



Standard Test Method for Measurement of Particulate Emissions and Heating Efficiency of Outdoor Solid Fuel-Fired Hydronic Heating Appliances¹

This standard is issued under the fixed designation E 2618; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method applies to wood-fired or automatically fed biomass burning hydronic heating appliances, which the manufacturer specifies for outdoor installation or in structures not normally occupied by humans. These appliances transfer heat to the indoor environment through circulation of a liquid heat exchange media such as water or a water-antifreeze mixture.

1.2 The test method simulates hand loading of seasoned cordwood or fueling with a specified biomass fuel and measures particulate emissions and delivered heating efficiency at specified heat output rates based on the appliance's rated heating capacity.

1.3 Particulate emissions are measured by the dilution tunnel method as specified in Test Method [E 2515](#). Delivered efficiency is measured by determining the heat output through measurement of the flow rate and temperature change of water circulated through a heat exchanger external to the appliance and determining the input from the mass of dry fuel and its higher heating value. Delivered efficiency does not attempt to account for pipeline loss.

1.4 Products covered by this test method include both pressurized and non-pressurized heating appliances intended to be fired with wood or automatically fed biomass fuels. These products are hydronic heating appliances which the manufacturer specifies for outdoor installation or in structures not normally occupied by humans. They are often connected to an indoor heat exchanger by insulated pipes buried in the ground and normally include a pump to circulate heated liquid. They are used to heat structures such as homes, barns, and greenhouses and can heat domestic hot water, spas, or swimming pools.

1.5 Distinguishing features of products covered by this standard include:

1.5.1 Manufacturers specify outdoor installation or installation in structures not normally occupied by humans.

1.5.2 A firebox with an access door for hand loading of fuel or a hopper and automated feed system for delivery of particulate fuel such as wood pellets or solid biomass fuel to a burn pot or combustion chamber.

1.5.3 Typically a thermostatic control device that controls combustion air supply or fuel delivery, or both, to maintain the liquid in the appliance within a predetermined temperature range provided sufficient fuel is available in the firebox or hopper.

1.5.4 A chimney or vent that exhausts combustion products from the appliance.

1.6 The values stated are to be regarded as the standard whether in inch-pound or SI units. The values given in parentheses are for information only.

1.7 *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 standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*²

- [D 4442](#) Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials
- [E 631](#) Terminology of Building Constructions
- [E 711](#) Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter
- [E 2515](#) Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel

3. Terminology

3.1 *Definitions*—Definitions are in accordance with Terminology [E 631](#), unless otherwise indicated.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *burn rate*—the rate at which test fuel is consumed in an appliance measured in kilograms or pounds of fuel (dry basis) per hour.

¹ This test method 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 Appliances.

Current edition approved Feb. 15, 2009. Published April 2009. Originally approved in 2008. Last previous edition approved in 2008 as E 2618 – 08.

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.2 *delivered efficiency*—the percentage of heat available in a test fuel charge that is delivered to a simulated heating load as specified in this test method. This test does not account for jacket losses or for transfer line losses which will vary with actual application.

3.2.3 *firebox*—the chamber in the appliance in which the test fuel charge is placed and combusted.

3.2.4 *hydronic heating*—a heating system in which a heat source supplies energy to a liquid heat exchange media such as water that is circulated to a heating load and returned to the heat source through pipes.

3.2.5 *manufacturer's rated heat output capacity*—the value in Btu/h (MJ/h) that the manufacturer specifies a particular model of hydronic heating appliance is capable of supplying at its design capacity as verified by testing, in accordance with Section 12.

3.2.6 *test fuel charge*—a full load of fuel as specified in Section 12 placed in the appliance at the start of the emission test run or the mass of fuel consumed by automatically fed appliance during a test run.

3.2.7 *test run*—an individual emission test which encompasses the time required to consume the mass of the test fuel charge.

3.2.8 *thermostatic control*—a control device that opens, closes or modulates a circuit to control the rate of fuel consumption in response to the temperature of the heating media in the heating appliance.

4. Summary of Test Method

4.1 *Dilution Tunnel*—Emissions are determined using the “dilution tunnel” method specified in Test Method E 2515. The flow rate in the dilution tunnel is maintained at a constant level throughout the test cycle and accurately measured. Samples of the dilution tunnel flow stream are extracted at a constant flow rate and drawn through high efficiency filters. The filters are dried and weighed before and after the test to determine the particulate emissions catch and this value is multiplied by the ratio of tunnel flow to filter flow to determine the total emissions produced in the test cycle.

4.2 *Delivered Efficiency*—The efficiency test procedure takes advantage of the fact that this type of appliance delivers heat through circulation of the heated liquid (water) from the appliance to a remote heat exchanger and back to the appliance. Measurements of the water temperature difference as it enters and exits the heat exchanger along with the measured flow rate allow for an accurate determination of the useful heat output of the appliance. The input is determined by weight of the test fuel charge, adjusted for moisture content, multiplied by the higher heating value. Additional measurements of the appliance weight and temperature at the beginning and end of a test cycle are used to correct for heat stored in the appliance.

4.3 *Operation*—Appliance operation is conducted on a hot-to-hot test cycle meaning that the appliance is brought to operating temperature and a coal bed is established prior to the addition of the test fuel charge and measurements are made for each test fuel charge cycle. The measurements are made under constant heat draw conditions within predetermined ranges. No attempt is made to modulate the heat demand to simulate an

indoor thermostat cycling on and off in response to changes in the indoor environment. Four test categories are used. These are:

4.3.1 *Category I*—A heat output of 15 % or less of Manufacturer's Rated Heat Output Capacity.

4.3.2 *Category II*—A heat output of 16 to 24 % of Manufacturer's Rated Heat Output Capacity.

4.3.3 *Category III*—A heat output of 25 to 50 % of Manufacturer's Rated Heat Output Capacity.

4.3.4 *Category IV*—Manufacturer's Rated Heat Output Capacity.

5. Significance and Use

5.1 The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

5.1.1 These measurements, when approved by federal or state agencies, are often required for the purpose of determining compliance with regulations and statutes.

5.1.2 The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturer's research and development programs.

5.2 Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

5.3 This is a laboratory method and is not intended to be fully representative of all actual field use. It is recognized that users of hand-fired wood burning equipment have a great deal of influence over the performance of any wood-burning appliance. Some compromises in realism have been made in the interest of providing a reliable and repeatable test method.

6. Apparatus

6.1 *Scale*—A platform scale capable of weighing the appliance under test and associated parts and accessories when completely filled with water to an accuracy of ± 1.0 lb (± 0.5 kg).

6.2 *Heat Exchanger*—A water-to-water heat exchanger capable of dissipating the expected heat output from the system under test.

6.3 *Temperature Difference Measurement*—Thermocouples or a thermopile installed in thermowells shall be used to measure the temperature difference in water entering and leaving the heat exchanger. The temperature difference measurement shall have an uncertainty of $\pm 0.50^\circ\text{F}$ ($\pm 0.25^\circ\text{C}$).

6.4 *Water Flow Meter*—A totalizing type water flow meter with a resolution of 0.1 gal (0.025 L) and an accuracy of 0.5 % of volume recorded or a flow meter with an accuracy of ± 0.01 gal/min (± 0.0025 L/min).

6.5 *Recirculation Pump*—Circulating pump used during test to prevent stratification of liquid being heated.

7. Hazards

7.1 These tests involve combustion of solid fuel and substantial release of heat and products of combustion. The

heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Pressurized (closed system) appliances must include an appropriately rated American Society of Mechanical Engineers (ASME) pressure relief device and a pressure vessel that complies with the ASME Pressure Vessel Code. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion.

8. Sampling, Test Specimens, and Test Appliances

8.1 Test specimens shall be supplied as complete appliances including all controls and accessories necessary for installation in the test facility. A full set of specifications and design and assembly drawings shall be provided when the product is to be placed under certification of a third-party agency. The manufacturer's written installation and operating instructions are to be used as a guide in the set up and testing of the appliance.

9. Preparation of Apparatus

9.1 The appliance is to be placed on a scale capable of weighing the appliance fully loaded with a resolution of ± 1.0 lb (± 0.5 kg).

9.2 The appliance shall be fitted with the type of chimney recommended or provided by the manufacture and extending to 15 ± 0.5 ft (4.6 ± 0.15 m) from the upper surface of the scale. If no flue or chimney system is recommended or provided connect the appliance to a flue of a diameter equal to the flue outlet of the appliance and extending 15 ± 0.5 ft (4.6 ± 0.15 m) from the top of the scale. For flue systems not provided by the manufacturer, the flue section from the appliance flue collar to 8 ± 0.5 ft (2.44 ± 0.15 m) above the scale shall be single wall stove pipe and the remainder of the flue shall be double wall insulated Class A chimney.

9.3 The manufacturer may request that a recirculation pump be installed between connections at the top and bottom of the appliance to minimize thermal stratification. The pump shall not be installed in such a way as to change or affect the flow rate between the appliance and the heat exchanger. As an alternative, the testing lab may employ a thermocouple tree to determine the average unit temperature.

9.4 Prior to filling the tank, weigh and record the appliance mass.

9.5 Plumb the unit to a water-to-water heat exchanger with sufficient capacity to draw off heat at the maximum rate anticipated. Route hoses and electrical cables and instrument wires in a manner that does not influence the weighing accuracy of the scale as indicated by placing dead weights on the platform and verifying the scale's accuracy.

9.6 Locate thermocouples to measure the water temperature at the inlet and outlet of the heat exchanger in the supply line and return line from the cooling water system. Also install a calibrated water flow meter. If temperature differences are expected to be small, a differential thermopile should be used to measure the water delta-T. The water flow meter is to be installed on the cooling water inlet side of the heat exchanger so that it will operate at the same temperature as its calibration. Place the heat exchanger in a box with 2 in. (50 mm) of expanded polystyrene (EPS) foam insulation surrounding it to minimize heat losses from the heat exchanger. The reported efficiency and heat output rate shall be based on measurements made on the load side of the system. (See Fig. 1 and Fig. 2.)

9.7 Temperature instrumentation shall be installed in the output and return lines from the appliance (supply side). The average of the outlet and return water temperature on the supply side of the system shall be considered the average

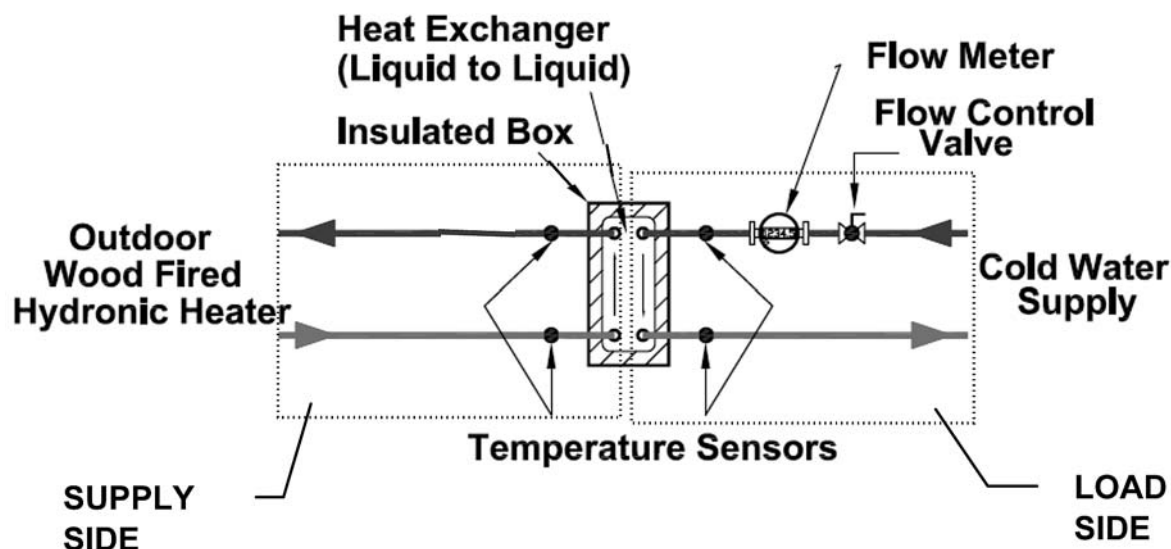


FIG. 1 Heat Exchanger Schematic

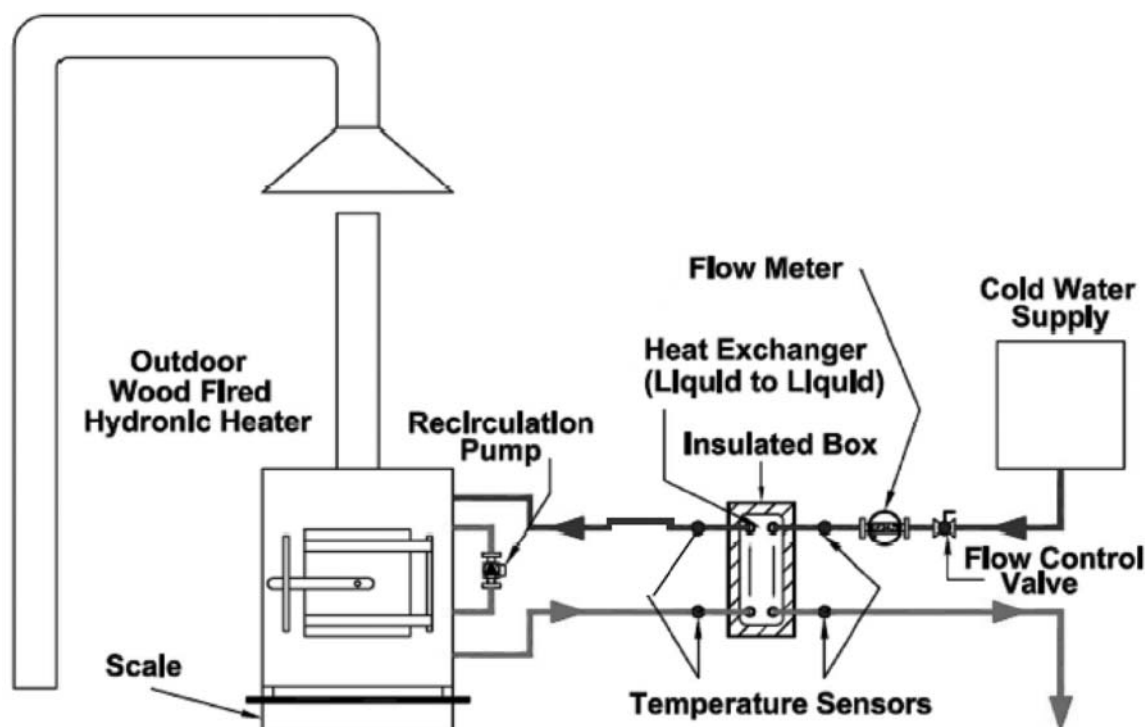


FIG. 2 Set-Up Schematic

appliance temperature for calculation of heat storage in the appliance (TF_{avg} and TI_{avg}).

9.8 Fill the system with water. Determine the total weight of the water in the appliance when the water is circulating. Verify that the scale indicates a stable weight under operating conditions. Make sure air is purged properly.

10. Calibration and Standardization

10.1 *Temperature Sensors*—Temperature measuring equipment shall be calibrated to National Institute of Standards and Technology (NIST) traceable standards at least once every six months.

10.2 *Water Flow Meter*—The water flow meter shall be calibrated using NIST Traceable methods at least once every six months. At the conclusion of each test run that accuracy of the water meter shall be verified by collecting water from the outlet of the load side of the system for a timed interval and weighing the water collected. The flow rate in gallons per minute shall be within $\pm 0.5\%$ of that indicated by the water meter.

10.3 *Scales*—The scales used to weigh the appliance and test fuel charge shall be calibrated using NIST Traceable methods at least once every six months.

10.4 *Moisture Meter*—The moisture meter shall be calibrated per the manufacturer's instructions and checked before each use.

11. Conditioning

11.1 Prior to testing, the non-catalytic appliance is to be operated for a minimum of 10 h using a medium heat draw rate. Catalytic units shall be operated for a minimum of 50 h using a medium heat draw rate. The pre-burn for the first test

can be included as part of the conditioning requirement. If conditioning is included in pre-burn, then the appliance shall be aged with fuel meeting the specifications outlined in 12.2 with a moisture content between 18 and 28 % on a dry basis. Operate the appliance at a medium burn rate (Category II or III) for at least 10 h for non-catalytic appliances and 50 h for catalytic appliances. Record and report hourly flue gas exit temperature data and the hours of operation. The aging procedure shall be conducted and documented by a testing laboratory.

12. Procedure

12.1 *Appliance Installation*—Assemble the appliance and parts in conformance with the manufacturer's written installation instructions. Clean the flue with an appropriately sized, wire chimney brush before each certification test series.

12.2 Cordwood Fueled Appliances:

12.2.1 *Fuel*—Test fuel charge fuel shall be white or red oak cordwood 18 to 28 % moisture content—dry basis. Cord wood used shall be split on at least one face, have a maximum cross sectional dimension of 10 in. (254 mm) and a minimum cross sectional dimension, measured at the widest point on a line perpendicular to the longest cross section dimension, of 3 in. (76 mm). Only cordwood pieces that are free of decay, fungus, and loose bark shall be used. All pieces selected shall weigh between 4.4 and 22 lb (2 to 10 kg). For each test fuel load at least 80 % of the load weight shall be comprised of fuel pieces weighing between 8 and 18 lb (3.6 and 8.2 kg). Piece length shall be 20 ± 4 in. (490 ± 102 mm). (See Fig. 3.) Pieces are to be placed in the firebox parallel to the longest firebox dimension or in the direction specified in the manufacturer's

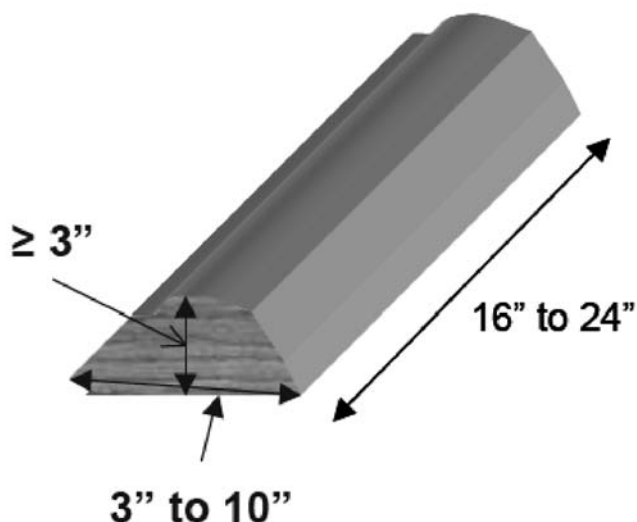


FIG. 3 Cord Wood Fuel

printed operating instructions. When loading test fuel loads, no effort shall be made to stack fuel pieces in a particular manner.

12.2.2 Moisture Content—Determine the test fuel moisture content with a calibrated electrical resistance moisture meter. Determine fuel moisture for each fuel piece by averaging at least three moisture meter readings, one from each of three sides, measured parallel to the wood grain. Measure the moisture content within 2 to 3 in. (50 to 75 mm) of each end and at the center of each piece. Average all the readings for each fuel piece in the test fuel charge. Penetration of the moisture meter insulated electrodes shall be at least 0.75 in. (19 mm). Measure the moisture content within a 4 h period prior to the test run.

12.2.3 Firebox Volume—Determine the firebox volume in cubic feet. Firebox volume shall include all areas accessible through the fuel loading door where firewood could reasonably be placed up to the horizontal plane defined by the top of the loading door. A drawing of the firebox showing front, side and plan views or an isometric view with interior dimensions shall be provided by the manufacturer and verified by the laboratory. Calculations for firebox volume from computer aided design (CAD) software programs are acceptable and shall be included in the test report if used. If the firebox volume is calculated by the laboratory the firebox drawings and calculations shall be included in the test report.

12.2.4 Test Fuel Charge—Test fuel charges shall be determined by multiplying the firebox volume by 10 lb (4.54 kg), or a higher load density as recommended by the manufacturer's printed operating instructions, of wood (as used wet weight) per cubic foot. Select the number of pieces of fuel that most nearly match this target weight. When the manufacturer's printed instructions specify fuel loading to a specific level, the firebox shall be loaded with fuel as specified in 12.2.1 to the level indicated and the weight of the fuel load recorded. This weight shall then be divided by the firebox volume as determined in accordance with 12.2.3 and the resulting loading

density shall be reported. If this loading density is less than 10 lb/ft³ (160 kg/m³), all tests shall be run with fuel load densities of 10 lb/ft³ (160 kg/m³) even though this could require loading to a level higher than indicated in the manufacturer's instructions.

12.2.5 Sampling Equipment—Prepare the sampling equipment as defined by Test Method E 2515.

12.2.6 Appliance Start-Up—The appliance shall be fired with wood fuel of any species, size and moisture content at the laboratories discretion to bring it up to operating temperature. Operate the appliance until the water is heated to the upper operating control limit and has cycled at least two times. Then remove all unburned fuel, zero the scale, and verify the scales accuracy using dead weights.

12.2.7 Pretest Burn Cycle—Reload appliance with oak fuel wood and allow it to burn down to the specified coal bed weight. Pretest burn cycle fuel charge weight shall be within $\pm 10\%$ of the test fuel charge weight. At least 2 h prior to starting the test run, adjust water flow to the heat exchanger to establish the target heat draw for the test. For the first test run the heat draw rate shall be equal to the manufacturer's rated heat output capacity.

12.2.8 Allowable Adjustments—Fuel addition or subtractions, and coal bed raking shall be kept to a minimum but are allowed up to 15 min prior to the start of the test run. For the purposes of this method, coal bed raking is the use of a metal tool (poker) to stir coals, break burning fuel into smaller pieces and dislodge fuel pieces from positions of poor combustion. Record all adjustments to and additions or subtractions of fuel, and any other changes to the appliance operations that occur during pretest ignition period. During the 15-min period prior to the start of the test run, the appliance loading door shall not be open more than a total of 1 min. Coal bed raking is the only adjustment allowed during this period.

12.2.9 Coal Bed Weight—The appliance is to be loaded with the test fuel charge when the coal bed weight is between 10 and 20 % of the test fuel charge weight. Coals may be raked as necessary to level the coal bed or position coals as recommended in the manufacturer's printed operating instructions but may only be raked and stirred once between 15 to 20 min prior to the addition of the test fuel charge.

12.2.10 Test Cycle—Complete a test run in each heat output rate category, as follows:

12.2.10.1 Test Run Start—Once the appliance is operating normally and the pretest coal bed weight has reached the target value in accordance with 12.2.9, tare the scale, start all sampling systems and load the full test charge into the appliance. Time for loading shall not exceed 5 min. The actual weight of the test fuel charge shall be measured and recorded within 30 min prior to loading. Record all data at intervals of 10 min or less. Record water flow and temperature data and monitor the average heat output rate. If the heat output rate gets close to the upper or lower limit of the target range adjust the water flow through the heat exchanger to compensate. Make changes as infrequently as possible while maintaining the target heat output rate. The first test run shall be conducted at

the Category IV heat output rate to validate that the appliance is capable of producing the manufacturer's rated heat output capacity.

12.2.10.2 Test Fuel Charge Adjustment—It is acceptable to adjust the test fuel charge (that is, reposition) once during a test run if more than 60 % of the initial test fuel charge weight has been consumed and more than 10 min have elapsed without a measurable (1 lb (0.5 kg) or 1 % of the test fuel load weight, whichever is greater) weight change while the operating control is in the demand mode. The time used to make this adjustment shall be less than 60 s.

12.2.10.3 Test Run Completion—The test run is completed when the remaining weight of the test fuel charge is 0.0 lb (0.0 kg). End the test run when the scale has indicated a test fuel charge weight of 0.0 lb (0.0 kg) or less for 30 s. At the end of the test run, stop the particulate sampling and record the run time and all final measurement values.

12.2.11 Heat Output Capacity Validation—The first test run must produce a heat output rate that is within 10 % of the manufacturer's rated heat output capacity (Category IV). If the appliance is not capable of producing a heat output within these limits, the manufacturer's rated heat output capacity is considered not validated and testing is to be terminated. In such cases, the tests may be continued using the heat output capacity as measured as the Manufacturer's Rated Heat Output Capacity if requested by the manufacturer.

12.2.12 Additional Test Runs—Using the Manufacturer's Rated Heat Output Capacity as a basis, conduct a test for additional heat output categories as specified in 4.3. It is not required to run these tests in any particular order.

12.2.13 Alternative Heat Output Rate for Category I—If an appliance cannot be operated in the Category I heat output range due to stopped combustion two test runs shall be conducted at heat output rates within Category II. When this is the case, the weightings for the weighted averages indicated in 14.1.14 shall be the average of the Category I and II weightings and shall be applied to both Category II results. Appliances that are not capable of operation within Category II (<25 % of maximum) cannot be evaluated by this test method.

12.2.14 Stopped Fuel Combustion—Evidence that an appliance cannot be operated at a Category I heat output rate due to stopped fuel combustion shall include documentation of two or more attempts to operate the appliance in burn rate Category I and fuel combustion has stopped prior to complete consumption of the test fuel charge. Stopped fuel combustion is evidenced when an elapsed time of 60 min or more has occurred without a measurable (1 lb (0.5 kg) or 1 % of the test load weight, whichever is greater) weight change in the test fuel charge while the appliance operating control is in the demand mode. Report the evidence and the reasoning used to determine that a test in burn rate Category I cannot be achieved. For example, two unsuccessful attempts to operate at an output rate of 10 % of the rated output capacity are not sufficient evidence that burn rate Category I cannot be achieved.

12.2.15 Appliance Overheating—Appliances shall be capable of operating in all heat output categories without overheating to be rated by this test method. Appliance over-

heating occurs when the rate of heat withdrawal from the appliance is lower than the rate of heat production when the unit control is in the idle mode. This condition results in the water in the appliance continuing to increase in temperature well above the upper limit setting of the operating control. Evidence of overheating includes: 1 h or more of appliance water temperature increase above the upper temperature set-point of the operating control, exceeding the temperature limit of a safety control device (independent from the operating control), boiling water in a non-pressurized system or activation of a pressure or temperature relief valve in a pressurized system.

12.2.16 Additional Test Runs—The testing laboratory may conduct more than one test run in each of the heat output categories specified in 4.3. If more than one test run is conducted at a specified heat output rate, the results from at least two thirds of the test runs in that heat output rate category shall be used in calculating the weighted average emission rate (see 14.1.14). The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the weighted average emission rate.

12.3 Automatically Fueled Appliances:

12.3.1 Appliances designed to burn automatically fed fuels such as wood pellets, shelled corn, wood chips or other biomass shall be tested using the fuel or fuels specified in the manufacturer's operating instructions.

12.3.2 Operation—The fuel used shall have representative samples taken and tested for higher heating value in accordance with Test Method E 711 and for moisture content by the oven drying method (Test Methods D 4442, Method A or B). Sufficient fuel for the tests shall be placed in a hopper on a scale that allows for measurement of the mass of fuel consumed during the test runs to an accuracy of ± 1 lb (± 0.5 kg). The unit shall be set up and operated in accordance with the manufacturer's instructions. A heat exchanger as specified in Section 9 shall be used to draw heat from the appliance at the rates specified for the categories specified in 4.3. The unit shall be operated for a minimum of 2 h at the specified heat output rate prior to starting the measurement phase of the test.

12.3.3 Measurement Phase—Record the weight of the fuel in the hopper after the unit has been in operation at the specified heat draw rate for 2 h. Start the emissions measurement sampling train and data collection as required in Test Method E 2515. Continue operation for a minimum of 4 h. At the end of the test period, stop the sampling train and record the final weight of the fuel in the hopper. Calculate the emissions, efficiency and heat output rate as specified in Section 13 using the mass of fuel consumed and the higher heating value for the fuel. Repeat this procedure for each heat output rate category. If more than one fuel type is specified, repeat the entire rating procedure for each fuel type.

13. Calculation of Results

13.1 Symbols:

E_T = total particulate emissions measured during a full test cycle, grams (from Test Method E 2515 Eq. 10)

$E_{g/MJ}$ = emission rate in grams per mega joule of heat output

$E_{lb/MMBtu \text{ Output}}$ = emissions rate in pounds per million Btu of heat output

$E_{lb/MMBtu Input}$ = emissions rate in pounds per million Btu of heat input

$E_{g/kg}$ = emissions factor in grams per kilogram of dry fuel burned

$E_{g/h}$ = emission factor in grams per hour

HHV = higher heating value of fuel = 8550 Btu/lb (19.874 MJ/kg) or as tested in accordance with Test Method E 711

LHV = lower heating value of fuel = 7478 Btu/lb (17.382 MJ/kg) or as tested in accordance with Test Method E 711

ΔT = temperature difference between water entering and exiting the heat exchanger

Q_{out} = total heat output in Btu (MJ)

Q_{in} = total heat input available in test fuel charge in Btu (MJ)

$\dot{M}$ = mass flow rate of water lb/min (kg/min)

v_i = volume of water indicated by a totalizing flow meter at the i th reading in gallons (litres)

v_f = volumetric flow rate of water in heat exchange system in gallons per minute (litres per minute)

t_i = elapsed time from start of test run at i th reading in minutes

η = delivered heating efficiency in percent

F_i = weighting factor for heat output category i

T_{avg} = average temperature of water in the load side of the heat exchanger

TI_{avg} = average temperature of the appliance and water at start of the test

TF_{avg} = average temperature of the appliance and water at the end of the test

MC = fuel moisture content in percent based on dry fuel weight

MC_i = average moisture content of individual fuel pieces on a dry weight basis

MC_{sp} = moisture content of spacers assumed to be 10 %

σ = density of water (lb/gal)

C_p = specific heat of water in Btu per pound °F

C_{steel} = specific heat of steel (0.1 Btu/lb·°F)

W_{fuel} = fuel charge weight in pounds (kilograms)

W_i = weight of individual fuel pieces in pounds (kilograms)

W_{sp} = weight of all spacers used in a fuel load in pounds (kilograms)

W_{app} = weight of appliance in pounds

W_{water} = weight of water in supply side of the system in pounds

NOTE 1—After the test is completed, determine the particulate emissions in accordance with Test Method E 2515 Eq. 10 (E_T).

13.2 Determine Average Fuel Load Moisture Content:

$$MC_{Ave} = \frac{[\sum W_i \cdot MC_i]}{\sum W_i}$$

13.3 Determine Heat Input:

$$Q_{in} = (W_{fuel}/(1 + (MC_{ave}/100))) \times HHV$$

$$Q_{in LHV} = (W_{fuel}/(1 + (MC_{ave}/100))) \times LHV$$

13.4 Determine Heat Output and Efficiency:

13.4.1 Determine heat output as:

$$Q_{out} = \sum [C_p \times \Delta T \times \text{mass flow rate (lb/min)} \times \text{time interval (min)}] + \text{change in heat stored in the appliance}$$

$$Q_{out} = [\sum (C_p \cdot \Delta T \cdot \dot{M} \cdot t)] + (W_{app} \cdot C_{steel} + C_p W_{water}) \cdot (TF_{avg} - TI_{avg})$$

$$\dot{M} = \text{mass flow rate} = \text{gal/min} \times \text{density of water (lb/gal)} = \text{lb/min}$$

$$\dot{M} = V_f \cdot \sigma$$

$$\sigma = (62.56 + (-0.0003413 \times T_{avg}) + (-0.00006225 \times T_{avg}^2)) 0.1337 \text{ lb/gal}$$

$$C_p = 1.0014 + (-0.000003485 \times T_{avg}) \text{ Btu/lb } ^\circ\text{F}$$

$$C_{steel} = 0.1 \text{ Btu/lb } ^\circ\text{F}$$

$$V_f = (V_i - V_{i-1})/(t_i - t_{i-1})$$

NOTE 2— V_i is the total water volume at the end of interval i and V_{i-1} is the total water volume at the beginning of the time interval. This calculation is necessary when a totalizing type water meter is used.

Change in heat stored in the appliance

$$= [(\text{weight of the appliance} \times 0.1)$$

$$+ (\text{weight of water in the appliance} \times C_p)]$$

$$\times (\text{final average temperature of the appliance}$$

$$- \text{initial average temperature of the appliance})$$

where:

C_p = specific heat of water.

13.4.2 Determine heat output rate as:

$$\text{Heat Output Rate} = Q_{out}/\text{test cycle duration in hours}$$

13.4.3 Determine emission rates as:

$$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$$

$$E_{lb/MM Btu Output} = (E_T/453.59)/(Q_{out} \times 10^{-6})$$

$$E_{lb/MM Btu Input} = (E_T/453.59)/(Q_{in} \times 10^{-6})$$

$$E_{g/kg} = E_T/(W_{fuel}/(1 + MC/100))$$

$$E_{g/h} = E_{T\text{test duration}}$$

13.4.4 Determine delivered efficiency as:

$$\eta_{del} = (Q_{out}/Q_{in}) \times 100$$

$$\eta_{del LHV} = (Q_{out}/Q_{in LHV}) \times 100$$

13.5 Weighted Average Emissions and Efficiency:

13.5.1 Determine the weighted average emission rate and delivered efficiency from the individual tests in the specified heat output categories. The weighting factors (F_i) are derived from an analysis of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Bin Data which provides details of normal building heating requirements in terms of percent of design capacity and time in a particular capacity range (or “bin”) over the course of a heating season. The values used in this method represent an average of data from several cities located in the northern United States.

$$\text{Weighted average delivered efficiency: } \eta_{avg} = \sum \eta_j \times F_j$$

$$\text{Weighted average emissions: } E_{avg} = \sum E_j \times F_j$$

13.5.2 Average Btu/h for 8 h Burn Time (does not apply to particulate fueled appliances):

13.5.2.1 Units tested under this standard typically require infrequent fuelling, 8 to 12 h intervals being typical. Rating unit's based on an Average Output sustainable over an 8 h duration will assist consumers in appropriately sizing units to match the theoretical heat demand of their application.

13.5.2.2 Calculations:

$$\begin{aligned} & \text{Average Btu/h for 8 h burn time} \\ & = X1 + \{(8 - Y1) \times [(X2 - X1) / (Y2 - Y1)]\} \end{aligned}$$

where:

- Y1 = test duration just above 8 h,
- Y2 = test duration just below 8 h,
- X1 = actual load for duration Y1, and
- X2 = actual load for duration Y2

13.5.2.3 Determine the test durations and actual load for each category as recorded in Table 1.

13.5.2.4 Determine the data point that has the nearest duration greater than 8 h.

X1 = Actual Load and Y1 = Test Duration for this data point

13.5.2.5 Determine the data point that has the nearest duration less than 8 h.

X2 = Actual Load and Y2 = Test Duration for this data point

13.5.2.6 Example:

Category	Actual Load (Btu/h)	Duration (h)
I	15 000	10.2
II	26 000	8.4
III	50 000	6.4
IV	100 000	4.7

Category II Duration is just above 8 h, therefore:

X1 = 26 000 Btu/h and Y1 = 8.4 h

Category III Duration is just below 8 h, therefore:

X2 = 50 000 Btu/h and Y2 = 6.4 h

$$\begin{aligned} 8 \text{ h Burn Load} &= 26\,000 + \{(8 - 8.4) \times [(50\,000 - 26\,000) / (6.4 - 8.4)]\} \\ &= 30\,800 \text{ Btu/h} \end{aligned}$$

14. Report

14.1 The report shall include the following:

14.1.1 Name and location of the laboratory conducting the test.

14.1.2 A description of the appliance tested and its condition, date of receipt and dates of tests.

14.1.3 A statement that the test results apply only to the specific appliance tested.

14.1.4 A statement that the test report shall not be reproduced except in full, without the written approval of the laboratory.

14.1.5 A description of the test procedures.

14.1.6 Details of deviations from, additions to or exclusions from the test method, and information on specific test conditions, such as environmental conditions.

14.1.7 A list of participants and observers present for the tests.

14.1.8 Data and drawings indicating the fire box size and location of the fuel charge.

14.1.9 Drawings and calculations used to determine firebox volume.

14.1.10 Information for each test run fuel charge including piece size, moisture content, and weight.

14.1.11 Temperature, appliance weight, fuel charge weight, and water flow data recorded during each test run.

14.1.12 Test run duration for each test.

14.1.13 Calculated results for delivered efficiency at each burn rate and the weighted average Emissions reported as total emissions in grams, pounds per million Btu of delivered heat, grams per mega joule of delivered heat, grams per kilogram of dry fuel and grams per hour. Results shall be reported for each heat output category and the weighted average.

14.1.14 Tables 1-3 must be used for presentation of results in test reports.

14.1.15 A statement of the estimated uncertainty of measurement of the emissions and efficiency test results.

14.1.16 Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of seven years.

15. Precision and Bias

15.1 *Precision*—It is not possible to specify the precision of the procedure in this test method for measuring solid fuel burning outdoor hydronic heater emissions because the appliance operation and fueling protocols and the appliances themselves produce variable amounts of emissions and cannot be used to determine reproducibility or repeatability of this measurement method.

15.2 *Bias*—No definitive information can be presented on the bias of the procedure in this test method for measuring solid fuel burning outdoor hydronic heater emissions because no material having an accepted reference value is available.

TABLE 1

CAT	Load % Capacity	Tgt Load (Btu/h)	Act Load (Btu/h)	Test Duration (h)	Wood Wt (lb)	Q _{in} (Btu)	Q _{out} (Btu)	η _{in} (%)	E _T (g)	E (g/MJ)	E (lb/MMBtu Output)	E (lb/MMBtu Input)	E (g/h)	E (g/Kg)
I	<15 % of max													
II	16–24 % of max													
III	25–50 % of max													
IV	Max capacity													
Average Btu/h for 8 h burn time _____														

TABLE 2 Heating Season Weighting

CAT	Weighting Factor (F_j)	$\eta_j \times F_j$	$E_{g/MJ, j} \times F_j$	$E_{g/kg, j} \times F_j$	$E_{lb/MMBtu \text{ Output}, j} \times F_j$	$E_{lb/MMBtu \text{ Input}, j} \times F_j$	$E_{g/h, j} \times F_j$
I	0.175						
II	0.275						
III	0.450						
IV	0.100						
Totals	1.000						

TABLE 3 Year-Round Use Weighting

CAT	Weighting Factor (F_j)	$\eta_j \times F_j$	$E_{g/MJ, j} \times F_j$	$E_{g/kg, j} \times F_j$	$E_{lb/MMBtu \text{ Output}, j} \times F_j$	$E_{lb/MMBtu \text{ Input}, j} \times F_j$	$E_{g/h, j} \times F_j$
I	0.437						
II	0.238						
III	0.275						
IV	0.050						
Totals	1.000						

16. Keywords

16.1 hydronic heating appliances; outdoor hydronic heaters; solid fuel; wood-burning

APPENDIX

(Nonmandatory Information)

X1. MODIFIED TEST METHOD FOR WOOD-FIRED HYDRONIC APPLIANCES THAT UTILIZE THERMAL STORAGE

X1.1 Scope

X1.1.1 **Appendix X1** describes a modified test method that is to be utilized for wood-fired hydronic heating appliances, both non-pressurized and pressurized, that incorporate, either integrally or remotely, mass thermal storage. A mass storage unit transfers heat to the indoor environment through the circulation of a liquid heat exchange media such as water or water/antifreeze mixtures. Such appliances are used to heat structures such as homes, barns, small commercial facilities, greenhouses, etc., and can heat domestic hot water, spas, or swimming pools.

X1.1.2 Appliances covered by **Appendix X1** must incorporate sufficient thermal storage capacity to safely accept the entire heat output of a full fuel load without heat draw-off, without over heating, and without activating any safety limit controls provided with the appliance. Sufficient thermal storage capacity must be provided by the manufacturer to allow a 4-h carry over between firings when providing the maximum rated heat output.

X1.1.3 This test method simulates hand loading of seasoned firewood and measures particulate emissions and delivered efficiency. The rate at which energy is delivered to a building is independent of the combustion process and burn rate; however, some heat losses from the system to the outdoor environment occur over time and are termed *stand-by loss* for the purposes of this test procedure. When heat is required, it is withdrawn from thermal storage whether or not combustion is occurring. The only function of the combustion process is to periodically recharge the thermal storage with energy through

a batch burn process. Optimization of this batch burn process minimizes particulate emissions and increases combustion efficiency.

X1.1.4 Particulate emissions are measured by the dilution tunnel method as specified in Test Method **E 2515**. Delivered efficiency is measured by determining the temperature rise of the thermal storage and determining the input from the mass of dry wood fuel consumed based upon its higher heating value and its moisture content.

X1.1.5 This procedure includes a stand-by loss test which determines the average rate heat is expected to be lost from the system to the environment when in operation. This data, along with the heat storage measurements, are used to calculate equivalent efficiency and emissions performance for heat output categories as defined in the main standard based on the manufacturer's stated maximum heat output capacity. This capacity must not exceed a level that the test data indicates can be sustained for a minimum period of 4 h from one full fuel charge. An equivalent 8-h heat output capacity is also calculated.

X1.1.6 Distinguishing features of products covered by **Appendix X1** include:

X1.1.6.1 A firebox with an access door for hand loading of fuel.

X1.1.6.2 Thermal energy storage (water, refractory, sand, concrete, brick, soapstone, metal, etc.) either remote or integral as part of the appliance.

X1.1.6.3 A liquid heat transfer media circulated between the heat storage mass and heated space to facilitate the transfer of stored heat energy to the heated space.

X1.1.6.4 Sufficient thermal storage capacity to safely accept the entire heat output of a full fuel load without heat draw-off, without over heating, and without activating any safety controls provided with the appliance. An operating control does not cycle the combustion air on and off based on storage temperature. The appliance burns the entire fuel load at its high burn rate.

X1.1.6.5 A chimney or vent that exhausts combustion products from the appliance.

X1.2 *Operation*—Appliance operation is conducted utilizing a batch burn cold-to-cold test cycle, meaning that a hot coal bed is not established at the beginning of each test cycle and the fuel load is fully consumed during the test. For liquid-based systems, the appliance (including the thermal storage) is brought up to a beginning test temperature of $125^{\circ}\text{F} \pm 5^{\circ}\text{F}$ ($52^{\circ}\text{C} \pm 2.8^{\circ}\text{C}$). A test fuel load and kindling is placed within the combustion chamber, the various temperature measurements are recorded, emission instrumentation is activated, the kindling is ignited, and the test begins. The test run terminates when the test fuel load is fully consumed and there is no additional temperature rise of the thermal storage media. Following a test run the thermal storage is brought back down to the beginning test temperature and made ready for another test run.

NOTE X1.1—It is feasible to use non-water-based heat storage media such as rock, sand, or other solid materials. Application of this procedure to such systems will require additional information and modified procedures. At a minimum instrumentation would be required to measure temperatures in the heat storage media sufficient to determine a true average temperature. The mass and specific heat of the media would also need to be determined. Alternatively, total heat stored can be determined by measuring the flow rate and temperature change of heat transfer media (for example, water) between the appliance and the heat storage media until no temperature change occurs between the inlet and outlet temperatures at the heat storage media.

X1.3 Apparatus

X1.3.1 *Scales*—A certified platform scale capable of weighing the appliance in test condition to an accuracy of ± 1 lb (± 0.5 kg). This scale should also be capable of weighing the thermal storage if remote from the appliance proper. Where the thermal storage exceeds the capacity of an available certified scale, calculations based upon manufacturer submitted computer aided design drawings shall be used to determine the mass of the thermal storage. Since the test requires burning of single complete fuel loads, a scale capable of weighing the appliance is not required to determine the end of the test. A separate scale is required to weigh the test load with an uncertainty of ± 0.5 % of the fuel load weight.

X1.3.2 *Heat Exchanger*—A water-to-water heat exchanger capable of removing the heat in the thermal storage in order to bring the thermal storage back down to its starting temperature and ready for another test run.

X1.3.3 *Temperature Measurement*—Thermocouples shall be used to measure the temperature of the thermal storage media and appliance. The temperature measurements shall have an uncertainty of $\pm 0.50^{\circ}\text{F}$ ($\pm 1^{\circ}\text{C}$). All appliance surfaces

in contact with the storage media or within the insulated envelope shall be assumed to be at the same temperature as the storage media.

X1.3.4 *Flow Meter*—A totalizing flow meter with a resolution of 0.1 gal (3.8 L) and an accuracy of 0.5 % of volume recorded or a flow meter with an accuracy of ± 0.01 gal/min (± 0.038 L/min).

X1.3.5 *Destratification Pump*—An inline pump used to eliminate thermal stratification in liquid-based thermal storage systems to prevent false and inaccurate initial and final temperature readings. The pump capacity should be capable of “turning over” the liquid at least once every 60 to 90 min. In addition to a destratification pump, a 3-D thermocouple array securely mounted within the liquid thermal storage may be used to confirm the average initial and final thermal storage temperature. Thermocouples shall be placed at the outlet and return of the recirculation and the average of the two shall be used to determine the average temperature of the heat storage mass.

X1.4 *Hazards*—Refer to Section 7.

X1.5 *Sampling, Test Specimens, and Test Appliances*—Test specimens shall be supplied as complete appliances including all controls and accessories necessary for installation in the test facility. A full set of specifications and design and assembly drawings shall be provided when the product is to be placed under certification of a third-party agency. The manufacturer’s written installation and operating instructions are to be used as the guide in the set-up and testing of the appliance. Variations or changes to the manufacturer’s suggested installation methods must be approved by the manufacturer.

X1.6 Preparation of the Appliance

X1.6.1 The appliance and thermal storage shall be weighed. If not possible, the mass of each shall be calculated based upon manufacturers supplied certified AutoCAD (or equivalent computer-based) drawings and confirming lab measurements. If utilizing a liquid-based system, fill the thermal storage through the totalizing flow meter in order to confirm the liquid volume. Record the volume or mass, or both, of the appliance, firebrick, and thermal storage.

X1.6.2 Install the destratification pump for liquid-based thermal storage systems. The pump shall be piped so that a thorough mixing of the liquid storage medium occurs, thus eliminating any significant thermal stratification.

X1.6.3 Install all thermocouples necessary to measure the thermal storage temperature. In addition, install the heat exchanger with a totalizing flow meter and a thermopile on the supply/return connections on the heat rejection (load) side of the heat exchanger. The water flow meter is to be installed on the cooling water inlet side of the heat exchanger so that it will operate at the same temperature as its calibration. Place the heat exchanger in a box with 2 in. (50 mm) of EPS foam insulation surrounding it to minimize heat losses from the heat exchanger.

X1.6.4 The total energy added to the thermal storage shall be obtained by multiplying the temperature change recorded for the appliance and thermal storage media by their respective masses and specific heats in accordance with X1.10.2.

X1.7 Calibration and Standardization—Refer to Section 10.

X1.8 Conditioning—The appliance (including the thermal storage) is to be brought to a beginning test temperature of 125°F ± 5°F (52°C ± 2.8°C). This is to be accomplished by normal operation of the unit sufficient to heat the storage media to at least 150°F (65.5°C) and then removing heat using the external simulated load until the temperature reaches 125°F to 130°F (52°C to 65.5°C). The unit shall then be allowed to equilibrate for a minimum of 4 h with no heat draw before the test run is started. For liquid-based thermal storage appliances, activate the destratification pump for a sufficient period of time prior to the beginning of a test run to eliminate thermal stratification. All ash and debris from conditioning or a previous test is to be removed from the combustion chamber and the combustion chamber is to be brushed clean before each test run.

X1.8.1 Prior to testing, a non-catalytic appliance is to be operated for a minimum of 10 h. Catalytic units shall be operated for a minimum of 50 h prior to testing.

X1.9 Procedure—Refer to 12.2, 12.2.1, 12.2.2, and 12.3.

X1.9.1 Fuel Load Size—Determine fuel load weight and piece size in accordance with 12.2.4. For a portion of this load weight, it is acceptable to substitute up to 5 % of the fuel load mass in kindling, which includes smaller and dryer fuel pieces than the primary fuel load. Weigh and determine the moisture content of all kindling that is used. Record all weights and moisture contents. The full test load and kindling are to be weighed within 3 h prior to loading on a scale with and accuracy of ±0.1 lb (±0.05 kg) or ±0.5 % of the load weight, whichever is greater. Newspaper is to be used to ignite the kindling and weighed with the kindling.

X1.9.2 Begin Test Run—Record the time and all initial temperatures including the average heat storage media temperature. Activate all instrumentation, light the kindling, and close the loading door.

X1.9.3 Test Run Completion—As the test load burns, monitor and record the increase in thermal storage temperature at intervals of 10 min or less. The test run terminates when the test fuel load is fully consumed and there is no additional thermal storage temperature rise. It is acceptable to open the door and reposition the fuel once during the test to insure that all fuel is consumed. Fuel adjustment, if performed, shall be done only when it is apparent that the fire is dying out as evidenced by a steady decline in flue gas temperature. Fuel adjustments shall be accomplished in no more than 2 min. Maximum thermal storage temperature is attained when the temperature of the thermal storage media shows a decline or no measurable increase for 1 h. Record the highest temperature reached. The particulate sampling system shall be run until combustion has ceased as evidenced by flue gas temperatures falling to within 5°F (2.8°C) of the appliance temperature, flue gas oxygen, or carbon dioxide concentrations within 0.5 % of ambient or no additional thermal storage temperature rise (<°F) in two consecutive 10-min readings.

X1.9.3.1 Test completion is to be confirmed by visual observation of fuel consumption prior to terminating the

sampling. At the end of the test run, stop the particulate sampling, record the run time, and record all final measurement values.

X1.9.4 Stored Energy Measurement:

X1.9.4.1 Record the heat storage media temperature once the heat storage has reached its maximum.

X1.9.5 Additional Test Runs—The testing laboratory is to conduct at least three test runs. The results from at least two-thirds of the test runs (all three runs if only three runs are completed) shall be used for calculating the average emission rate and efficiency. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the average emission rate and efficiency.

X1.10 Calculation of Results—Refer to 13.1 and 13.2.

X1.10.1 For each test run, determine heat input (Q_{in}). Include the weight of the wood fuel test load and any kindling used when determining the heat input.

$$Q_{in} = \left[\left(\frac{W_{kindling}}{1 + (MC_{kind}/100)} \right) + \left(\frac{W_{fuel}}{1 + (MC_{fuel}/100)} \right) \right] \times HHV$$

where:

HHV = the higher heating value of the fuel used (Btu/lb, MJ/kg),

MC = average fuel moisture content (percent-dry basis),

W = weight of the fuel (lb, kg).

NOTE X1.2—The HHV is obtained from a Bomb Calorimeter Test in accordance with Test Method E 711, or use the default value of 8550 Btu/lb (19.874 MJ/kg).

X1.10.2 For each run, determine heat stored as measured by net temperature increase.

Q_{stored} = change in heat stored in the appliance

$$Q_{stored} = (W_{app} \cdot C_{steel} + C_p \cdot W_{water}) \cdot (TF_{avg} - TI_{avg})$$

$$C_p = 1.0014 + (-0.000003485 \times T_{avg}) \text{ (Btu/lb-°F)}$$

$$C_p = 1.294 + (-0.000000965 \times T_{avg}) \text{ (kJ/kg-°C)}$$

$$C_{steel} = 0.1 \text{ Btu/lb-°F (0.1293 kJ/kg-°C)}$$

TF_{avg} = final average heat storage media temperature (°F, °C)

TI_{avg} = initial average heat storage media temperature (°F, °C)

T_{avg} = average of TF_{avg} and TI_{avg} (°F, °C)

X1.11 Stand-by Loss Determination

X1.11.1 Stand-by loss is a measure of the level of insulation of the heat storage system expressed in Btu/h · °F (kJ/h-°C).

X1.11.2 Procedure:

X1.11.2.1 Fire the appliance with sufficient fuel of any type to bring the temperature of the storage media to at least 170°F (77°C). The recirculation pump as described in X1.6.2, shall be turned on for a minimum of 1 h before making the water temperature measurement. This test can be run as a continuation of a heat storage measurement test run.

X1.11.2.2 The external heat exchange load and the recirculation pump shall be turned off and no water shall be allowed to circulate from the appliance through the heat exchanger during this test. The system shall then be allowed to equilibrate for a minimum of 8 h before conducting the stand-by loss measurement. No heat draw is applied during this test.

X1.11.2.3 Record the average heat storage media temperature and ambient temperature at least every 30 min during this test.

X1.11.2.4 Start a timer when the 8-h equilibration period has elapsed and record the system average temperature. After an additional minimum of 12 h has elapsed record the system temperature again. The recirculation pump shall be turned off until 1 h before the final temperature measurement is made.

X1.11.2.5 Calculate the stand-by heat loss as follows:

$$Q_{s-b \text{ loss}} = \frac{(T_1 - T_2) \cdot [C_p \cdot W_{\text{water}} + C_{\text{steel}} \cdot W_{\text{steel}}]}{t \cdot [(T_1 + T_2)/2 - T_{\text{amb ave}}]}, (\text{Btu/h } ^\circ\text{F, kJ/h } ^\circ\text{C})$$

where:

- C_p = specific heat of heat storage media at $(T_1 + T_2)/2$,
- W_{water} = weight of heat storage media in the appliance,
- C_{steel} = specific heat of steel = 0.1 Btu/lb $^\circ\text{F}$ (0.1292 kJ/kg $^\circ\text{C}$),
- W_{steel} = weight of the appliance (lb, kg),
- t = test duration (h),
- T_1 = average temperature of heat storage media at the start of the test ($^\circ\text{F}$, $^\circ\text{C}$),
- T_2 = average temperature of heat storage media at the end of the test ($^\circ\text{F}$, $^\circ\text{C}$), and
- $T_{\text{amb ave}}$ = average ambient temperature ($^\circ\text{F}$, $^\circ\text{C}$).

X1.11.3 For calculations of efficiency and emissions the average input, stored energy and total emissions shall be used in the following calculations.

X1.11.4 *Determination of Efficiency:*

X1.11.4.1 Efficiency shall be determined for each heat output category (I-IV) based on the manufacturer's stated maximum capacity (Category IV).

X1.11.4.2 Calculate output rates as follows:

$$Q_I = Q_{IV} \times 0.15$$

$$Q_{II} = Q_{IV} \times 0.20$$

$$Q_{III} = Q_{IV} \times 0.375$$

$$Q_{IV} = \text{manufacturer's stated capacity}$$

NOTE X1.3—These represent the mid-points of the range specified for Categories II and III.

X1.11.4.3 Determine the duration for heat output for each category:

$$t_i = \frac{Q_{\text{stored}}}{Q_i + (85 \times Q_{s-b \text{ loss}})}$$

where:

- t_i = the time in hours that heat can be drawn at Q_i Btu/h,
- 85 = assumed temperature difference of storage average temperature (155 $^\circ\text{F}$) and lab ambient (70 $^\circ\text{F}$), and
- Q_{stored} = average heat stored in a minimum of three test runs.

X1.11.4.4 Determine delivered efficiency for each heat output category.

$$\eta_{\text{del}, i} = \left[\frac{Q_{\text{stored}} - (t_i \times 85 \times Q_{s-b \text{ loss}})}{Q_{\text{in}}} \right] \times 100$$

X1.11.5 Determine the average burn rate (average of the minimum three individual burn rates).

$$\text{Average burn rate (kg/h)} = \text{fuel load weight (dry basis)/test duration, h}$$

where:

test duration = the time in hours required to consume the test fuel.

X1.11.6 *Emissions Rate* (ET = average emissions from test runs): Subscript j denotes data calculated for each heat output category.

$$E_{g/\text{MJ}, j} = E_T / (Q_{\text{out}, j} \times 0.001055)$$

$$E_{g/1000 \text{ Btu}, j} = E_T / (Q_{\text{out}, j} \times 0.001)$$

$$E_{g/\text{kg}, j} = E_T / ((W_{\text{kindling}} / (1 + MC_{\text{kind}}/100)) + (W_{\text{fuel}} / (1 + MC_{\text{fuel}}/100)))$$

$$E_{\text{lb/MMBtu Output}, j} = (E_T / 453.59) / (Q_{\text{out}, j} \times 10^{-6})$$

$$E_{\text{lb/MMBtu Input}, j} = (E_T / 453.59) / (Q_{\text{in}, j} \times 10^{-6})$$

X1.11.7 Calculate 8-h heat output rate.

$$Q_{8-h} = (Q_{\text{stored}} - (8 \times 85 \times Q_{s-b \text{ loss}})) / 8$$

X1.12 Report

X1.12.1 The report shall include the following minimum information:

X1.12.1.1 Name and location of the laboratory conducting the test.

X1.12.1.2 A description of the appliance tested, its condition, date of receipt and dates of test. Include a description of the appliance enclosure including insulation type, thickness, location, and nominal R-value.

X1.12.1.3 A statement that the test results apply only to the specific appliance tested.

X1.12.1.4 A description of the test procedures employed and a list of participants and observers present for the tests.

X1.12.1.5 Details of deviations from, additions to or exclusions from the test method, and information on specific test conditions, such as environmental conditions.

X1.12.1.6 Data and drawings indicating the fire box size and location of the fuel charge.

X1.12.1.7 Information for each fuel charge including piece size, moisture content, and weight.

X1.12.1.8 All recorded temperatures, appliance weight, fuel charge weight, thermal storage weight, water flow data, and refractory weight.

X1.12.1.9 Calculated results for delivered efficiency, emissions, and weighted averages as indicated in **Tables 1-3**.

X1.12.1.10 Stand-by heat loss rate in Btu/h $^\circ\text{F}$.

X1.12.1.11 Any pictures that would help to clarify the test unit and set up.

X1.12.1.12 Any required lab certification information or instrumentation calibration information, or both.

X1.12.1.13 Statement of the estimated uncertainty of measurement of the emissions and efficiency test results.

X1.12.1.14 Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of seven years.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).