those tests, the ISO-accredited/EPA approved laboratory used the firebox volume listed in the certification report; therefore, the replicates tests at the ISO-accredited/EPA approved laboratory used similar fuel loads to those in the certification tests, matching them to the greatest extent possible. The other test used the owner's manual information to guide the operation and fueling of the appliance. The fuel lengths and load volumes used in those tests were determined by the ISO-accredited/EPA approved laboratory firebox measurements or the firebox dimensions specified in the owner's manual. All other test elements, including fuel species, were held constant when possible. A comparison of the fueling and operating parameters in the two sets of tests is shown in Table 2. While this study conducted two sets of tests intended to replicate the manufacturers' instructions given to the certification test labs and the manufacturers' instructions provided in the owner's manual, we note that differing instructions for the certification lab versus the owner's manual may not meet the NSPS requirements contained in 40 CFR §60.536(g)(1), which requires instructions given to the lab for certification testing be consistent with the instructions included in the owner's manual.

Table 2. Differences between Owner's Manual and Laboratory Instruction Tests.

	Fuel Species	Fuel Length Difference (inches)	Fuel Placement	Air Settings	Bypass	Fan	Start-up Procedures	Firebox Volume
Stove 9 - #1	No	0	Yes	No	Yes	Yes	No	No
Stove 9 - #2	No	3.5	Yes	No	Yes	Yes	No	No
Stove 15	No	2	No	No	NA	NA	No	No
Stove 16	No	2	Yes	No	NA	Yes	Yes	Yes
Stove 24	No	2	No	No	NA	NA	No	No
Stove 26	No	2 & 4	No	No	NA	NA	No	Yes
Stove 27	No	2	Yes	Yes	NA	NA	No	No
Stove 28	No	0	No	No	Yes	Yes	No	No

2.1.3 Test Fuel

ASTM E3053 does not identify species of wood that can be used in testing but instead requires the fuel to be a species of cordwood with a specific gravity in the range of 0.48 to 0.73 on a dry basis. A large number of wood species have a specific gravity in that range. To replicate the certification test and not introduce new variables, the ISO-accredited/EPA approved laboratory used the wood species identified in the stove's certification report when possible. Replicate testing used the same fuel that was used in the certification test: oak for Stoves 15, 16, and 26, and maple for Stoves 9 and 27. The Stove 16 certification report specified a mix of maple and oak but did not identify how many pieces of each fuel species were used in the certification test. When testing that stove, the ISO-accredited/EPA approved laboratory used a

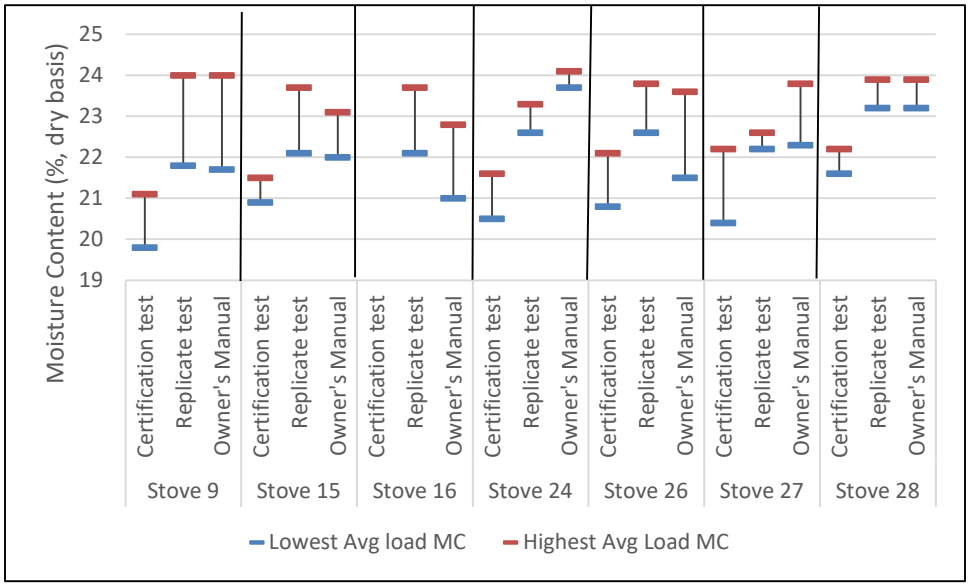
mixture of 70% maple and 30% oak fuel. The certification test of Stove 28 used cherry fuel; however, that species was not available to the ISO-accredited/EPA approved laboratory, so the study used maple fuel.

ASTM E3053 specifies that "(t)he average moisture content of the test fuel load shall be in the range of 19.0 to 25.0% on a dry basis." As shown in Table 3 and Figure 3, the moisture content of the wood loads used in all certification tests and all the ISO-accredited/EPA approved laboratory runs was within the specified range. However, the moisture content of the fuel in the ISO-accredited/EPA approved laboratory tests tended to be higher than those specified in the certification reports. In some runs, the use of higher moisture content fuel was intentional in an attempt to obtain the lower burn rates reported in certification test. For example, additional low-fire test runs were completed on Stove 15. The additional test runs used fuel with moisture content in the upper end of the allowed range in an attempt to reduce burn rates to conform to the low-fire burn rate criteria detailed in ASTM E3053.

Table 3. Fuel Species and Load Dry Moisture Content (MC) (%) in Certification and Replicate ASTM Test Fuel.

Stove	Certification Report Runs		Replicate Lab Instruction Runs		Replicate Owner's Manual Runs	
	Species	***Load MC***	***Species***	***Load MC***	***Species***	***Load MC***
9	maple	19.8-21.1	maple	21.8-24.0	maple	21.7-24.0
15	oak (type not specified)	20.9-21.5	red oak	22.1-23.7	red oak	22.0-23.1
16	unspecified	unspecified	maple/oak	22.1-23.7	maple/oak	21.0-22.8
24	oak	20.5-21.6	red oak	22.6-23.3	red oak	23.7-24.1
26	oak	20.8-22.1	red oak	22.6-23.8	red oak	21.5-23.6
27	maple	20.4-22.2	maple	22.2-22.6	maple	22.3-23.8
28	cherry	21.6-22.2	maple	23.2-23.9	maple	23.3-23.9

Figure 3. Comparison of Average Load Moisture Contents (% Dry Basis) in Certification Tests and Lab Instruction and Owner's Manual Tests.



ASTM E3053 is not prescriptive about fuel length, saying only, "The nominal test fuel piece length used shall be in accordance with the manufacturer's written instructions." The test that mimicked the certification tests used wood pieces the same length as those specified in the corresponding certification test report. In the second set of study tests, information from the owner's manual was used to determine fuel length.

If the owner's manual specified the use of longer fuel pieces than those used in the certification test, the longest recommended fuel length was used in the second set of tests. In Stove 9, the ISO-accredited/EPA approved laboratory ran three complete Alt-125 tests, one replicating the certification test conditions, including 14.5-inch fuel length, the second using the owner's manual recommendations and 14.5-inch fuel, and the third with the owner's manual recommendations and 18-inch fuel. Although the Stove 9 owner's manual indicated that fuel lengths up to 20.5 inches could be used, the ISO-accredited/EPA approved laboratory determined that the use of fuel of that length in the stove was not feasible, and used a fuel length of 18 inches instead. Fuel lengths and the number of pieces in each load listed in the certification report and used in the replicate tests are shown in Table 4.

.

Table 4. Fuel Piece Length (inches) and Number of Pieces per Load.

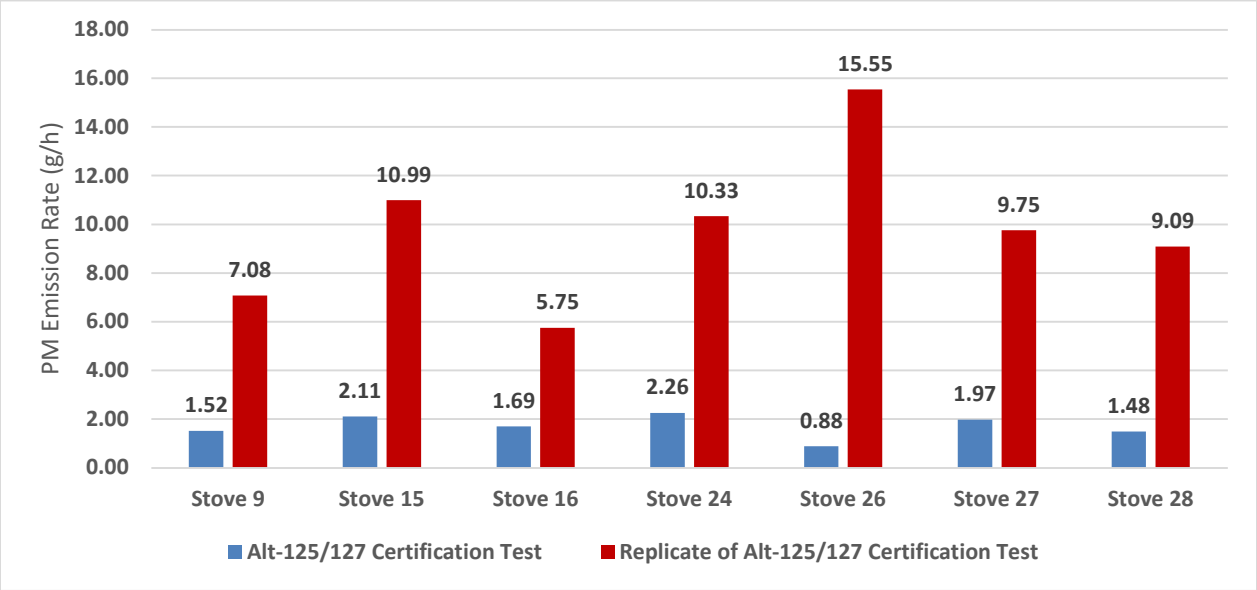
Stove	Certification Test Report		Replicate of E3053-based Certification Test		E3053-based test with Owner's Manual Instructions	
	# Pieces	Piece length	# Pieces	Piece length	# Pieces	Piece length
9	6	14.5-15.5	6	14.5-15.5	6	18
15	4-5	14	4-6	14	4-6	14
16	unspecified	16	6	16	6	18
24	5	16	5-6	16	5	18
26	5	17	5-6	17	5	19-21
27	5-6	18	6	18	6	20
28	5-6	15-16	5-6	15-16	5-6	16

2.2 Emission Rate Results

2.2.1 Emission Rates

The Step 2 emissions limit for residential wood stoves in the 2015 NSPS is 2.0 g/h; however, stoves that are certified using a cordwood method are allowed a higher emission rate (ER) of 2.5 g/h. The certification ER for stoves tested with ASTM E3053-based test methods is calculated as 0.2 times the ER measured in the high-fire burn, including the cold start, plus 0.4 times the low-fire ER and 0.4 times the medium-fire ER. A comparison of the weighted average ERs for the seven study stoves reported in their certification test reports and those measured in the replicate tests of this study is shown in Figure 4. At least two high-fire runs occur in all ASTM E3053-based tests, but the test protocol does not prescribe which high-fire burn is used in the certification ER calculation. For the ER comparisons below, the replicate high-burn run in the same sequence as that in the certification test was used.

Figure 4. Comparison of Emission Rates in Certification and Replicate Tests.



In the certification reports, the weighted average ERs were below 2.0 g/h for all but one of the seven stoves and were all below the 2.5 g/h NSPS criterion for cordwood tests. In contrast, in the replicate tests, the lowest ER measured that followed the instructions given to the certification laboratory was 5.75 g/h in Stove 16, which is three times higher than the certification report ER for that stove and more than twice the NSPS limit. The divergence between the study ERs and that in the certification reports was particularly striking for Stove 26. This stove had the lowest certification ER of all the stoves yet had a replicate ER more than 17 times higher than the reported certification test result. This was also the highest ER measured among the seven stoves in the study.

We note that, according to the NSPS specifications, EPA would initiate procedures to revoke an appliance's certification if the ER measured in a compliance audit test conducted with the same testing method as that used in the certification test exceeds the applicable NSPS emission standard by more than 50%. For woodstove certifications based on cordwood tests, the revocation trigger is 3.75 g/h (150% of 2.5 g/h). In this study, all of the ERs measured in the lab tests following the stoves' certification test methods were substantially above that level.

The ISO-accredited/EPA approved laboratory contracted for this work also conducted a second set of tests using practices recommended in the owner's manuals to evaluate the effect of alterations of fueling and operational parameters on stove performance as allowed in ASTM E3053. The differences between the elements in the two sets of tests in each stove are shown in Table 2. A comparison of the weighted average ERs for the two tests is shown in Figure 5, and the values of the certification ERs and the ERs measured in the two study tests are shown in Figure 6.

Figure 5. Comparison of Weighted Average Emission Rates in Runs Using Certification Laboratory Instructions and Owner's Manual Recommendations.

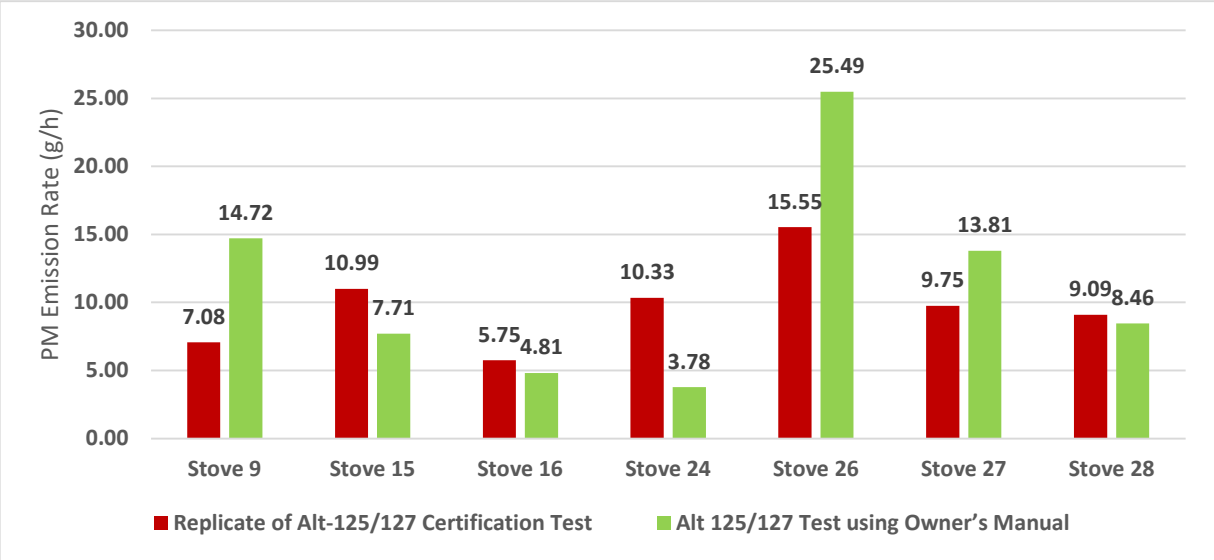
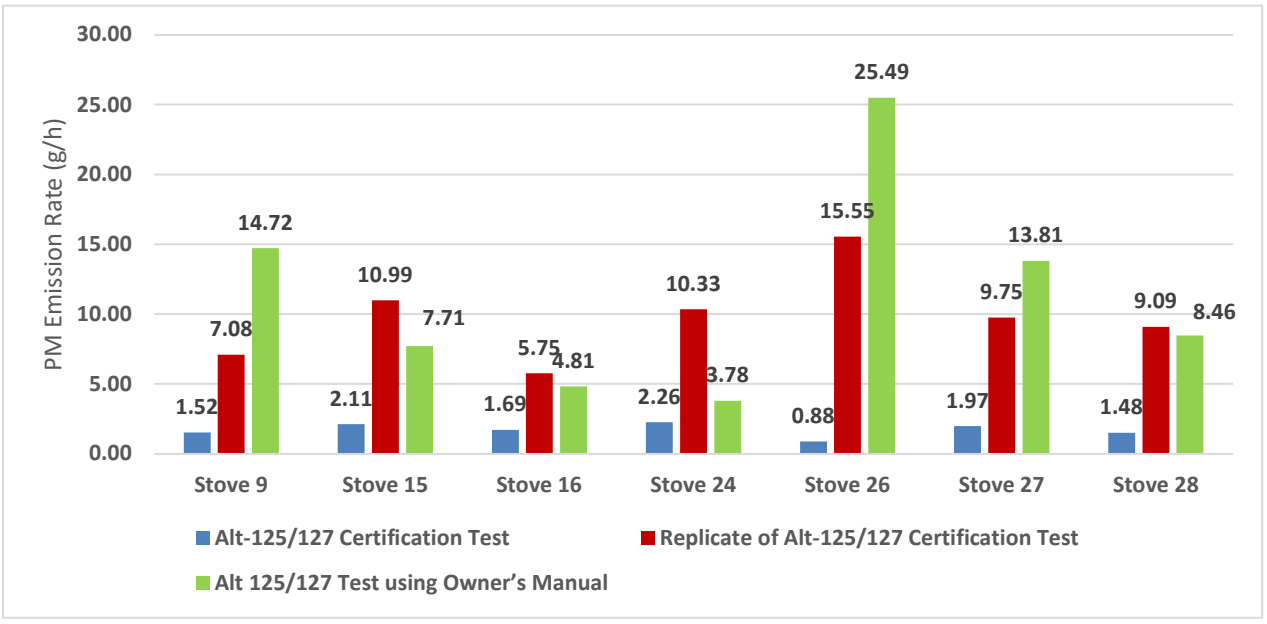


Figure 6. Comparison of All Weighted Average Emission Rate Values from Seven Stoves Study.



For Stoves 27, 26, and 9, the owner's manual test ERs were 42%, 64%, and 108% higher than the laboratory instruction test ERs, respectively. In those appliances, the owner's manual tests differed from the tests that replicated the certification test instruction in fuel length, fuel placement, and, in one case, in the firebox volume used to calculate the load. Conversely, for Stoves 15 and 24, the owner's manual test

ERs were 30% and 63%, respectively, lower than the ERs for the laboratory instruction tests. The only difference in the two sets of study tests in those stoves was using two-inch longer fuel pieces in the owner's manual runs. ERs were not substantially affected for Stoves 16 and 28.

As discussed above, the ISO-accredited/EPA approved laboratory ran two owner's manual tests for Stove 9. Fuel placement and the use of the bypass and fan were the same in the two owner's manual tests and differed from the replicate test that sought to replicate the certification test. However, in one owner's manual test on that stove, the fuel length was maintained at the same length as the certification test, 14.5 inches, while the second test used 18-inch fuel. Note that the installation and owner's manual specifies the firebox may accept wood pieces up to 20.5 inches in length; however, the research team determined that a load of 20.5-inch wood could not reasonably be loaded into the firebox.

The Stove 9 owner's manual ERs shown in the above graphs are for the runs that used the longer (18-inch) fuel. As discussed above, the ER measured in that test (14.72 g/h) was more than twice that in the replicate test that replicated the certification test conditions (7.08 g/h). The ER for the owner's manual tests with the smaller fuel length (12.83 g/h) was also elevated relative to the certification replicate test, an indication that factors other than fuel length may play an important role in the increased ERs in the owner's manual tests relative to that of the certification replicate test.

2.2.2 Burn Rates

Burn rate is an important metric because it can affect emissions. A complete ASTM E3053 test consists of burns at three air settings: high-, medium-, and low-fire burns. The ERs measured in the low- and medium-fire burns each contribute 40% to the composite ER for the test, while the high-fire ER accounts for 20% of that value. Burn rates for each burn category, as reported in the certification reports and in the test runs from this study, are discussed below.

2.2.2.1 Low-fire Runs

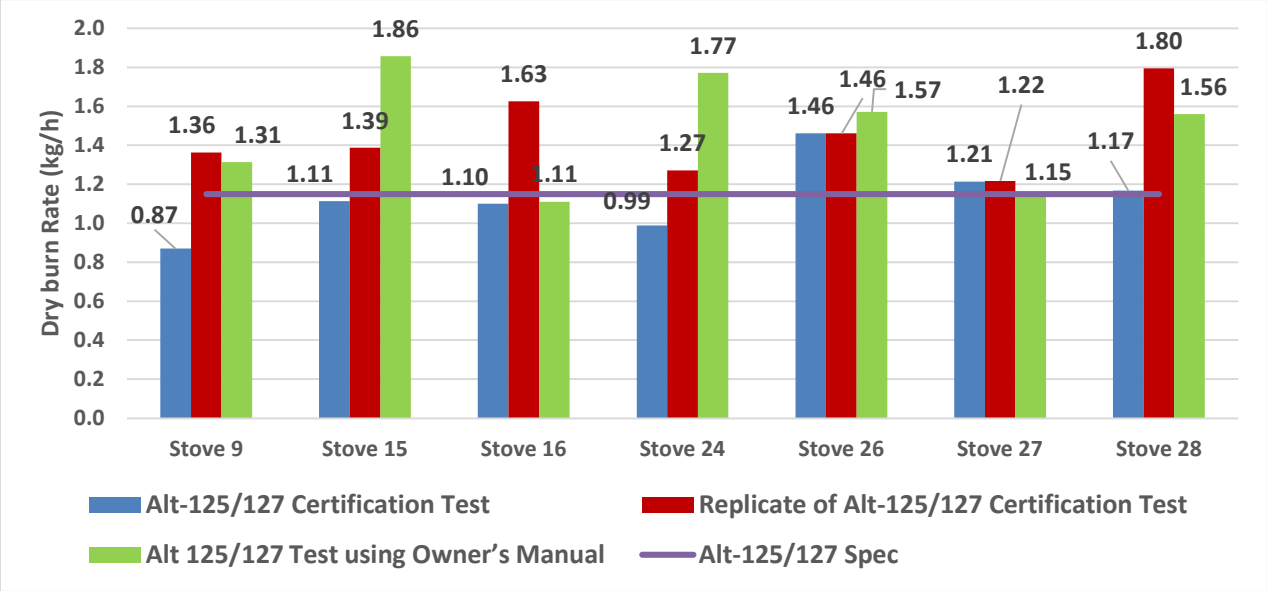
The NSPS specifies that "the burn rate for the low burn rate category must be no greater than the rate an operator can achieve in home use and no greater than is advertised by the manufacturer or retailer" [40 CFR 60.533(b)(5)]. ASTM E3053 requires that air settings in the low burn rate run "shall be set at the lowest airflow position and must result in a burn time of at least 8 hours or a minimum burn rate of 1.15 kg/hr."

According to the certification test reports, all of the low-fire certification test runs met the ASTM E3053 low-burn criteria. As shown in Figure 7, the low-fire dry burn rates reported in the certification reports for Stoves 26, 27, and 28 were above 1.15 kg/h; however, for the low-fire runs in each of the stoves, the certification tests report a burn time of at least 8 hours (480 minutes). In this study, after several attempts, the test lab replicating the certification test could not achieve burn rates low enough to meet the ASTM

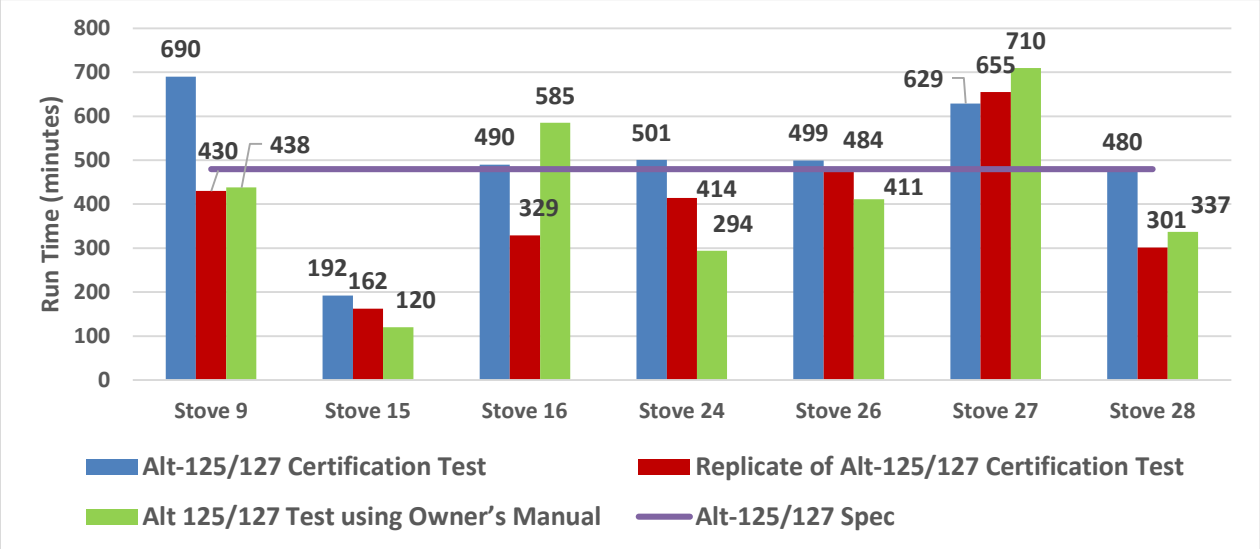
E3053 low-burn criteria in four of the seven study stoves - Stoves 9, 15, 24, and 28. The test reports do not describe how the certification testing laboratories achieved the low burn rates specified in the ASTM method.

Figure 7. Low-fire Burn Rates and Run Times for the Seven Stoves Study.

(a) Low-fire Dry Burn Rate (kg/h)



(b) Low-fire Run Time (minutes)



2.2.2.2 Medium-fire Runs

ASTM E3053 does not include specific burn rate requirements for the medium-fire test run, and air settings for the medium-fire runs are not specified in the protocol. The only criterion for medium-fire air settings in ASTM E3053 is that "the primary combustion air control(s) shall be set at a position no greater than halfway between the lowest and highest primary air control settings as measured on the control actuator." The lack of specific requirements for medium-fire air settings or burn rates in ASTM E3053 results in poorly separated burn criteria that can overlap with low-fire conditions. As shown in Figure 8, the medium-fire burn rates reported in the certification test reports for the seven study stoves were similar to those in the low-fire runs. Burn rates were 0.0 – 0.3 kg/h higher in the medium than in the low-fire runs in the certification tests.

Figure 8. Comparison of Dry Burn Rates (kg/h) in High-, Medium-, and Low-fire Runs in Certification Reports for the Seven Stoves Study.

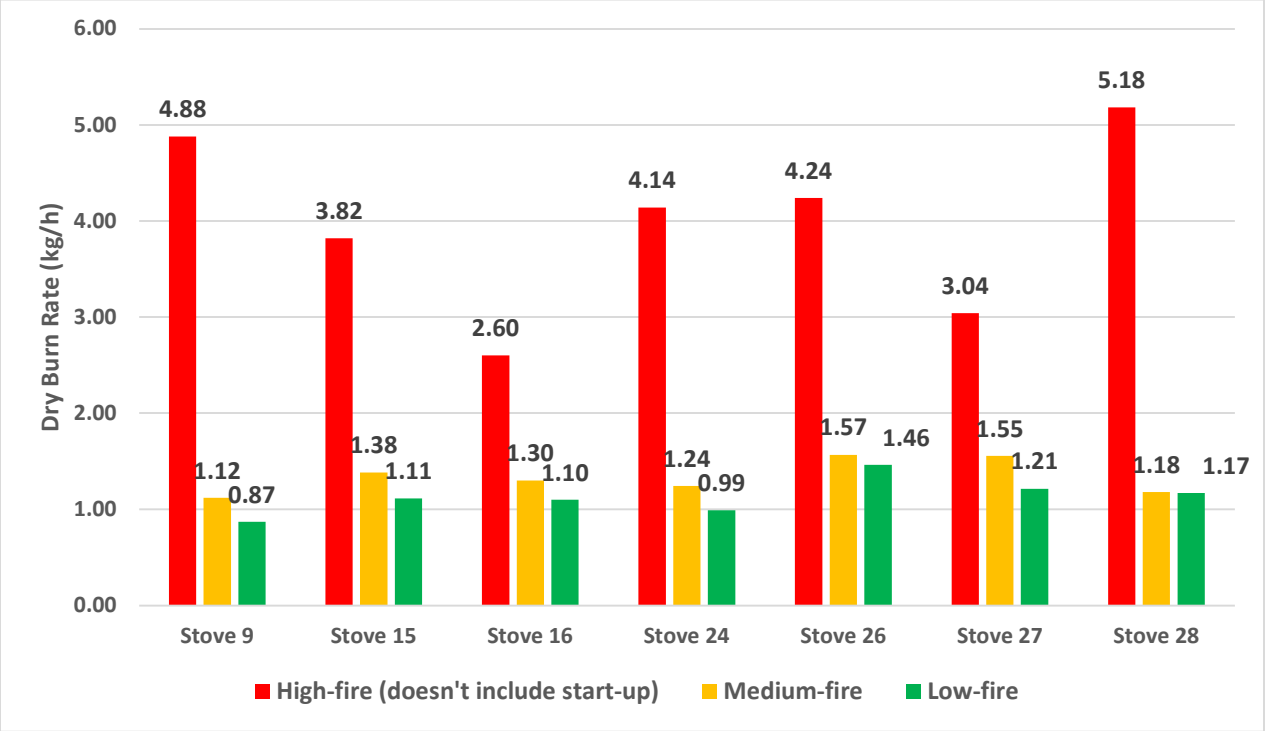


Figure 9 and Figure 10 compare the burn rates (kg/h) and run times, respectively, for the medium-fire burns in the certification and replicate tests. In all stoves except Stove 27, the medium-fire burn rates were higher and had shorter run times than the certification tests. Longer run times reduce the measured ER.

Figure 9. Comparison of Burn Rates (kg/h) for Medium-Fire Run - Certification and Replicate Tests.

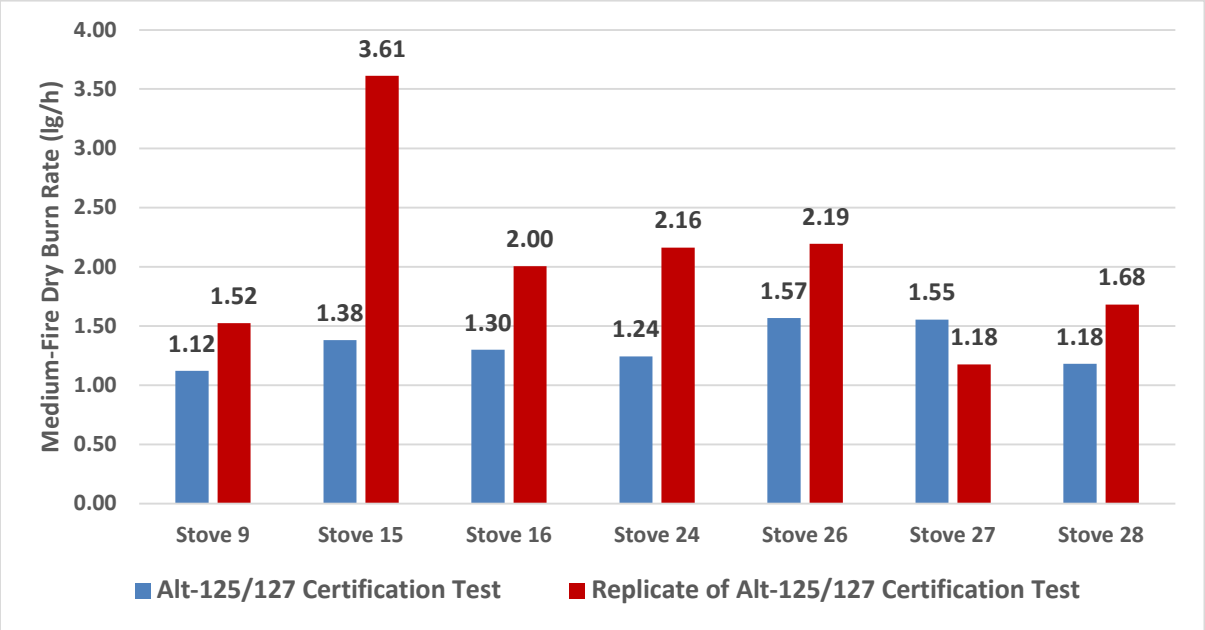
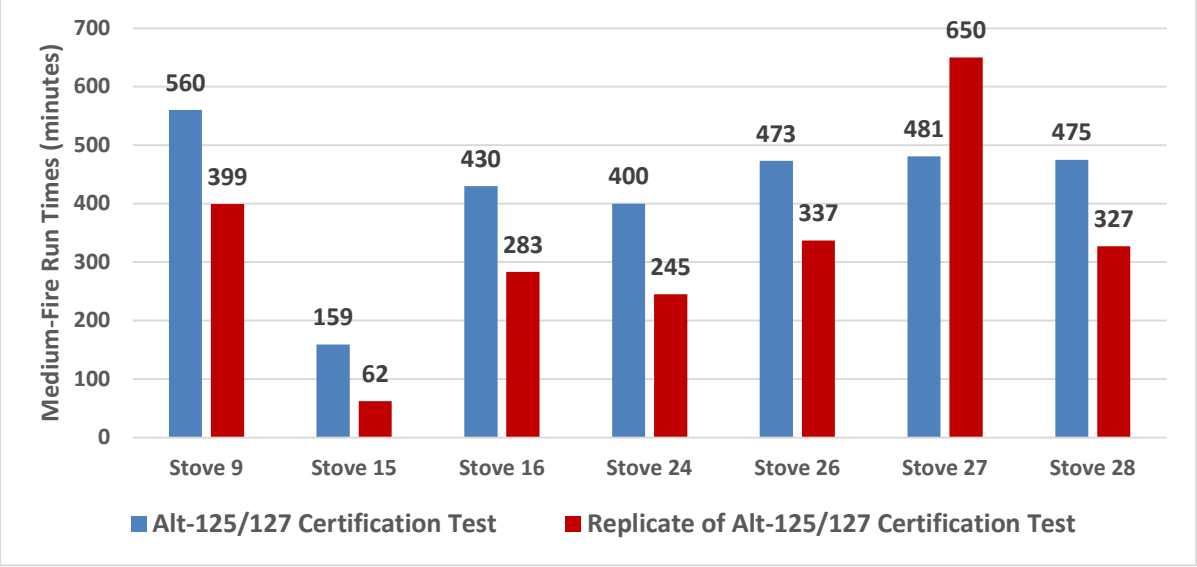


Figure 10. Comparison of Time to Complete Medium-Fire Run - Certification and Replicate Tests.



2.2.2.3 High-fire Runs

High-fire runs, which include a cold start, often have higher ERs than the other ASTM E3053 runs. However, the ERs measured in the high-fire runs make up only 20% of the weighted average ER in the ASTM E3053 method. The impact of high-fire emissions on the composite ER is further reduced because the method allows the testing laboratory to choose among high-fire runs in making the ER calculation. The ASTM E3053 methodology requires both the low- and medium-fire runs to be preceded by a high-fire run, so every test includes at least two high-fire runs. The testing laboratory and manufacturer have the option of reporting and using the ERs from either of the two runs, an average of the ERs in the two runs, or results from another, free-standing high-fire run. This allowance introduces variability into the testing result.

For the seven stoves tested in this study, three of the certification test reports (Stoves 9, 24, and 27) used the ER for the high-fire run that preceded the low-fire run in the weighted-average ER calculation, two (Stoves 26 and 28) used the ER for the high-fire run that preceded the medium-fire run, one (Stove 15) used an average of the ER for the high-fire runs that preceded the low- and medium-fire runs, and one (Stove 16) used a free-standing high-fire run that was performed approximately one week after the other testing.

Because the certification reports only supplied emissions data for the high-fire runs used in the weighted average calculation, the effect of this flexibility in the ASTM method on the certification values for those stoves is unknown. However, as shown in Table 5, the composite ERs calculated for many of the replicate tests were substantially affected by whether the ER from the first or second high-fire run was used in the calculation. This indicates that the allowed flexibility in ASTM E3053 for calculating the ER with a choice among high-fire runs substantially affects the calculated result, hence is a potentially large source of ER variability in replicate testing.

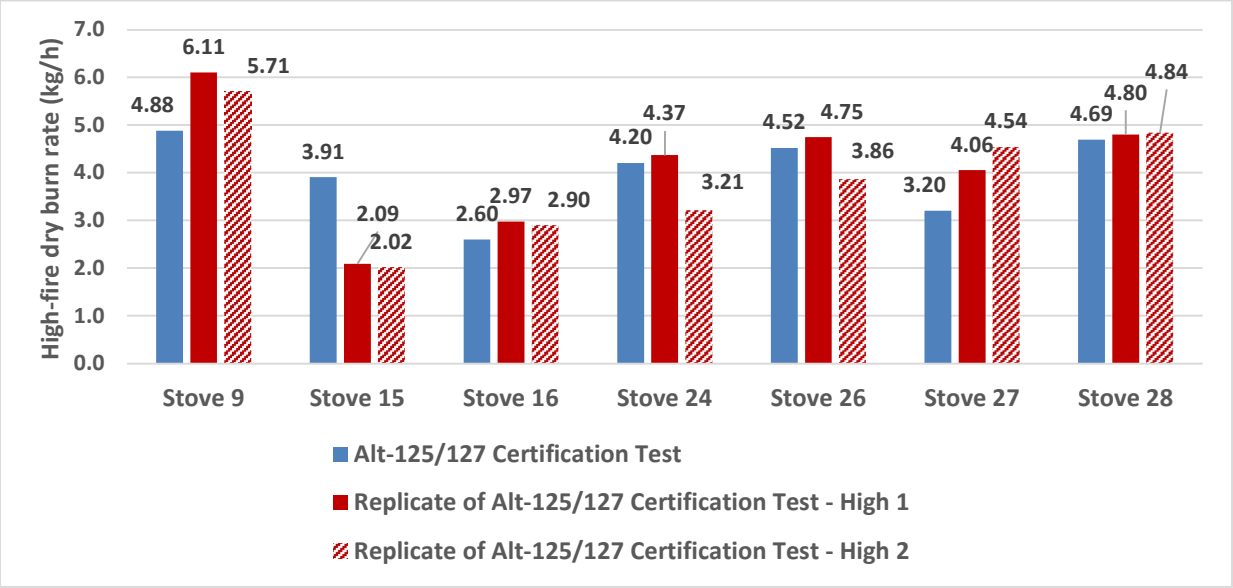
Table 5. Comparison of Weighted Average Values Using Different Start-up/High-fire (SU/H) Calculations.

		Weighted Average ER (g/h)			Percent Difference*
Appliance	**Test**	**Using 1st SU/H**	**Using 2nd SU/H**	**Using Avg SU/H**	
Stove 9	Replicate	7.08	5.90	6.49	20%
	Owner's Manual-1	12.83	11.43	12.13	12%
	Owner's Manual-2	14.72	10.27	12.49	43%
Stove 15	Replicate	6.43		10.99	
	Owner's Manual	8.41	7.01	7.71	20%
Stove 16	Replicate	5.36	5.75	5.55	7%
	Owner's Manual	6.72	4.81	5.77	40%
Stove 24	Replicate	10.33	9.53	9.93	8%
	Owner's Manual	3.78	7.14	5.46	89%
Stove 26	Replicate	14.67	15.83	15.25	8%
	Owner's Manual	23.21	25.49	24.35	10%
Stove 27	Replicate	9.75	9.91	9.83	2%
	Owner's Manual	13.81	14.25	14.03	3%
Stove 28	Replicate	9.09	8.4	8.75	8%
	Owner's Manual	8.46	10.03	9.24	19%

* Percent Difference was calculated for each test as:
(higher composite ER – lower composite ER) / lower composite ER.

Figure 11 compares the high-fire burn rates in the certification tests and the replicate runs. Note that certification tests report the high-fire burn rate for the hot-to-hot period, but for comparison purposes, the start-up period is included in all burn rates in that figure. The start-up/high-fire burn rates in the certification tests and the replicate high-fire runs were similar in four stoves (Stoves 16, 24, 26, and 28), reflecting greater comparability than found in the low- and medium-fire runs. The certification test burn rates in Stoves 9 and 27 were 20-25% lower than those of the replicate runs, and, in Stove 15, the burn rates were approximately 50% less than those measured in the certification test.

Figure 11. Comparison of High-fire Burn Rates with Start-up - Certification and Replicate Tests.



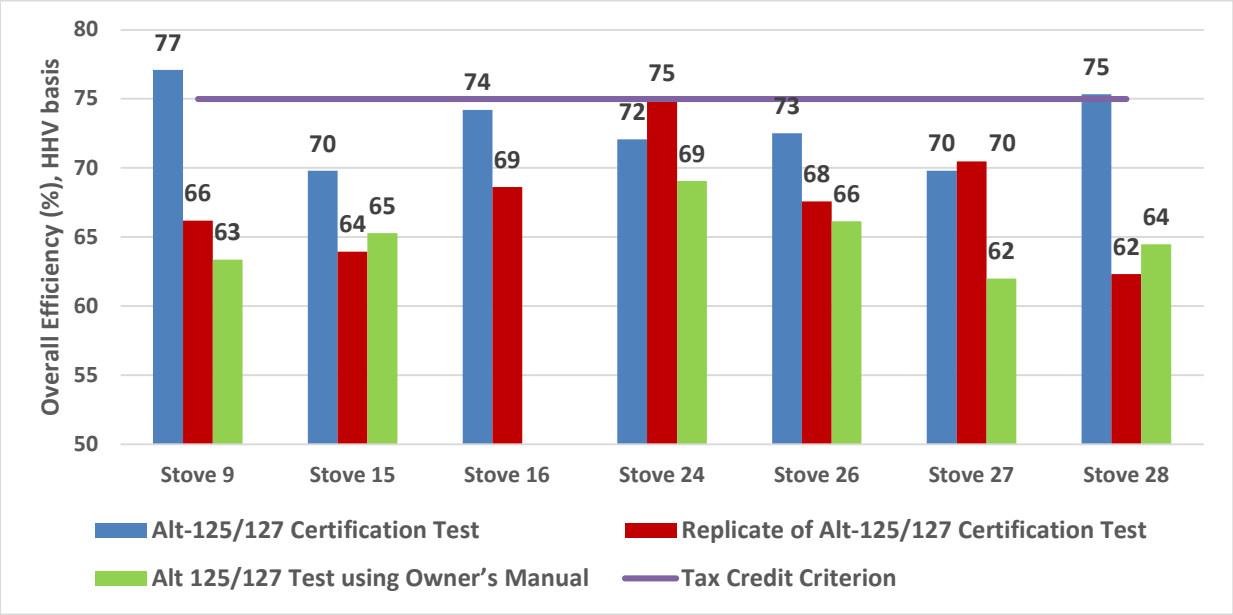
2.3 Thermal Efficiency

The NSPS does not include specifications for minimum thermal (heating) efficiencies but requires reporting of those efficiencies in the certification process.

The overall higher heating value (HHV) thermal efficiencies for the seven study stoves reported in the certification reports and measured in the comparable runs from this study are shown in Figure 12. Efficiencies are calculated using the same weighting factors as those used for the ER (the sum of 20% of the high-fire run efficiency plus 40% of the low- and medium-fire run efficiencies). However, unlike the ER, the high-fire efficiency does not include the start-up period. As seen in the figure, the efficiencies in the certification reports for five of the seven stoves are higher than those measured by replicate tests.

The largest divergence in measured efficiencies between the certification tests and the replicates are Stoves 9 and 28, which are also the only two stoves reporting efficiencies greater than 75%. We note that stove efficiencies greater than 75% are eligible for federal tax credits as of 2021.

Figure 12. Comparison of Certification Report and Replicate Overall Thermal Efficiencies.



3 Summary

In order for EPA to approve a broadly applicable alternative test method (BA-ATM), *"The EPA Administrator or his authorized representative must be satisfied that the test method alternative will produce results adequate to determine compliance. In other words, the EPA Administrator or authorized representative, such as a State having delegated authority, generally must be assured that a test method change provides a determination of compliance status at the same or greater stringency as the test method specified in the applicable regulation."*[15] Once broadly applicable status is granted, the regulated community can use the BA-ATM without requesting a case-by-base approval. EPA granted BA-ATM status to ASTM E3053-based methods in 2018 (Alt-125 and Alt-127). The results of this study call into question the adequacy of ASTM E3053-based testing for determining compliance of residential wood stoves with the NSPS.

This study's replicate testing of seven non-catalytic wood stoves' certification test procedures obtained weighted emission rates 3.4 to 17.7 times higher than the stoves' reported certification values. The seven stoves tested represent about 10% of the non-catalytic stoves that have been certified as compliant with the Step 2 NSPS using the ASTM E3053-based test methods.

In addition to the replicate testing, a second set of ASTM E3053-based testing was performed following the owner's manual instructions provided by the manufacturer to the stove user. The owner's manual instructions can differ from instructions provided by the manufacturer to the certification test lab for certification testing. The practice of differing instructions to the lab versus those in the owner's manual can raise questions about conformance to the NSPS requirements contained in 40 CFR §60.536(g)(1), which requires that instructions given to the lab for certification testing are consistent with the instructions included in the owner's manual. This testing found that the different sets of instructions greatly altered the tested emission results, from doubling the emission rate in one stove to reducing it by almost two-thirds in another.

When this report was being completed, the EPA withdrew approval of the use of Alt-125 and Alt-127 as Broadly Approved Alternate Test Methods for compliance testing of residential cordwood stoves.[16] The study results presented here provide additional support for the withdrawal of these methods for use in NSPS certification testing.

[15] 72 Fed. Reg. 4257 (January 30, 2007), at 4261.

[16] 87 Fed. Reg. 3532 (January 24, 2022).