Method For Measuring The Thermal Performance of Residential Wood-Fired Masonry Heaters

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1. Scope

This standard describes the procedures for measuring the thermal performance of wood-fired masonry heaters. The protocols described herein include specifications for test-period duration, test fuel requirements, masonry heater test period operating requirements, and test data-recording requirements.

1.1 Applicability and Principal**.** The prescribed specifications and procedures contained in this method are performed on masonry heaters installed in accordance with their builder's and/or manufacturer's specifications. The method specifies flue-gas temperature criteria used to initiate test periods and flue-gas oxygen (O_2) (or alternatively carbon dioxide [CO_2] plus carbon monoxide [CO]) concentration criteria used for determining fuel re-charging times and test completion. Combustion gases sampled at a standardized sampling location and analyzed for O_2 (or alternatively, CO_2 plus CO) concentrations may be used for calculating the flue-gas flow rates which are, in turn, used for calculating thermal efficiency.

1.2 Values given in SI units are to be regarded as standard. Inch/pound units may be rounded (see IEEE/ASTM SI-10). All dimensions are nominal unless specifically stated otherwise.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this method to establish appropriate safety and health protections and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 Method for Test-Fueling Wood-Fired Masonry Heaters: The Masonry Heater Association of North America: www.mha-net.org

2.2 Other Standards:

2.2.1 Title 40 of the U.S. Code of Federal Regulations (CFR) Part 60, Subpart AAA[1]

2.2.2 EN 15250:2007 Slow heat Release Appliances Fired by Solid Fuel - Requirements and Test Methods: Community of European Nations (CEN), Brussels, Belgium

3. Terminology

Terms as used in this document are defined as follows:

[1] Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

gas analyzer calibration error, n - the difference between the concentration of analyte gas measured by an analyzer and the known concentration of that analyte in the calibration gas when the calibration gas is introduced directly to the analyzer.

burn rate, n - the average rate at which test ~~-~~fuel is consumed in a test appliance during a test-burn period prescribed by the Standard Method for Test-Fueling Masonry Heaters; reported as mass of dry wood burned per hour (kg/h, lb/h~~our~~).

calibration drift, n - the difference between an initial analyte gas calibration measurement made at a mid-range calibration value and the analyte calibration measurement made using the same calibration gas after a one-hour period of analyzer operation during which no maintenance, repair, or adjustment has taken place.

calibration gas, n - a known concentration of analyte gas in nitrogen (N_2).

certification audit test, n - the completion of at least one, three-fuel-load test period in accordance with the operating, sampling, and measurement procedures of this Standard.

Masonry Heater Association (MHA) – aka; The Masonry Heater Association of North America: www.mha-net.org

effective flue-gas duct/chimney diameter, n - the effective chimney diameter of a circular flue-gas duct is the actual diameter. The effective diameter (*ED*) of a rectangular flue-gas duct is determined using 3.1.8.1:

$$ED = 2 \times (L \times W) / (L + W) \quad \text{(Eq. 3.1.8.1)}$$

Where: L = Flue rectangular length and

W = Flue rectangular width.

firebox, n - the chamber in a test appliance in which test-fuel charges are placed and burned.

flue-gas exhaust duct, n - the connector pipe, chimney, or other duct form that conveys exhaust gases from the firebox to the atmosphere. For purposes of model line certification, the flue-gas exhaust duct is considered to be an integral component of a model, model line or design. Flue-gas exhaust duct cross-sectional area is calculated using duct dimensions measured at the narrowest point downstream from the horizontal plane that intersects the top-most edge of the fuel loading door opening.

test appliance design, n - the construction or fabrication specifications or both including all dimensions and materials specifications required for manufacturing or building a test appliance.

model line, n - a series of test appliance models having the same internal assembly, including flue-gas exhaust ducting and grate height above hearth. Each model in a model line can have different facade designs and external decorative features.

response time, n - the amount of time required for a gas sampling and measurement system to respond and display 90% of a step change in gas concentration.

sampling system bias, n - the difference between the gas concentrations displayed by an analyzer when a gas of known concentration is introduced at the inlet of the sampling probe and the gas concentration displayed when the gas of known concentration is introduced directly to the analyzer.

span, n - the upper limit of the gas concentration measurement range (see 7.4.1.7).

test-burn or test period, n - the period of time it takes to complete the combustion of 3 full fuel loads as specified in the Standard Practice for Test Fueling Masonry Heaters. The time required to consume at least 90% of the mass of three consecutively burned test-fuel loads.

test facility, n - the building enclosure in which the test appliance is installed and operated during a test period.

thermal performance (ie, efficiency, n -)

a) ***combustion efficiency, n –*** a measure of the completeness of the chemical oxidizing and reducing reactions taking place within heated fuel and between fuel and oxygen during combustion. Combustion efficiency is expressed as the percentage of the total heat potential of the fuel that is actually released or converted to heat energy through combustion**.** For the purpose of this standard, a default combustion efficiency of 97.0% shall be used for qualified masonry heaters only. If a measured combustion efficiency is required, use the Total Combustible Carbon method contained in Canadian Standards Association (CSA) B415-1: 2000; Annex D.

b) ***heat transfer efficiency, n -*** a measure of how much of the heat produced by the chemical combustion reaction processes is transferred from a firebox into the mass of the test appliance or into the room or both in which the test appliance is located. Heat transfer efficiency is expressed as a percentage of the heat produced in the firebox and transferred into the mass of the test appliance and/or the room in which the test appliance is located.

c) ***overall thermal efficiency, n -*** a measure of how much of the heat potential of fuel is absorbed into the mass of the test appliance or reaches the room in which the test appliance is located or both. It is expressed as that percentage of the total heat potential of the fuel absorbed into the mass of the test appliance or reaches the room in which the test appliance is located or both. Overall thermal efficiency is calculated as the multiplication product of the combustion efficiency and the heat transfer efficiency.

usable hearth area, n - the firebox floor (or hearth) area, within the fire chamber of a test appliance upon which a fire may be, or is intended to be built. Usable firebox area is calculated using the following definitions:

zero drift, n -the difference between the initial gas analyzer calibration response at a zero concentration level and the calibration response at the zero concentration level after a 4-hour period of instrument operation during which no maintenance, repair, or adjustment took place.

5. Significance and Use

5.1 This method can be used to compare and distinguish test appliances from other wood-fired appliances like the commonly generalized categories of "woodstoves" and "fireplaces". In order to use the thermal efficiency results obtained using this standard to compare and distinguish the masonry heater test appliance from a fireplace, the fireplace shall have been tested using the fueling protocols of the ASTM 2558 Method for Measuring Emissions from Wood-Fired Low Mass Fireplaces and the performance parameter measurements, and calculation processes of this standard. This standard method may be referenced in other standards such as those for specifying standardized firing protocols or measuring test appliance safety and emissions performance.

6. Test Method

6.1 *Scope* - The methods described in this section are applicable for establishing thermal efficiency and useful heat output from test appliances.

6.2 *Principle* - Thermal performance is a measure of the amount of total fuel heat potential is converted to useful heating of the space in which a test appliance is installed. Thermal performance measurements are made on a test appliance installed and operated in accordance with the specific requirements of this method. Overall thermal efficiency is the arithmetic product of chemical combustion efficiency and heat transfer efficiency. For this method, a default chemical heat loss value of 3.0% of the total fuel heat potential is assigned (that is, a chemical or combustion efficiency of 97.0 %). The default chemical heat loss value of 3.0 % includes the higher heating values of flue-gas carbon monoxide and all the other combustible volatile, semi-volatile, and solid carbonaceous materials generated by the incomplete combustion of batch-loaded wood fuel. Total sensible and latent heat losses are determined from measured flue-gas oxygen concentrations, temperatures, and the burn rate and calculated flue-gas moisture concentrations using measured fuel moisture and the estimated fuel hydrogen content of 7.0%.

6.3 *Significance and Use*

6.3.1.This test method was developed for use in determining a thermal performance and useful heat output ratings for wood-fired residential appliances.

6.4 *Apparatus*

6.4.1The following test apparatus is required for performing the thermal efficiency measurement procedures contained in this method:

6.4.1.1 *Test appliance temperature sensors*- Device(s) capable of measuring flue-gas temperature to within 1.0% of expected absolute temperature values. These monitors are to be sited in accordance with 6.3.

6.4.1.2 *Test facility temperature sensor*- A device located centrally in a vertically oriented pipe-shield 6-in. (150 mm) long and 2-in. (50 mm) inside diameter that is open at both ends and capable of measuring air temperature to within 1.0% of expected absolute temperature values. These monitors are to be sited in accordance with 6.9.7.

6.4.1.4 *Anemometer* - Device capable of detecting air velocities of less than 20 feet/min (0.10 m/s), for measuring air velocities near the test appliance being tested.

6.4.1.5 *Barometer* - Barometer, capable of measuring atmospheric pressure to within 0.1 in. (2.5 mm) of mercury.

6.4.1.6 *Draft* - Electro--manometer or inclined liquid manometer for the determination of flue draft (that is, static pressure) readable to within 0.01 in. of water column (0.50 Pa).

6.4.1.7 *Flue-gas oxygen analyzer*- A combustion gas analyzer for measuring oxygen (O_2) in the range of 0.0 to 25.0 % shall be used for conducting the gas analysis requirements. The gas analyzer must meet the following measurement system performance specifications:

(1) *Analyzer Calibration error* - Shall be less than ±2 % of the span value for the zero, low-range, mid-range and high-range calibration gases.

(2) *Sampling system bias* - Shall be less than ±3 % of the span value for the zero, low-range, mid-range and high-range calibration gases.

(3) *Zero drift*- Shall be less than ±2 % of the span value over the time of each test period.

(4) *Calibration Drift* - Shall be less than ±2 % of the span value over the time of each test period

(5) *Response time* - Shall be less than 1.5 min.

6.5 *Reagents and Materials*

6.5.1 *Calibration Gases* - Oxygen calibration gas shall have concentrations at each of the nominal levels indicated in Table 1.

TABLE 1 Calibration Gases	
Flue-Gas Oxygen Analyzer Calibration Level	**O_2 Concentration (Approximate Volume %)**
High-Level	20
Mid-Level	14
Zero	0

Note 1: All calibration gas mixtures shall be certified by the calibration gas supplier.

6.6 *Preparation*

6.6.1 *Test Appliance Installation* - The appliance being tested must be constructed and installed in accordance with the designer's/manufacturer's written instructions. The chimney shall have a total vertical height above the floor of the room in which the appliance is installed of not less than 4.6 m (15 ft). The appliance flue/chimney exit to the atmosphere must be freely communicating with the test appliance combustion-air makeup source. This is to ensure that no artificial atmospheric pressure differential exists between the chimney exit to the atmosphere and the test appliance combustion-air inlet. The flue/chimney configuration and grate height above hearth shall be noted for purposes of model, model line, or design identification.

6.6.3 *Thermal Efficiency Temperature Measurement Location* - A thermal efficiency temperature probe is to be located in the center of the chimney at a point 2.44 m (8 ft) above the floor of the room in which the appliance is installed to obtain data which is representative of where the last possible thermal donation would occur in a standard 2.44-m (8-ft) high room. This shall be referred to as the thermal efficiency temperature probe.

NOTE 1. - Penetrating the chimney wall for insertion of the thermal efficiency temperature probe may void the factory warranty of the chimney.

6.6.3.1 *Secondary temperature measurement location*- A secondary temperature probe shall be required if the test appliance is equipped with an emissions control device located in the flue, downstream from the test appliance firebox. This probe shall be positioned one equivalent flue/chimney diameter upstream from the flue-gas inlet to the emission control device. This location shall be referred to as the secondary sampling location and these measurements shall be referred to as secondary temperature readings.

6.6.4 *Curing* - A test appliance of any type shall be cured according to it's manufacturer's/builder's written instructions before certification testing begins.

6.6.4.1 *Test Appliances Equipped with Catalytically Active Emissions Control Components* - Operate a catalyst equipped test appliance for a period of at least

50 hours before conducting a test burn. Fuel for this 50-hour burn period shall meet the fuel specifications presented in ASTM ???? Standard Method for Test-Fueling Wood-Fired Masonry Heaters[2] and shall be burned at an average rate of at least 2.0 kg/hour. Record and report the hours of operation, hourly catalyst operating temperatures, flue-gas temperatures, and the weight and moisture content of all fuel burned during the heat-aging and curing period.

6.6.4.2 Heat-Aging and Curing Period -For test appliances equipped with catalytically active emissions control components, operate the non-catalytic test appliance for a period of at least 50 hours before conducting a test burn. For test appliances not equipped with catalytically active emissions control components, operate the non-catalytic test appliance for a period of at least 10 hours before conducting a test burn. Fuel for these heat-aging and curing periods shall meet the fuel specifications presented in ASTM ???? Standard Method for Test-Fueling Wood-Fired Masonry Heaters[3]. An average burn rate of at least 2.0 kg/hour shall be maintained during the heat-aging and curing period. The hours of operation, hourly flue-gas temperatures, and the weight and moisture content of all fuel burned during the heat-aging and curing period shall be recorded.

6.6.5 *Flue-Gas Stratification Check* - During the last 5 h of the aging and curing period specified in 7.6.4.2, use the flue-gas oxygen analyzer and sampling system specified in 6.4.1.7 to determine whether flue gases become stratified in the flue/chimney cross- section at the sampling location.

6.6.5.1 *Flue-gas stratification procedure* - Stratification of flue-gas oxygen concentrations shall be determined by first sampling at the center of the flue duct for at least 1 min and then moving the sampling probe to within 25 mm (1 in.) of the flue duct wall for an additional minute. This procedure is to be repeated on at least two traverses of the flue duct that are 90^{o} from each other. Flue-gas oxygen concentration changes of more than 15 % (that is, 15% of the oxygen concentration measured) when the sample probe is moved from the center of the flue duct to within 25 mm (1 in.) of the flue duct wall shall be considered stratified.

6.6.5.2 *Flue-stratification remedies* - The presence of a stratified flue-gas at the flue/chimney sampling location shall be remedied by either changing the flue/chimney duct design, changing the flue-gas sampling location, or changing the flue-gas sampling probe so that it simultaneously and equally samples the flue-gases in the center of at least 4 (four) separate and equal areas of the flue/chimney cross- section.

6.7 *Preparation of Test Fuel –* Test fuel charges (cribs) and a kindling bed shall be prepared in accordance with ASTM E???? Standard Method for Test-

[2] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.54 on Solid Fuel Burning MASONRY HEATERs. Current edition approved XXX, XX, XXXX. Published XXX XXXX.

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Fueling Wood-Fired Masonry Heaters[4]. A kindling bed and three equal (± 5 %) test-fuel crib charges shall be prepared for each test- burn period.

6.8 *Calibration and Standardization*

6.8.1 *Scale* - Within 3 h before a test period, the scale used for weighing test-fuel charges shall be audited by weighing at least one calibration weight (Class F) that is in the range of 20 to 80% of the expected test-fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.05 kg (0.1 lb) or 1 % of the expected test-fuel charge weight, whichever is greater, re-calibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

6.8.2 *Temperature Monitor* - Calibrate the temperature monitor before the first test period and semiannually thereafter.

6.8.4 *Anemometer* - Calibrate the anemometer in accordance with the manufacturer's instructions before the first test period and semiannually thereafter.

6.8.5 *Barometer* - Calibrate the barometer against a mercury barometer before the first test period and semiannually thereafter.

6.8.6 *Draft Gauge* **-** Calibrate the draft gauge in accordance with the manufacturer's instructions before the first test period and semiannually thereafter.

> **Note 2.** - An inclined liquid manometer does not require calibration but must be checked for level (zero tilt) before each test period.

6.8.7 *Sample Gas Flow Meters* **-** Sample gas flow meters shall be calibrated once before the first test period and semiannually thereafter or once after every ten tests whichever occurs first.

6.9 *Conditioning*

6.9.1 *Cooling Period* - No fuel shall be burned in the test appliance and no other means for heating the appliance may be used within 12 h preceding the start of a test period.

6.9.2 *Pre-Test Flue-Gas Temperature Determination* **-** At least1 h before initiating a test period (that is, ignition of a fire in the test appliance), close all air supply controls and test appliance fuel loading door(s). If the test appliance is not equipped with a door(s), use other means for closing the open face area of the test appliance. After 1 h of closure and within 10.0 min of opening the test appliance for test-fire ignition, measure and record the pre-test flue-gas temperature at the thermal efficiency temperature location or the secondary sampling location, whichever is closer to the hearth floor.

[4] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.54 on Solid Fuel Burning MASONRY HEATERs. Current edition approved XXX, XX, XXXX. Published XXX XXXX.

6.9.3 *Test appliance Description* **-** Record test appliance model and, if equipped, catalyst or add-on emissions control device descriptions. The test appliance description shall include photographs showing all externally observable features and drawings showing all internal and external dimensions needed for fabrication or construction or both. The drawings must be verified as representing the test appliance being tested and signed by an authorized representative of the testing laboratory.

6.9.4 *Test Fuel Description* - Record test-fuel charge dimensions, moisture content, and weights.

6.9.5 *Leak Checks* - A pre-analysis leak check of the oxygen analyzer train is recommended to be performed within 2.0 h before each test period initiation. A post-analysis leak check is mandatory at the conclusion of the sample analysis.

6.9.5.1 *Leak-check procedure* **-** Seal the sample inlet probe nozzle for each sampling system or train. Use the sample pump controls to create a vacuum greater than either twice the maximum vacuum encountered during test period sampling, or 125 mm (5 in.) of mercury, whichever is greater. Record the resulting sample flow rate indicated by the instrument flow meter when the required vacuum is achieved, corrected for system pressure, if applicable.

6.9.5.2 *Leak check acceptance criteria* - If the vacuum leakage rate is found to be in excess of 2 % of the average test-period sampling rate, the test results shall be invalid.

6.9.6 *Room-Air Velocity* - Using an anemometer, measure and record the room-air velocity within 0.6 m (2 ft) of the test appliance within 1 h before test initiation. Air velocity within 0.6 m (2 ft) of the test appliance shall be less than 250 mm/s (50 ft/min). No external means shall be used to affect air velocities within 0.6 m (2 ft) of the test appliance during a test period.

6.9.7 *Test Facility Ambient Temperature Probe* - Locate the test-facility ambient temperature probe on the horizontal plane that includes the primary air intake opening for the test appliance. Locate the temperature monitor probe at a distance of 1.0 to 2.0 m (3 to 6 ft) from the front of the test appliance and in a 90º sector defined by lines drawn at ±45º from a perpendicular line to centerline of the test appliance face.

6.9.8 *Barometric Pressure* - Measure and record the barometric pressure within 1 h before test period initiation.

6.10 *Procedure*

6.10.1 *Test appliance Operation and Testing Protocols*

6.10.1.1 *Required test configurations* - One, three fuel-load test period shall be conducted for each of the following operating configurations:

- With fuel-elevating hearth grate, and
- Without fuel-elevating hearth grate,

6.10.1.1.1 *All testing* - For all test configurations, the fuel loading door(s) shall be closed within 5.0 min after the addition of the first test-fuel crib in a test period. During a test period, the fuel loading door(s) shall not be re-opened except during test-fuel reloading and adjustment as specified in 6.10.1.8 and 6.10.1.9 of these protocols.

6.10.1.1. 2 *Additional tests* **-** The testing manager may conduct more than one test for each of the applicable configurations specified in 6.10.1.1. If more than one test is conducted for a specified configuration, the results from at least two thirds of the tests for that configuration shall be used for calculating the average thermal performance for that configuration. The measurement data and results of all tests conducted shall be reported regardless of which values are used in calculating the average thermal performance for that configuration.

6.10.1.2 Test fuel placement - All test appliances shall be tested using a conventional fuel-load placement for burning in the firebox. For the purposes of this Standard, "conventional" shall be defined as the long axes of the fuel pieces/cribs having horizontal or approximately horizontal placement parallel to the hearth floor and the long axis of the hearth area.

6.10.1.2.1 *Non-conventional fuel placement configuration* - If a manufacturer's or builder's written operating instructions specify the stacking or placement of fuel in a non-conventional configuration, the manufacturer or builder shall perform an additional set of tests using the proposed "non-conventional" fuel-loading configuration for each applicable test appliance configuration required in 6.10.1.1 of this Standard. Results of the tests performed with conventional fuel-load positioning and tests performed with the manufacturer's or builder's specified fuel placement configuration shall be averaged for the final results.

6.10.1.3 *Combustion air supply adjustment* - Any means for controlling combustion air supplies may only be adjusted during the first 5.0 min after the addition of each test-fuel crib. After the first 5.0 min, after the addition of each test-fuel charge, all air supply control settings shall be set to the lowest level and shall remain at the lowest setting throughout the remaining burning time for each test-fuel charge.

6.10.1.3.1 If the minimum combustion air supplies setting results in an overall test period average dry burn rate of less than 20% of its fuel load weight per hour, the appliance shall be tested two times for each configuration specified in 6.1.10.1: once at the minimum air supplies setting and once at a combustion air supplies setting that produces a dry burn rate greater than 20% of the fuel load weight per h. The results of these tests shall be averaged for reporting thermal performance values.

6.10.1.4 *Auxiliary test appliance equipment operation* - Only auxiliary equipment permanently installed and integrated into the design and construction

of a test appliance may be used during a test period. Where provided, electrically powered heat exchange blowers shall be operated during all test burns following the manufacturer's written instructions. If no manufacturer's written instructions are available, operate heat exchange blowers in their "high" or maximum position. (Automatically operated blowers shall be operated as designed.) Shaker grates, catalysts, afterburners, emissions control equipment by-pass mechanisms, or any other auxiliary equipment allowed under this section may be adjusted only once during the entire test period and the adjustment shall be in accordance with the manufacturer's written instructions. All operational adjustments made on a test appliance or the auxiliary equipment associated with the test appliance during the test period shall be recorded.

> **Note 4.** The total energy losses used to calculate thermal efficiency shall be increased by the amount of fuel gas (for example natural or propane gas) energy or electrical energy used by heat exchange blowers, afterburners, or emissions control equipment used during the test period. Use standard engineering handbooks or local suppliers for energy content of natural and propane gases and use 3419 Btu per KW-hour of electrical energy.

6.10.1.5 *Test-period sampling, parameter measurements, and data recording requirements* - The following information shall be recorded for each test:

Date
Test-period starting time
Test-period ending time
Total length of sampling period
Fuel load data:
Time charged
Weight of each charge
Moisture of each fuel piece (except kindling and spacers)

6.10.1.6 *Test-burn ignition*- The test burn shall be started only with matches (that is, no charcoal-lighter torches or other high-temperature devices). The weight of the starting paper shall not be included in test-fuel charge weight.

> **Note 3. -** Before fuel charge ignition in some types of wood-burning appliances, it may be necessary to first establish an operational flue draft so that combustion gases exit properly through the convoluted venting path and out the chimney exit. Otherwise, initial firebox combustion gases might vent out the fuel-loading door or extinguish test fuel combustion. Establish sufficient operating draft by first heating the venting path with burning paper or kindling or both, so that flue draft is at least 5 Pa (0.02 in. of water column) measured at the 2.44 m (8 ft) sampling level. The weight of paper used to initiate a draft for nominal test appliance operation are not considered part of the fuel load charges and are not included in total fuel weight determinations.

6.10.1.7 *Sampling period initiation* **-** Flue-gas oxygen sampling is initiated after the kindling has been ignited and within 15 s of when flue-gas temperature at the center of the flue at the thermal efficiency temperature measurement location, or the upstream flue-gas measurement location of an emissions control device reaches 14°C (25°F) greater than the pre-test flue-gas temperature. If the flue-gases were pre-warmed to temperatures above 14^{o} C (25^{o}) greater than the pretest flue-gas temperature by burning paper in the flue to initiate an operational

draft (See Note 3) or by having an emissions control device turned on, test sampling shall be initiated immediately upon ignition of the kindling bed. Once all test sampling and measurements have been initiated, all test sampling and measurements shall continue without interruption until the test is terminated in accordance with 6.10.1.2.

6.10.1.7.1 Once all test sampling and measurements have begun in accordance with 6.10.1.4 (that is, "zero" time), all test sampling, parameter measurement, and data recording requirements shall be conducted on a 10-min interval basis and shall continue without interruption until the test is terminated in accordance with 6.10.1.12. Test-period sampling and measurement parameters to be recorded at each 10-minute interval shall include:

Flue-Gas Oxygen (O_2)
Temperatures:
Ambiant air
Flue-gas extracted from the thermal efficiency temperature measurement location
Before emissions control device
After emissions control device, and
Draft pressure at the thermal efficiency flue-gas sampling and measurement location.

6.10.1.8 *Fuel crib loading* - The first test-fuel charge crib must be added to the kindling fire 7.5 minutes (+ or – 15 s) after the lowest kindling-fire flue-gas oxygen concentration is measured.

6.10.1.8.1 *Test facility ambient temperatures* **-** Test facility ambient temperatures shall be maintained between 18 and 32°C (65 and 95°F) during all test periods.

6.10.1.9 *Test fuel additions*- The second and third test-fuel loads for a test-burn period shall be placed and burned in the fire chamber only after flue-gas oxygen concentrations have increased by at least 80 % but not more than 82% from the minimum flue-gas oxygen concentration resulting from combustion of the previous test-fuel load. Only oxygen concentrations measured at each 10-minute test-period interval shall be used in this determination. 20.9% shall be used as the baseline ambient air-supply oxygen concentration. As an example, if the minimum 10-minute-interval flue-gas oxygen concentration resulting from the burning of a precedent fuel load was 17.50%, the next fuel load may only be loaded after a 10-minute-interval-measured flue-gas oxygen concentration has returned to a value of at least 20.2% (that is; ((0.80 x (20.9-17.5)) + 17.5) = 20.22%) but not more than 20.3 % (that is; ((0.82 x (20.9-17.5) + 17.5) = 20.3%)

6.10.1.9.1 *Inadequate coal bed* - If the coal bed remaining after the flue-gas oxygen concentration has increased 80 % from the minimum flue-gas oxygen generated by combustion of the precedent fuel load and is not adequate for restarting the next test-fuel load within 5.0 min

after loading the test-fuel charge, newspaper or kindling or both may be added and the test-fuel load re-positioned to facilitate “reasonable” ignition of the added test-fuel load.

6.10.1.9.1(a)The addition of all newspaper or kindling or both and the entire test-fuel charge including any additional newspaper or fuel or both added shall be completed within 5.0 min from the time the first piece of the test-fuel charge is loaded into the firebox.

6.10.1.9.1(b) The weight of newspaper or kindling both added shall be weighed to the nearest 0.05 kg (0.1 lb) and recorded. The weight of the newspaper or additional kindling or both added shall NOT be included in the total test-fuel weight for the test period.

6.10.1.10 *Test-fuel charge adjustments* - Test-fuel charges may be adjusted (that is; repositioned) once during the burning of each test-fuel charge. The time used to make this adjustment shall not exceed 15 s.

6.10.1.11 *Test completion* - A test (that is; a three fuel-load test-burn period) is completed and all sampling and test-period measurements are stopped at the time the flue-gas oxygen concentration has increased by at least 95 % but not more than 97 % from the minimum flue-gas oxygen concentrations resulting from combustion of the third test-fuel load. All test parameter measurements and recordings shall stop at test completion.

6.11 *Post-Test Clean-up*

6.11.1 *Room-Air Velocities* - Using an anemometer, measure and record the room-air velocity within 0.6 m (2 ft) of the test appliance within 10 min after test completion. Air velocity within 0.6 m (2 ft) of the test appliance shall be less than 250 mm/s (50 ft/min) without the test appliance operating.

6.11.2 *Fuel Weight at Test Completion* - Within 5 min after the test-burn is completed and all measurements and sampling has stopped, the remaining coals or unburned fuel or both, and ash shall be removed from the firebox and weighed to the nearest 0.05 kg (0.1 lb). (It is recommended that the coals first be extinguished with carbon dioxide.) The weight of these unburned materials and ash shall be subtracted from the total test-burn fuel weight when calculating the test period burn rate.

NOTES 5. A test-burn shall be invalid if less than 90 % of the weight of the total test-fuel loads plus the kindling weight have been consumed during the test period.

6.11.3 *Barometric Pressure at Test Completion* - Measure and record the barometric pressure within 10 min after test period completion.

6.11.4 *Leak Checks* - Leak checks of the combustion gas analyzer systems shall be performed within 2.0 h after test completion. Leak checks shall be performed as described in 6.9.5.1.

6.11.4.1 *Leak check acceptance criteria* - Unless the leakage rate under the required vacuum is less than 2% of the average sample processing (that is; analyzer flow) rate, analysis results shall be invalid.

6.12 *Calculations*

6.12.1 *Operating Performance* - After test completion, data sheets shall be reviewed for completeness and proper equipment operation. The data sheets, log books, and records maintained by field and laboratory staff shall be reviewed to ensure sample integrity. Test period data sheets shall be used in conjunction with flue-gas analyses to calculate the test appliance operational parameters.

6.12.1.1 *Total test period and sampling time* - The total test period (t_{tt}) in minutes is calculated using Eq.2 as follows:

$$(t_{tt}) = (t_c \times N_{T>25°F/CO2+CO>95\ \%}) \quad (2)$$

where:

t_c = the data-recording cycle (10.0 min for these protocols and

$N_{T>25°F/CO2+CO>95\ \%}$ = the total number of whole 10-min data-recording cycles that occurred between the time when the flue-gas temperature after test-burn ignition first exceeded 25 F (14 C) more than the pre-test flue-gas temperature (this is; test period initiation as defined in 6.10.1.4) and the time when the flue-gas oxygen concentration recovery back to the ambient oxygen concentration from the third test-fuel charge exceeded 95 % (that is; test period completion as defined in 6.10.1.12).

6.12.1.2 *Burn rate* - Multiplying the emission factor by the average burn rate yields the particulate emission rate. Burn rate (kg/h) is calculated by Eq 3 as follows:

$$\text{Burn Rate} = \frac{\text{Total Fuel} \times 60}{t_{tt}} \quad (3)$$

where

Total Fuel = the dry weight of the total fuel, including kindling, added during the entire test-burn period minus the remaining unburned materials and ash at the end of the test-burn period (kilograms).

6.12.2 *Thermal Efficiency* - In the following calculations, retain at least one extra decimal place beyond that of the acquired data. Round off figures to significant digits after each final calculation. (Other forms of the following equations may be used if they provide equivalent results.)

6.2.2.1 *Nomenclature for thermal efficiency calculations*

C_{mf} = mass fraction of carbon in dry (zero moisture content) fuel; use 0.510 for Douglas fir fuel (that is; derived from the carbon molar fraction of Douglas fuel used by the U.S. EPA (that is; 0.0425 kg-mole/kg x 12 kg/kg-mole = 0.510): 40CFR Part 60 Appendix A Methods 5H and 28).

C_{FG} = average specific heat of dry flue-gas: kilojoule/kg- K (Btu/lb-°R).

C_{H2O} = specific heat of water vapor: 1.9 kilojoule/kg-^{O}K (0.45 Btu/lb-^{O}R).

E_{LL} = latent energy loss, assuming complete combustion: kilojoule (Btu).

E_{SL} = sensible energy loss: kilojoule (Btu).

E_W = fuel (wood) chemical energy: kilojoule (Btu).

EF_C = combustion efficiency: percent reported to nearest 0.1% (default value of EF_C for qualified masonry heaters is 97.0%).

EF_{HT} = heat transfer efficiency: percent reported to nearest 0.1%.

EF_{OA} = overall thermal energy efficiency percent reported to nearest 0.1%.

h = enthalpy of water vaporization at room temperature: use 2442 kilojoule/kg (1050 Btu/lb).

H = mass fraction of hydrogen in dry (zero moisture content) fuel; use 0.073 for Douglas fir fuel ("The Total Combustible Carbon Method for Determination of Energy Efficiency of Wood-Fired Heaters" *Federal Register*, Vol 55, No.161, Monday, Aug. 20, 1990, pp. 33925-33935).

LHV_W = lower heating value of the dry wood fuel: use 17,600 kilojoule/kg (7600 Btu/lb) or actual ultimate analysis results.

HHV_W = higher heating value of the dry wood fuel: use 19,800 kilojoule/kg or actual ultimate analysis results (8516 Btu/lb).

m_d = mass of fuel load, dry basis: kg (lb) = $m_W / (1 + MC_d)$.

m_{H2O} = mass of water released and generated assuming wet fuel is completely oxidized: kg (lb).

m_{FG} = total mass of dry flue-gas: kg (lb).

m_W = mass of fuel load, wet (as-fired) basis, kg (lb).

M_d = flue-gas molecular weight: g/g-mole (lb/lb-mole).

MC_d = moisture content of fuel, dry basis: percent.

P = average heat output rate (power: kW (kilojoule/hour or Btu/hr).

T_A = average ambient temperature : K (R).

T_{FG} = average flue-gas temperature: K (R).

Note: If no emission control device is installed as described in 6.6.3.1, use the average flue-gas temperature measured at the thermal efficiency temperature measurement location. If an emissions control device is installed as described in 6.6.3.1, use the average flue-gas temperature of whichever location (that is; upstream from the emissions control device or downstream from the emission control device) that has the highest average flue-gas temperature during the test-burn period.

6.12.2.2 *Fuel and combustion moisture* - Calculate the total theoretical mass of water vapor released from fuel moisture and generated by the combustion of wood-based hydrogen during the test period (m_{H2O}) (assuming complete combustion) using Eq 6 as follows:

$$m_{H2O} = m_d \times (9H + (\frac{MC_d}{100})) \quad \text{(6)}$$

6.12.2.3 *Flue-gas molecular weight* - Calculate the test-period average molecular weight of the dry flue-gas (M_d) using Eq 7 as follows:

$$M_d = \frac{(44 \times (20.3 - O_2)) + (32 \times (O_{2_{FI}})) + (28 \times (100 - O_2 - O_{2_{FI}}))}{100} \quad \text{(7)}$$

6.12.2.4 *Flue-gas specific heat* - Calculate the test-period average flue-gas specific heat (C_{FG}) in kj/kg K using Eq 8 as follows:

$$C_{FG} = 1.003 + ((0.00345) \times (T_{FG} - T_A)) \quad \text{(8)}$$

6.12.2.5 *Mass of dry flue-gas* - Calculate the total mass of dry flue-gas (m_{FG}) generated during the test period using Eq 9 as follows:

$$M_{FG} = \frac{M_d \times C_{mf} \times m_d}{12 \times CO_{2_{FI}} / 100} \quad \text{(9)}$$

6.12.2.6 *Wood-fuel energy input* - Calculate the total wood-fuel energy input during the test period (E_W) using Eq 10 as follows:

$$E_W = m_d \times HHV_W \quad \text{(10)}$$

6.12.2.7 *Latent heat losses* - Calculate the total latent heat losses during the test period (E_{LL}) using Eq 11 as follows:

$$E_{LL} = m_{H2O} \times h \quad \text{(11)}$$

6.12.2.8 *Sensible heat losses* - Calculate the total sensible heat losses during the test period (E_{SL}) using Eq 12 as follows:

$$E_{SL} = ((m_{FG} \times C_{FG}) + (m_{H2O} \times C_{H2O})) \times (T_{FG} - T_A) \quad \text{(12)}$$

6.12.2.9 *Average overall thermal efficiency* - Calculate the average overall thermal efficiency for the test period (EF_{OA}) using Eq 13 as follows:

$$EF_{OA} = \frac{100 \times (E_W - (E_{LL} + E_{SL} + 0.03))}{E_W} \quad \text{(13)}$$

6.12.2.10 *Average heat output rate* - Calculate the average heat output rate for the test period in Btu/hour (kw) using Eq 14 as follows:

$$P = \left(\frac{EF_{OA}}{100}\right) \times \left(\frac{E_W \times 60}{t_{tt}}\right) \quad \text{(14)}$$

6.13 *Report*

6.13.1 Include both raw and reduced data for all tests. All test information and test appliance drawings shall be verified by the tester who performs the tests. Specific reporting requirements are as follows:

6.13.1.1 *Test appliance identification* - Report test appliance identification information including manufacturer or builder, model, model line, or design and serial number of the appliance tested. Also include the published installation and operating instructions as an appendix to the report.

6.13.1.2 *Test facility information* - Report test facility location, elevation, temperature, and air velocity information.

6.13.1.3 *Test equipment calibration and audit information* - Report calibration and audit results for the test-fuel scale, test-fuel moisture meter, and flue-gas oxygen analyzer.

6.13.1.4 *Pretest information and conditions* - Report all pretest conditions including test-fuel charge weights, test appliance temperatures, and air supply settings.

6.13.1.5 *Required test report information and suggested format* **-** Test report information requirements are presented in the following recommended report format:

(1) *Introduction*

(2) *Test appliance identification* - Manufacturer, model name or number, catalytic/non-catalytic, emissions control equipment, and any optional equipment. Include a copy of test appliance installation and operation manuals.

(3) *The tester that performed the testing* - Name, address, and certifications and other qualifications.

(4) *Test information* **-** Date test appliance was received, if factory-built, date construction was completed, if site-built, date that each test was conducted, a description of each configuration tested as required in Section 6.10.1.1, and the number of test burns conducted for each appliance configuration.

(5) *Test method or test appliance operating protocol deviations or both* - The report shall contain a complete description of any test method or operating protocol deviation conducted in the performance of the required test procedures

prescribed in this test standard. The report must provide detailed rationale explaining the necessity for the deviation and the possible effects the deviation(s) may have had on the results.

(6) *Summary and discussion of results*

(a) *Table of results*- Test-burn numbers, test appliance configurations, burn rates, overall thermal efficiency, and averages (indicate which test- burns are included in the averages presented). An example test period summary table is presented in 2 and 3.

THERMAL PERFORMANCE TEST RESULTS

Manufacturer: Manufacturer
Test Conducted By: Tester
Test Run Number: #
Test Period Start Date/Time: xx/xx/xxxx, xx:xx:xx AM/PM
Test Period End Date/Time: xx/xx/xxxx, xx:xx:xx AM/PM
Model Tested: Model Name and/or Number
Test appliance Combustion Type: Catalytic/Non-Catalytic
Configuration: With Grate/Without Grate

Time		
Total Test Period	xx.x	Hours
Test Data Recording Cycle	10.0	Minutes

Fuel		
Total Fuel Used	xx.x	kg wet
Average Fuel Moisture	xx.x%	Dry Basis
Total Fuel Burned	xx.x	kg dry
Average Burn Rate During Operation	x.xx	kg/hour (dry)

Average Flue-Gas Concentrations	
Oxygen	xx.x%

Average Thermal Performance (HHV)	
Combustion Efficiency	xx%
Heat Transfer Efficiency	xx%
Overall HHV Thermal Efficiency Rating	xx%

Average Thermal Performance (LHV)	
	Xx%
Combustion Efficiency	Xx%
Heat Transfer Efficiency	Xx%
Overall LHV Thermal Efficiency Rating	Xx%

Average Temperatures				
Flue-Gas Temperature (at 8 feet above floor)	xxx	° F	xxx	° C
Test Facility Ambient Temperature During Test	xxx	° F	xxx	° C

Test Notes:
Test Note Number 1: STP for this test is: 1.0 Atmosphere and 68°F (20°C)

TABLE 3 Test Burn Numbers

Run Number	Configuration	Burn Rate, kg/hour	Overall Thermal Efficiency, %
1	With Grate	x.xx	Xx
2	Without Grate	x.xx	Xx
	Average	x.xx	Xx
	Required Thermal Efficiency Rating (HHV)		>44.9%
	Required Thermal Efficiency Rating (LHV)		>50.0%
	Compliance with Efficiency Requirement ?		Yes or No

(b) *Summary of other data* - Test facility conditions, surface temperature averages, catalyst temperature averages, test-fuel charge weights, and test-burn times.

(c) *Discussion* - Include which test appliance certification was determined from the test results, specific test-burn problems and solutions and rationale for, and for not testing specific configurations like an open-door configuration.

(7) *Description*

(a) *Test appliance dimensions* - Firebox height, width, length (or any other pertinent dimensions), weight, and hearth area used for calculating fuel-charge weight. Include a complete set of accredited tester verified drawings of the test appliance tested.

(B) *Firebox internal assembly configuration* - Including the laboratory- certified verification of the construction or assembly drawings, photographs showing air supply locations and operating mechanisms, combustion air supply pathway(s), refractory materials and dimensions, catalyst location, baffle and/or by-pass configurations and operating mechanisms.

(c) *Add-on emissions control equipment* - If the test appliance being submitted for certification uses add-on emissions control equipment or a catalytic device for reducing test appliance emissions, provide a complete description of each component including drawings, photographs, and materials used in its construction for production.

(d) *Test appliance operating procedures used during each test period* - Air supply settings and adjustments, fuel-bed/coal-bed adjustments, and draft.

(e) *Test fuel* - Test fuel properties (moisture and temperature), test-fuel description (include drawings or photograph), and the test-fuel charge loading factor.

(8) *Sampling locations* - Describe sampling location relative to test appliance components. Include drawings or photographs or both.

(9) *Sampling procedure*

(a) *Measurement methods* **-** A brief reference to operational and measurement procedures, and optional and alternative procedures used. Include details of any parts of the procedures differing from the prescribed methods. Include a copy of this standard method as an appendix to the report.

(10) *Quality control and quality assurance (QC/QA) procedures and results*

(a) *Description of calibration procedures and results*

(b) *Test method quality control procedures* **-** This shall include leak-checks.

(11) *Appendices*

(a) *Raw data results and example calculations* **-** Include complete data tables and accompanying examples of all calculations not performed in the format presented in 6.12.

(b) *Raw data* - Include copies of all original data sheets for sampling records, parameter measurements, and temperature records. Include copies of all burn-rate and test appliance temperature data.

(c) *Construction/assembly drawings* - Test appliance construction or assembly drawings that clearly show all dimensions needed for completing the requirements of 3.1.2.

(d) *Sampling and analytical procedures* - Include detailed description of procedures followed by laboratory personnel in conducting the certification tests being reported.

(e) *Calibration results* - Details of all calibrations, checks, and audits pertinent to the reported test results including dates.

(f) *Participants* - Test personnel, manufacturer representatives, and regulatory observers present during testing.

(g) *Sampling and operation records* - Copies of original records or logs of activities not included on raw data sheets (for example, test appliance door-open times and durations).

(h) *Additional information* - Test appliance manufacturer's or builder's written instructions for operation of the test appliance during the reported test periods and a copy of the production-ready (print-ready) permanent label required in 4.2.

6.14 *Precision and Bias*

6.14.1 *Statement of Precision –*

6.14.2 *Statement on Bias –*

Keywords

8.1 *MASONRY HEATER, test appliance, thermal efficiency, wood-burning, wood-fired*