Designation: E2618 – 13

Standard Test Method for Measurement of Particulate Emissions and Heating Efficiency of Solid Fuel-Fired Hydronic Heating Appliances[1]

This standard is issued under the fixed designation E2618; 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. 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 E2515. Delivered efficiency is determined by measurement of the usable heat output (determined through measurement of the flow rate and temperature change of water circulated through a heat exchanger external to the appliance) and the heat input (determined from the mass of dry fuel burned 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 or indoor installation. They are often connected to a heat exchanger by insulated pipes 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.

1.4.1 Hydronic heating systems that incorporate a high mass heat storage system that is capable of storing the entire heat output of a standard fuel load are tested by the procedure specified in Annex A1. Systems that incorporate high mass heat storage capable of storing a portion of the output from a standard fuel load are tested by the procedure specified in Annex A2.

1.5 Distinguishing features of products covered by this standard include:

1.5.1 Manufacturers specify indoor or outdoor installation.

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 in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.6.1 *Exception*—Metric units are used in 13.1, 13.4.3, Tables 4-6, and A1.11.6.

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]

D4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials

E631 Terminology of Building Constructions

[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.

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[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.

E711 Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter (Withdrawn 2011)[3]
E2515 Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel
2.2 *Other Standards:*
CAN/CSA-B415.1-2010 Performance Testing of Solid-Fuel-Burning Heating Appliances[4]
ASME Pressure Vessel Code[5]
EN303–5 Pressure Vessel Code[6]
NIST Traceable Methods[7]
2.3 *Other Documents:*[7]
Monograph 175 Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90

3. Terminology

3.1 *Definitions*—Definitions are in accordance with Terminology E631, 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.

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 *overall efficiency, also known as stack loss efficiency*—The efficiency for each test run as determined using the CSA B415.1-2010 Stack Loss Method (SLM)

3.2.7 *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.

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

3.2.9 *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 E2515. 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 *Efficiency:*
4.2.1 *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.
4.2.2 *Overall Efficiency*—Overall Efficiency (SLM) is determined using the CSA B415.1-2010 Stack Loss Method for data quality assurance purposes.

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.

[3] The last approved version of this historical standard is referenced on www.astm.org.
[4] Available from Canadian Standards Association (CSA), 5060 Spectrum Way, Mississauga, ON L4W 5N6, Canada, http://www.csa.ca.
[5] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990, http://www.asme.org.
[6] Available from European Committee for Standardization (CEN), Avenue Marnix 17, B-1000, Brussels, Belgium, http://www.cen.eu.
[7] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

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 *Water Temperature Difference Measurement*—A Type -T "special limits" thermopile with a minimum of five pairs of junctions shall be used to measure the temperature difference in water entering and leaving the heat exchanger. The temperature difference measurement uncertainty of this type of thermopile is equal to or less than ±0.50ºF (±0.25ºC). Other temperature measurement methods may be used if the temperature difference measurement uncertainty is equal to or less than ±0.50ºF (±0.25ºC).

6.4 *Load Side Water Flow Meter*—A water flow meter shall be installed in the inlet to the load side of the heat exchanger. The flow meter shall have an accuracy of ±1 % of measured flow.

6.4.1 *Optional Appliance Side Water Flow Meter*—A water flow meter with an accuracy of ±1 % of the flow rate is recommended but not required to monitor appliance side water flow rate to the heat exchanger.

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

6.6 *Water Temperature Measurement*—Thermocouples or other temperature sensors to measure the water temperature at the inlet and outlet of the load side of the heat exchanger. Must meet the calibration requirements specified in 10.1.

6.7 *Wood Moisture Meter*—Calibrated electrical resistance meter capable of measuring test fuel moisture to within 2 % moisture content. Must meet the calibration requirements specified in 10.4.

6.8 *Flue Gas Temperature Measurement*—Must meet the requirements of CSA B415.1-2010, Clause 6.2.2.

6.9 *Test Room Temperature Measurement*—Must meet the requirements of CSA B415.1-2010, Clause 6.2.1.

6.10 *Flue Gas Composition Measurement*—Must meet the requirements of CSA B415.1-2010, Clauses 6.3.1 through 6.3.3.

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 or EN303-5 pressure vessel code. Alternatively, a pressure vessel may be installed open to the atmosphere with a stand pipe if allowed by the manufacturer's installation instructions. 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 *Optional Equipment Installation:*

9.3.1 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.

9.3.2 If the manufacturer specifies that a thermal control valve or other device be installed and set to control the return water temperature to a specific set point, the valve or other device shall be installed and set per the manufacturer's written instructions.

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

9.5 *Heat Exchanger Temperature, Differential Temperature and Water Flow Instrumentation:*

9.5.1 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.

9.5.2 Locate thermocouples to measure the water temperature at the inlet and outlet of the load side of the heat exchanger.

9.5.3 Install a thermopile meeting the requirements of 6.3 to measure the water temperature difference between the inlet and outlet of the load side of the heat exchanger.

9.5.4 Install a calibrated water flow meter in the heat exchanger load side supply line. 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 temperature at which it is calibrated.

9.5.5 Place the heat exchanger in a box with 2 in. (51 mm) of expanded polystyrene (EPS) foam insulation surrounding it to minimize heat losses from the heat exchanger.

9.5.6 The reported efficiency and heat output rate shall be based on measurements made on the load side of the heat exchanger. (See Fig. 1.)

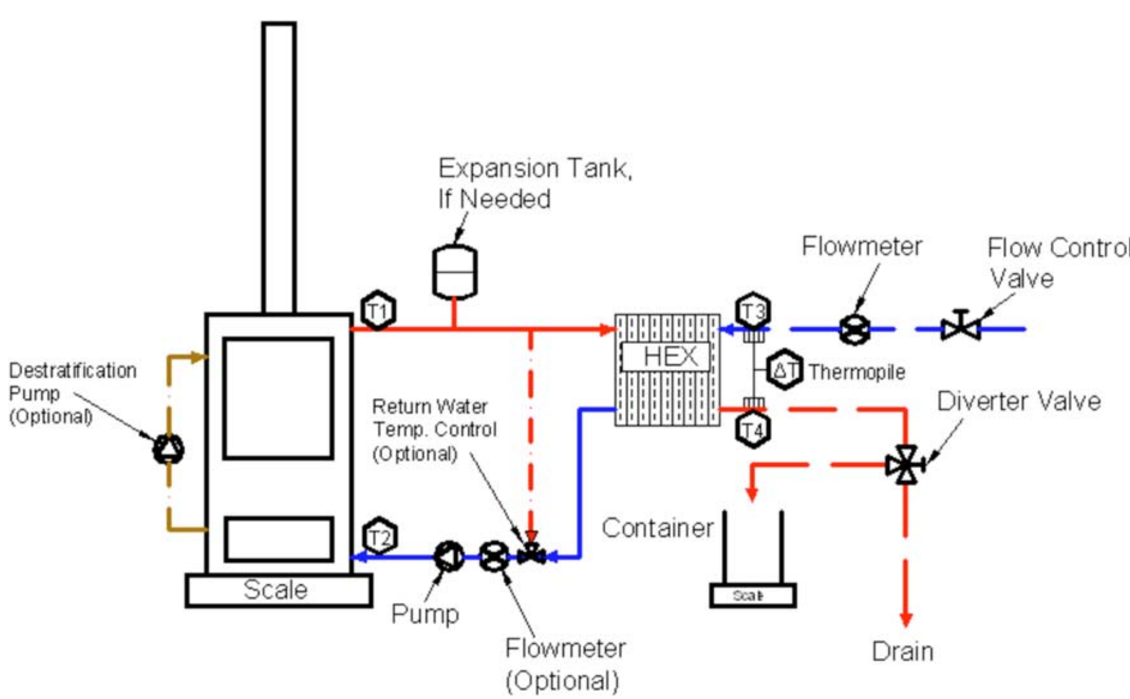
9.6 Temperature instrumentation shall be installed in the output and return lines from the appliance (supply side). The average of the outlet and return water temperature on the supply side of the system shall be considered the average appliance temperature for calculation of heat storage in the appliance (TF_{avg} and TI_{avg}). Installation of a water flow meter in the appliance (supply) side of the system is optional.

9.7 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 before initial use and at least semi-annually thereafter. Calibrations shall be in compliance with National Institute of Standards and Technology (NIST) Monograph 175, Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90.

10.2 *Water Flow Meter*—The heat exchanger load side water flow meter shall be calibrated within the flow range used for the test run using NIST Traceable Methods. Verify the calibration of the water flow meter before and after each test run by comparing the water flow rate indicated by the flow meter to the mass of water collected from the outlet of the heat exchanger over a timed interval. Volume of the collected water shall be determined based on the water density calculated from Eq 10, using the water temperature measured at the flow meter. The uncertainty in the verification procedure used shall be 1 %



Illustrated appliance pump location and flow path through the appliance are generic and may vary based on the unit being tested.

FIG. 1 Set-Up Schematic

or less. The water flow rate determined by the collection and weighing method shall be within 1 % of the flow rate indicated by the water flow 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 appliance is to be operated for a minimum of 48 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. Record and report hourly flue gas exit temperature data and the hours of operation. It is acceptable that the conditioning procedure may be conducted and documented by the manufacturer prior to submission of the test appliance to a testing laboratory or it may be conducted and documented by the 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 Properties:*

12.2.1.1 *Fuel Species and Properties*—The test fuel charge shall be comprised of any species of cordwood with a specific gravity in the range of 0.60 to 0.73 based on oven dry weight and volume. Refer to Table 1 for examples of some fuel species that typically meet the specific gravity requirement. Other fuel species may be used if they meet the specific gravity requirement. Only cordwood pieces that are free of decay, fungus and loose bark shall be used.

12.2.1.2 *Test Fuel Moisture*—Using a fuel moisture meter as specified in 6.7 of the test method, determine the fuel moisture for each test fuel piece used for the test fuel load by averaging at least five fuel moisture meter readings measured parallel to the wood grain. Penetration of the moisture meter insulated electrodes for all readings shall be 1/4 the thickness of the fuel piece or 3/4 in. (19 mm), whichever is greater. One measurement from each of three sides shall be made at approximately 3 in. from each end and the center. Two additional measurements at approximately 1/3 of the fuel piece thickness shall be made centered between the other three locations. Each individual moisture content reading shall be in the range of 18 to 28 % on a dry basis. The average moisture content of each piece of test fuel shall be in the range of 19 to 25 %. Moisture shall not be added to previously dried fuel pieces except by storage under high humidity conditions and temperature up to 100ºF. Fuel moisture shall be measured within 4 h of using the fuel for a test.

TABLE 1 Specific Gravity of Commercially Important Species of Wood Based on Oven-Dry Weight and Oven-Dry Volume

Species	Specific Gravity
Ash, white	0.63
Beech	0.67
Birch, sweet	0.71
Birch, yellow	0.65
Elm, rock	0.67
Maple, hard (black)	0.60
Maple, hard (sugar)	0.67
Oak, red	0.66
Oak, white	0.71
Pine, Southern, longleaf	0.64

NOTE 1—Once split cordwood pieces have dried to an average moisture content that is near the top of the allowable moisture content range, it has been found that to maintain the fuel pieces within the allowable moisture content range, storage at a relative humidity of 95 % or higher and temperature of 90 to 100ºF is necessary. In addition, storage at these conditions for a period of several months helps achieve a more uniform moisture content throughout the fuel pieces and thus improves the accuracy of the moisture content measurement.

12.2.2 *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.

12.2.3 *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 using Table 2 and Fig. 2 as a guide. 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/ft^3 (160 kg/m^3), all tests shall be run with fuel load densities of 10 lb/ft^3 (160 kg/m^3) even though this could require loading to a level higher than indicated in the manufacturer's instructions.

12.2.4 *Sampling Equipment*—Prepare the sampling equipment as defined by Test Method E2515.

12.2.5 *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.

12.2.6 *Pretest Burn Cycle*—Reload appliance with fuel wood meeting the requirements of 12.2.1 and allow it to burn

TABLE 2 Correlation of Cordwood Wood Pieces with Appliance Firebox Volume

Firebox Volume ft^3 (m^3)	Cross-section of piece in. (mm) Minimum	Maximum	Minimum weight of piece lb (kg)	Maximum weight of piece lb (kg)	80 % piece weight range lb (kg)	Number of pieces
<4 (<0.11)	2 (51)	6 (152)	2.2 (1)	13.2 (6)	3 to 11 (1.5 to 5)	4 to 7
4 to <10 (0.11 to <0.28)	2.5 (64)	8 (203)	4.4 (2)	17.6 (8)	6.6 to 15.4 (3 to 7)	5 to 10
10 to <20 (0.28 to <0.56)	3 (76)	10 (254)	6.6 (3)	22 (10)	8.8 to 19.8 (4 to 9)	8 to 15
≥20 (≥0.56)	3 (77)	12 (305)	8.8 (4)	26.5 (12)	8.8 to 22 (4 to 10)	>12

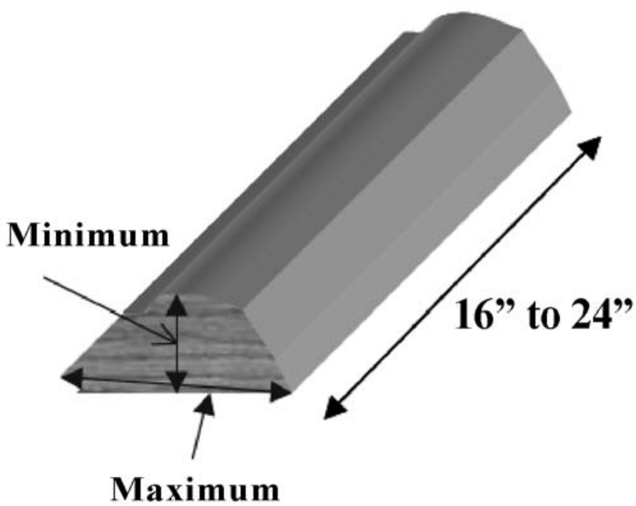


FIG. 2 Cordwood Fuel

down to the specified coal bed weight. Pretest burn cycle fuel charge weight shall be within ±10 % of the test fuel charge weight. At least 1 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.

12.2.7 *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.

12.2.8 *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.

12.2.9 *Test Cycle*—For all test runs, the return water temperature to the hydronic heater must be equal to or greater than 120°F. Aquastat or other heater output control device settings that are adjustable shall be set using manufacturer specifications, either as factory set or in accordance with the owner's manual, and shall remain the same for all burn categories. Complete a test run in each heat output rate category, as follows:

12.2.9.1 *Test Run Start*—Once the appliance is operating normally and the pretest coal bed weight has reached the target value in accordance with 12.2.8, 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.

(1) Record all water temperatures, differential water temperatures and water flow rates at time intervals of 1 min or less.

(2) Record particulate emissions data per the requirements of Test Method E2515.

(3) Record data needed to determine Overall Efficiency (SLM) per the requirements of CSA B415.1-2010 Clauses 6.2.1, 6.2.2, 6.3, 8.5.7, 10.4.3 (a), 10.4.3 (f), and 13.7.9.3

(a) Measure and record the test room air temperature in accordance with the requirements of Clauses 6.2.1, 8.5.7 and 10.4.3 (g).

(b) Measure and record the flue gas temperature in accordance with the requirements of Clauses 6.2.2, 8.5.7 and 10.4.3 (f).

(c) Determine and record the Carbon Monoxide (CO) and Carbon Dioxide (CO_2) concentrations in the flue gas in accordance with Clauses 6.3, 8.5.7 and 10.4.3 (i) and (j).

(d) Measure and record the test fuel weight per the requirements of Clauses 8.5.7 and 10.4.3 (h).

(e) Record the test run time per the requirements of Clause 10.4.3 (a).

(4) 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 (±5 %) 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.

12.2.9.2 *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.

12.2.9.3 *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.

12.2.10 *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.

12.2.11 *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.

12.2.12 *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.

12.2.13 *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.

12.2.14 *Appliance Overheating*—Appliances shall be capable of operating in all heat output categories without overheating to be rated by this test method. Appliance overheating 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 greater than 15°F (8°C) 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.

12.2.15 *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 E711 and for moisture content by the oven drying method (Test Methods D4442, 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 1 h. Start the emissions measurement sampling train and data collection as required in Test Method E2515. 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 E2515 Eq. 10)

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

$E_{lb/MMBtu\ Output}$ = 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 rate in grams per hour

E_{avg} = weighted average emissions in pounds per million Btu of heat output

HHV = higher heating value of fuel = 8600 Btu/lb (19 990 MJ/kg)

LHV = lower heating value of fuel = 7988 Btu/lb (18 567 MJ/kg)

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)

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 = data sampling interval in minutes

Θ = total length of test run in hours

η_{del} = delivered heating efficiency in percent

η_{SLM} = overall efficiency determined using the CSA B415.1-2010 stack loss method in percent

η_{avg} = weighted average delivered efficiency in percent

F_i = weighting factor for heat output category *i*

T1 = temperature of water at the inlet on the supply side of the heat exchanger, °F

T2 = temperature of the water at the outlet on the supply side of the heat exchanger, °F

T3 = temperature of water at the inlet to the load side of the heat exchanger, °F

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

TI_{avg} =

$$(T1 + T2)/2 \quad \text{at the end of the test,°F} \tag{1}$$

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

TF_{avg} =

$$(T1 + T2)/2 \quad \text{at the end of the test,°F} \tag{2}$$

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

σ = density of water (lb/gal)

C_p = specific heat of water in Btu per pound ºF

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

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

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

W_{app} = weight of empty appliance in pounds

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

NOTE 2—After the test is completed, determine the particulate emissions in accordance with Test Method E2515 Eq. 10 ($\boldsymbol{E_T}$).

13.2 *Determine Average Fuel Load Moisture Content:*

$$MC_{Ave} = \frac{\left[\sum W_i \cdot MC_i\right]}{\sum W_i} \tag{3}$$

13.3 *Determine Heat Input:*

$$Q_{in} = (W_{fuel} / (1 + (MC_{ave} / 100))) \times HHV \tag{4}$$

$$Q_{in\ LHV} = (W_{fuel} / (1 + (MC_{ave} / 100))) \times LHV \tag{5}$$

13.4 *Determine Heat Output and Efficiency:*

13.4.1 Determine heat output as:

$$Q_{out} = \sum[\text{Heat output determined for each sampling time interval}] + \text{Change in heat stored in the appliance} \tag{6}$$

$$Q_{out} = \left[\sum\left(C_{pi} \cdot \Delta T_i \cdot \dot{M}_i \cdot t_i\right)\right] + (W_{app} \cdot C_{steel} + C_{pa} \cdot W_{water}) \cdot (TF_{avg} - TI_{avg}), \text{ Btu (MJ)} \tag{7}$$

where:

$_i$ = parameter value for sampling time interval t_i

$$M_i = \text{Mass flow rate} = \text{gal/min} \times \text{Density of Water (lb/gal)} = \text{lb/min} \tag{8}$$

$$M_i = V_{f_i} \cdot \sigma_i, \text{ lb/min.} \tag{9}$$

$$\sigma_i = (62.56 + (-.0003413 \cdot T3_i) + (-.00006225 \cdot T3_i^{\,2})) \cdot 0.1337, \text{ lbs/gal.} \tag{10}$$

$$C_p = 1.0014 + (-\ .000003485 \cdot T3_i), \text{Btu/lb-°}F \tag{11}$$

$$C_{Steel} = 0.1 \text{ Btu/lb-°F} \tag{12}$$

$$C_{pa} = 1.0014 + (-.000003485 \cdot (TI_{avg} + TF_{avg})/2), \text{Btu/lb-°F} \tag{13}$$

$$V_{f_i} = (V_i - V_{i-1})/(t_i - t_{i-1}), \text{ gal/min.} \tag{14}$$

where:

V_i = total water volume at the end of interval *i*

V_{i-1} = total water volume at the beginning of the time interval. This calculation is necessary when a totalizing type water meter is used.

13.4.2 Determine heat output rate as:

$$\text{Heat Output Rate} = Q_{out} / \Theta, \text{ Btu/h (MJ/h)} \tag{15}$$

13.4.3 Determine emission rates and emission factors as:

$$E_{g/MJ} = E_T / (Q_{out} \times 0.001055), \text{ g/MJ} \tag{16}$$

$$E_{lbs/MM\ Btu\ output} = (E_T / 453.59)/(Q_{out} \times 10^{-6}), \text{ lbs/MMBtu Out} \tag{17}$$

$$E_{g/kg} = E_T / (W_{fuel} / (1 + MC/100)), \text{ g/dry kg} \tag{18}$$

$$E_{g/h} = E_T / \Theta, \text{g/h} \tag{19}$$

13.4.4 Determine delivered efficiency as:

$$\eta_{del} = (Q_{out} / Q_{in}) \times 100 \tag{20}$$

$$\eta_{del\ LHV} = (Q_{out} / Q_{in\ LHV}) \times 100 \tag{21}$$

13.4.5 Determine η_{SLM} - Overall Efficiency, also known as Stack Loss Efficiency, using Stack Loss Method (SLM). For determination of the average overall thermal efficiency (η_{SLM}) for the test run, use the data collected over the full test run and the calculations in accordance with CSA B415.1-2010, Clause 13.7

13.4.5.1 Whenever the overall efficiency (η_{SLM}) is found to be lower than the delivered efficiency (η_{del}), as determined by Eq 20 of this method, 14.1.7 of the test report must include a discussion of the reasons for this result.

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.

$$\eta_{avg} = \sum \eta_i \cdot F_i, \% \quad (22)$$

$$E_{avg} = \sum E_i \cdot F_i, \text{ lb/mm}BTU_{\text{Output}} \quad (23)$$

13.5.2 Estimated Average Heat Output ($Q_{out\text{-}8\ h}$) and Efficiency ($\eta_{avg\text{-}8\ h}$) 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:*

$$\eta_{avg\text{-}8h} = \eta_{del1} + \{(8 - Y1) \times [(\eta_{del2} - \eta_{del1})/(Y2 - Y1)]\}, \% \quad (24)$$

$$Q_{out\text{-}8h} = [(\eta_{avg\text{-}8h} / 100) \cdot \{(X1 + X2)/2\}]/8, \text{ Btu/h} \quad (25)$$

where:

$Y1$ = test duration just above 8 h,
$Y2$ = test duration just below 8 h,
$X1$ = total heat input for duration $Y1$
$X2$ = total heat input for duration $Y2$
η_{del1} = average delivered efficiency for duration $Y1$, and
η_{del2} = average delivered efficiency for duration $Y2$

13.5.2.3 Determine the test durations and actual load for each category as recorded in Table 3 and Table 4.

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

$X1$ = Actual total input, $Y1$ = Test Duration and η_{del1} = Average Delivered Efficiency for this data point

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

$X2$ = Actual total input, $Y2$ = Test Duration and η_{del2} = Average Delivered Efficiency for this data point

13.5.2.6 *Example:*

Category	Actual Load (Btu/h)	Duration (h)	η_{del} %	Total Input (Btu)
1	15 000	14	70.0	300 000
2	26 000	-8.56	75.5	290 000
3	50 000	-4.73	80.1	295 500
4	100 000	2.46	80.9	305 000

Category 2 Duration is just above 8 h, therefore:
$X1$ = 290 000 Btu, η_{del1} = 75.5 % and $Y1$ = 8.56 h
Category 3 Duration is just below 8 h, therefore:
$X2$ = 295 500 Btu, η_{del2} = 80.1 % and $Y2$ = 4.73 h
$\eta_{avg\text{-}8h}$ = 75.5 + {(8 - 8.456) x [(80.1 – 75.5)/(4.73 - 8.456)]} = 76.41%
$Q_{out\text{-}8h}$ = [(76.1/100) · {(290 000 + 295 500)/2}]/8 = 27 848 Btu/h

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 and test equipment including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.1.6 Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as 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.

TABLE 3 Test Condition Summary

						Θ	W_{fuel}	MC_{ave}	Q_{in}	Q_{out}
Category	Run No	Load % Capacity	Target Load Btu/h	Actual Load Btu/h	Actual Load % of max	Test Duration h	Wood Weight as Fired lb	Wood Moisture % DB	Heat Input Btu	Heat Output Btu
I		<15 % of max								
II		16 to 24 % of max								
III		25 to 50 % of max								
IV		Max capacity								

TABLE 4 Test Results Summary

Category	Run No	Load % Capacity	T2 Min Min Return Water Temp. °F	E_T Total PM Emissions g	E PM Output Based lb/MMBtu Out	E PM Output Based g/MJ	$E_{g/h}$ PM Rate g/h	$E_{g/kg}$ PM Factor g/kg	η_{del} Delivered Efficiency %	η_{SLM} Stack Loss Efficiency %
I		<15 % of max								
II		16 to 24 % of max								
III		25 to 50 % of max								
IV		Max capacity								

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 All required data for each test run shall be provided in spreadsheet format. Formulae used for all calculations shall be accessible for review.

14.1.15 Tables 3-6 must be used for presentation of results in test reports.

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

14.1.17 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 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 hydronic heater emissions because no material having an accepted reference value is available.

16. Keywords

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

TABLE 5 Heating Season Weighting

Category	Weighting Factor (F_i)	$\eta_{del,\,i} \times F_i$	$E_{g/MJ,\,i} \times F_i$	$E_{g/kg,\,i} \times F_i$	$E_{lb/MMBTU\ Out,\,i} \times F_i$	$E_{g/h,\,i} \times F_i$
I	0.175					
II	0.275					
III	0.450					
IV	0.100					
Totals	1.000					

TABLE 6 Year-Round Use Weighting

Category	Weighting Factor (F_i)	$\eta_{del,i} \times F_i$	$E_{g/MJ,\ i} \times F_i$	$E_{g/kg,\ i} \times F_i$	$E_{lb/MMBTU\ Out,\ i} \times F_i$	$E_{g/h,\ i} \times F_i$
I	0.437					
II	0.238					
III	0.275					
IV	0.050					
Totals	1.000					

ANNEXES

(Mandatory Information)

A1. MODIFIED TEST METHOD FOR WOOD-FIRED HYDRONIC APPLIANCES THAT UTILIZE FULL THERMAL STORAGE

A1.1 Scope

A1.1.1 Annex A1 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.

A1.1.2 Appliances covered by Annex A1 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.

A1.1.3 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 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.

A1.1.4 Particulate emissions are measured by the dilution tunnel method as specified in Test Method E2515. 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.

A1.1.5 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.

A1.1.6 Distinguishing features of products covered by Annex A1 include:

A1.1.6.1 A firebox with an access door for hand loading of fuel.

A1.1.6.2 Thermal energy storage (water, refractory, sand, concrete, brick, soapstone, metal, etc.) either remote or integral as part of the appliance.

A1.1.6.3 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.

A1.1.6.4 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.

A1.1.6.5 A chimney or vent that exhausts combustion products from the appliance.

A1.2 Operation

A1.2.1 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 ± 5ºF (52 ± 2.8°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 A1.1—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.

A1.3 Apparatus

A1.3.1 *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.

A1.3.2 *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.

A1.3.3 *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 ±0.50°F (±1°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.

A1.3.4 *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).

A1.3.5 *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.

A1.4 Hazards

A1.4.1 Refer to Section 7.

A1.5 Sampling, Test Specimens, and Test Appliances

A1.5.1 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 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.

A1.6 Preparation of the Appliance

A1.6.1 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.

A1.6.2 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.

A1.6.3 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. (51 mm) of EPS foam insulation surrounding it to minimize heat losses from the heat exchanger.

A1.6.4 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 A1.10.3.

A1.7 Calibration and Standardization

A1.7.1 Refer to Section 10.

A1.8 Conditioning

A1.8.1 The appliance (including the thermal storage) is to be brought to a beginning test temperature of 125 ± 5ºF (52 ± 2.8°C). This is to be accomplished by normal operation of the unit sufficient to heat the storage media to at least 150ºF

(65.5°C) and then removing heat using the external simulated load until the temperature reaches 125 to 130ºF (52 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.

A1.8.2 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.

A1.9 Procedure

A1.9.1 Refer to 12.2, 12.2.1, 12.2.2, and 12.3 in the main test method.

A1.9.2 *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.

A1.9.2.1 For hydronic heaters that include an automatic ignition system (such as a gas ignition burner or electric ignition heating element, the ignition system shall be operated in accordance with the manufacturer's written instructions. The energy input value from the ignition system shall be measured and added to the total energy input for the purpose of determining overall efficiency.

(1) No fuels or energy source other than natural wood, newspaper, natural gas, propane gas or electricity shall be used for ignition of the heater.

A1.9.3 *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.

A1.9.4 *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 ensure 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 5ºF (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 (<ºF) in two consecutive 10-min readings.

A1.9.4.1 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.

(a) Shovel all remaining unburned fuel and ash from the heater and extinguish in an air-tight container. Separate the ash from the unburned fuel by sifting using a 0.125 in. (3.2 mm) mesh screen. Weight the unburned fuel portion on a scale with an accuracy of ±0.1 lb (±0.05 kg). The maximum weight of unburned fuel must be less than 5 % of total test fuel weight for the test run to be valid.

A1.9.5 *Stored Energy Measurement:*

A1.9.5.1 Record the heat storage media temperature once the heat storage has reached its maximum.

A1.9.6 *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.

A1.10 Calculation of Results

A1.10.1 Refer to 13.1 and 13.2.

A1.10.2 For each test run, determine gross heat input ($Q_{in_{gross}}$). Include the weight of the wood fuel test load and any kindling used when determining the heat input. Also, include the equivalent heat input from any automatic ignition system if used.

$$Q_{in_{gross}} = \left[\left(\frac{W_{kindling}}{1+(MC_{kindling}/100)} \right) + \left(\frac{W_{fuel}}{1+(MC_{fuel}/100)} \right) \right] \cdot HHV + Q_{ign} \quad (A1.1)$$

where:

HHV	=	the assumed higher heating value of the fuel, 8600 Btu/lb (19 990 MJ/kg),
MC_{fuel}	=	average fuel moisture content, % dry basis,
$MC_{kindling}$	=	average kindling moisture content, % dry basis,
W_{fuel}	=	weight of main test fuel load, lb (kg),
W_{kind}	=	weight of kindling, lb (kg), and
Q_{ign}	=	heat input from ignition source, Btu (MJ).

A1.10.2.1 If the weight of the remaining test fuel is greater than 1 % of the total test fuel weight at the end of the test run, adjust the total heat input using the following equation:

$$Q_{in_{net}} = [Q_{in_{gross}} - (W_{Res} \cdot HHV_{Res})], \text{ Btu (MJ)} \quad (A1.2)$$

where:

$Q_{in_{net}}$	=	Net Heat Input, Btu (MJ),
W_{Res}	=	Mass of residual unburned fuel after ash is sifted out, lb (kg), and
HHV_{Res}	=	Assumed HHV of unburned fuel - 12 000 Btu/lb (27 890 MJ/kg).

A1.10.3 For each run, determine heat stored as measured by net temperature increase.

$$Q_{stored} = \text{change in heat stored in the appliance} \quad \text{(A1.3)}$$

$$Q_{stored} = (W_{app} \cdot C_{steel} + C_p \cdot W_{water}) \cdot (TF_{avg} - TI_{avg}) \quad \text{(A1.4)}$$

$$C_p = 1.0014 + (-0.000003485 \times T_{avg}) \text{ (Btu/lb} - \text{°F)} \quad \text{(A1.5)}$$

$$C_p = 1.294 + (-0.000000965 \times T_{avg}) \text{ (kJ/kg} - \text{°C)} \quad \text{(A1.6)}$$

$$C_{steel} = 0.1 \text{ Btu/lb} - \text{°F (0.1293 kJ/kg} - \text{°C)} \quad \text{(A1.7)}$$

where:

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)

A1.11 Stand-by Loss Determination

A1.11.1 Stand-by loss is a measure of the level of insulation of the heat storage system expressed in Btu/h · °F (kJ/h-°C).

A1.11.2 *Procedure:*

A1.11.2.1 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 A1.6.2, 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.

A1.11.2.2 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 4 h before conducting the stand-by loss measurement. No heat draw is applied during this test.

A1.11.2.3 Record the average heat storage media temperature and ambient temperature at least every 30 min during this test.

A1.11.2.4 Start a timer when the 4-h equilibration period has elapsed and record the system average temperature. After an additional minimum of 8 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.

A1.11.2.5 Calculate the stand-by heat loss as follows:

$$Q_{s-b\ loss} = \frac{(T_1 - T_2) \cdot [C_p \cdot W_{water} + C_{steel} \cdot W_{steel}]}{t \cdot [((T_1 + T_2)/2) - T_{amb\ ave}]}, \text{ (Btu/h °F, kJ/h°C)} \quad \text{(A1.8)}$$

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 °F (0.1292 kJ/kg °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, °F (°C),
T_2 = average temperature of heat storage media at the end of the test, °F (°C), and
$T_{amb\ ave}$ = average ambient temperature, °F (°C).

A1.11.3 For calculations of efficiency and emissions the average input, stored energy and total emissions shall be used in the following calculations.

A1.11.4 *Determination of Efficiency:*

A1.11.4.1 Efficiency shall be determined for each heat output category (I-IV) based on the manufacturer's stated maximum capacity (Category IV).

A1.11.4.2 Calculate output rates as follows:

$$Q_I = Q_{IV} \times 0.15 \quad \text{(A1.9)}$$

$$Q_{II} = Q_{IV} \times 0.20 \quad \text{(A1.10)}$$

$$Q_{III} = Q_{IV} \times 0.375 \quad \text{(A1.11)}$$

$$Q_{IV} = \text{manufacturer's stated capacity} \quad \text{(A1.12)}$$

NOTE A1.2—These represent the mid-points of the range specified for Categories II and III.

A1.11.4.3 Determine the duration for heat output for each category:

$$t_i = \frac{Q_{stored}}{Q_i + (85 \times Q_{s-b\ loss})} \quad \text{(A1.13)}$$

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°F) and lab ambient (70°F), and
Q_{stored} = average heat stored in a minimum of three test runs.

A1.11.4.4 Determine delivered efficiency for each heat output category.

$$\eta_{del,\ i} = \left[\frac{Q_{stored} - (t_i \times 85 \times Q_{s-b\ loss})}{Q_{in}}\right] \times 100 \quad \text{(A1.14)}$$

A1.11.5 Determine the average burn rate (average of the minimum three individual burn rates).

$$\text{Average burn rate (kg/h)} = \text{fuel load weight (dry basis)/test duration, h} \quad \text{(A1.15)}$$

where:

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

A1.11.6 *Emissions Rate* (ET = average emissions from test runs): Subscript *j* denotes data calculated for each heat output category.

$$E_{g/MJ,\ j} = E_T\ /(Q_{out,\ j} \times 0.001055) \quad \text{(A1.16)}$$

$$E_{g/1000\ Btu,\ j} = E_T\ /(Q_{out,\ j} \times 0.001) \quad \text{(A1.17)}$$

$$E_{g/kg,\ j} = E_T\ /((W_{kindling}\ /(1 + MC_{kind}\ /100)) + (W_{fuel}\ /(1 + MC_{fuel}\ /100))) \quad \text{(A1.18)}$$

$$E_{lb/MMBtu\ Output,\ j} = (E_T\ /453.59)/(Q_{out,\ j} \times 10^{-6}) \quad \text{(A1.19)}$$

$$E_{lb/MMBtu\ Input,\ j} = (E_T\ /453.59)/(Q_{in,\ j} \times 10^{-6}) \quad \text{(A1.20)}$$

A1.11.7 Calculate 8-h heat output rate.

$$Q_{8-h} = (Q_{stored} - (8 \times 85 \times Q_{s-b\ loss}))/8 \quad \text{(A1.21)}$$

A1.12 Report

A1.12.1 The report shall include the following minimum information:

A1.12.1.1 Name and location of the laboratory conducting the test.

A1.12.1.2 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.

A1.12.1.3 A statement that the test results apply only to the specific appliance tested.

A1.12.1.4 A description of the test procedures employed and a list of participants and observers present for the tests.

A1.12.1.5 Details of deviations from, additions to or exclusions from the test method, and information on specific test conditions, such as environmental conditions.

A1.12.1.6 Data and drawings indicating the fire box size and location of the fuel charge.

A1.12.1.7 Information for each fuel charge including piece size, moisture content, and weight.

A1.12.1.8 All recorded temperatures, appliance weight, fuel charge weight, thermal storage weight, water flow data, and refractory weight.

A1.12.1.9 Calculated results for delivered efficiency, emissions, and weighted averages as indicated in Tables 3-6.

A1.12.1.10 Stand-by heat loss rate in Btu/h · ºF.

A1.12.1.11 Any pictures that would help to clarify the test unit and set up.

A1.12.1.12 Any required lab certification information or instrumentation calibration information, or both.

A1.12.1.13 Statement of the estimated uncertainty of measurement of the emissions and efficiency test results.

A1.12.1.14 Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of seven years.

A2. MODIFIED TEST METHOD FOR WOOD-FIRED HYDRONIC APPLIANCES THAT UTILIZE PARTIAL THERMAL STORAGE

A2.1 Scope

A2.1.1 Annex A2 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, partial mass thermal storage. A partial 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.

A2.1.2 Appliances covered by Annex A2 generally:

(1) incorporate sufficient thermal storage capacity to safely accept the entire heat output during a test run including heat draw-off, without over-heating, and without activating any safety limit controls provided with the appliance.

(2) are designed to minimize or eliminate operation at low burn rates by having the capacity to store substantial amounts of excess heat. "Excess heat" is energy that cannot be used by the structure or other heat load at the time it is generated.

(3) are designed to provide stored heat to meet heating demands from the structure for substantial periods of time after the fuel load is fully consumed, and

(4) operate in that manner that implicates an empty firebox and a cold start whenever reloading the appliance with Category 1 or Category 2 load draws, since heating demands from the structure will always be met by stored heat for at least some period of time after the full fuel load is consumed.

A2.1.3 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 a component of this procedure.

A2.1.4 Particulate emissions are measured by the dilution tunnel method as specified in Test Method E2515. Delivered efficiency is determined by measurement of the usable heat output (determined through measurement of the flow rate and temperature change of water circulated through a heat exchanger external to the appliance plus any stored heat) and the heat input determined from the mass of dry fuel burned and its higher heating value. Delivered efficiency does not attempt to account for pipeline loss.

A2.1.5 This procedure includes four test runs covering the full heat output range of the heater as defined in A2.4.2 of this appendix. An equivalent 8-h heat output capacity is also calculated.

A2.1.6 Appliances tested using Annex A2 must satisfy the following requirements:

A2.1.6.1 The manufacturer requires the inclusion of thermal storage in all installations and the manufacturer's recommended minimum thermal storage is adequate to allow a full test fuel load to be consumed under a Category 2 heat load without a shut down or lock out that requires user intervention to restart the appliance.

A2.2 Referenced Documents

A2.2.1 Refer to Main Test Method, Section 2.

A2.3 Terminology

A2.3.1 Refer to Main Test Method, Section 3, except:

A2.3.2 *kindling*—split fuel pieces in addition to the test fuel load used to ignite the test fuel load from a cold start condition. Applies to Category I and Category II test runs only. Kindling moisture shall not be less than 7 % dry basis. Kindling piece size and placement shall be in accordance with the manufacturer's written instructions. Newspaper used to ignite the kindling is part of the kindling weight.

A2.3.3 *start-up fuel*—fuel pieces of any cross-section of at least 2 in. (51 mm) and in accordance with the manufacturer's written instructions comprising up to 10 % of the test fuel load weight, added to the fire in accordance with the manufacturer's written instructions to help ensure ignition of the remainder of the test fuel load as it is added to the firebox. Applies to Category I and Category II test runs only. Start-up fuel moisture must be in the same range as the test fuel load.

A2.3.4 *test fuel load*—a load of fuel (including start-up fuel) as specified in A2.12.3 placed in the appliance at the start of the emission test run.

A2.3.5 *test fuel piece length*—the nominal length of the fuel pieces comprising the test fuel load shall be in accordance with the manufacturer's written instructions. Individual test fuel pieces may vary from the nominal length by 1 in. (±25 mm).

A2.3.6 *total test fuel weight (dry basis)*—the total mass of test fuel adjusted to dry basis. Used in conjunction with the higher heating value to determine the total heat input during the test run.

A2.3.7 *total test fuel weight (wet basis)*—the total mass (wet basis) of fuel including the test fuel load plus kindling placed in the appliance during the test run. Applies to Category I and Category II test runs only.

A2.4 Summary of Test Method

A2.4.1 Refer to Main Test Method, Section 4, except:

A2.4.2 *Operation:*

A2.4.2.1 Appliance operation for Category IV employs a hot-to-hot test cycle identical to the main method.

A2.4.2.2 Appliance operation for Category III employs a hot-to-hot test cycle identical to the main test method except the temperature of the remote thermal storage is brought to a beginning test temperature of 125 ± 5ºF (52 ± 2.8°C) by adjusting the heat exchanger load as needed.

A2.4.2.3 Appliance operation for Category II employs a batch burn and a "cold" start with an empty firebox. The heater and remote thermal storage are first preheated and then allowed to cool so the temperature of the remote thermal storage is at a beginning test temperature of 125 ± 5ºF (52 ± 2.8°C). All residual preheat fuel and ash is removed from the firebox before kindling is added and a fresh fire is ignited to start the test run. A full test fuel load is used for the Category II test run. The test fuel load including kindling shall be fully consumed, as defined in A2.12.9, during the Category II test run.

A2.4.2.4 Appliance operation for Category I employs a batch burn and a "cold" start with an empty firebox. The heater and remote thermal storage are first preheated and then allowed to cool so the temperature of the thermal storage is at a beginning test temperature of 125 ± 5ºF (52 ± 2.8°C). All residual preheat fuel and ash is removed from the firebox before kindling is added and a fresh fire is ignited to start the test run. A partial test fuel load may be used for the Category I test run to prevent a shutdown or lockout conditions that would invalidate the Category I test run. The partial test fuel load mass is determined based on the ratio of the Category I target heat output to the measured Category II heat output multiplied by the nominal full test fuel load weight (wet basis). The test fuel load including kindling shall be fully consumed during the Category I test run.

A2.4.2.5 Test Categories I, II and IV are the same as the main test method. Category III is defined as a heat output of 25 to 60 % of the Manufacturer's Rated Heat Output Capacity.

A2.5 Significance and Use

A2.5.1 Refer to Main Test Method, Section 5.

A2.6 Apparatus

A2.6.1 Refer to Main Test Method, Section 6, except:

A2.6.2 The test apparatus shall include an intermediary heat exchanger placed between the heater and the remote thermal storage that will allow the mass of the remote thermal storage to be isolated from the appliance mass (See Fig. A2.1). Flexible piping (hose) shall be used in locations as needed in the test apparatus to ensure that water movement does not affect the determination of remaining test fuel load mass with the required resolution during the test run.

A2.6.3 The remote thermal storage tank(s) shall include internal thermocouples to measure the water temperature at the beginning and end of the test run. At least three thermocouples shall be used located on the vertical centerline of the tank(s) and spaced horizontally over the height of water in the tank in a manner that each thermocouple is at the center of equal water volumes in the tank(s).

A2.7 Hazards

A2.7.1 Refer to Main Test Method, Section 7.

A2.8 Sampling, Test Specimens, and Test Appliances

A2.8.1 Test specimens shall be supplied as complete appliances including all controls and accessories necessary for installation in the test facility. A tank or tanks accommodating the minimum thermal storage volume recommended by the appliance manufacturer may be supplied by the manufacturer or provided by the test laboratory. A full set of specifications and design and assembly drawings shall be provided. The manufacturer's written installation and operating instructions shall be followed in the set-up and testing of the appliance except where deviations are required or permitted by this appendix. Variations or changes to the manufacturer's recommended installation methods must be approved by the manufacturer and documented in the test report.

A2.9 Preparation of the Appliance

A2.9.1 Refer to Main Test Method, Section 9, except:

A2.9.2 The Category IV test may be conducted with or without the remote thermal storage as part of the test apparatus (See Fig. 1 in the main test method when testing without remote thermal storage).

A2.9.3 Prior to filling the appliance and any remote storage tank(s), weigh and record the appliance, intermediary heat exchanger and any associated plumbing that may affect the scale weight during testing.

A2.9.3.1 Fill the appliance with water and determine the on-scale water mass including the intermediary heat exchanger and associated plumbing water mass using the appliance scale. Determine the total weight of the water in the appliance,

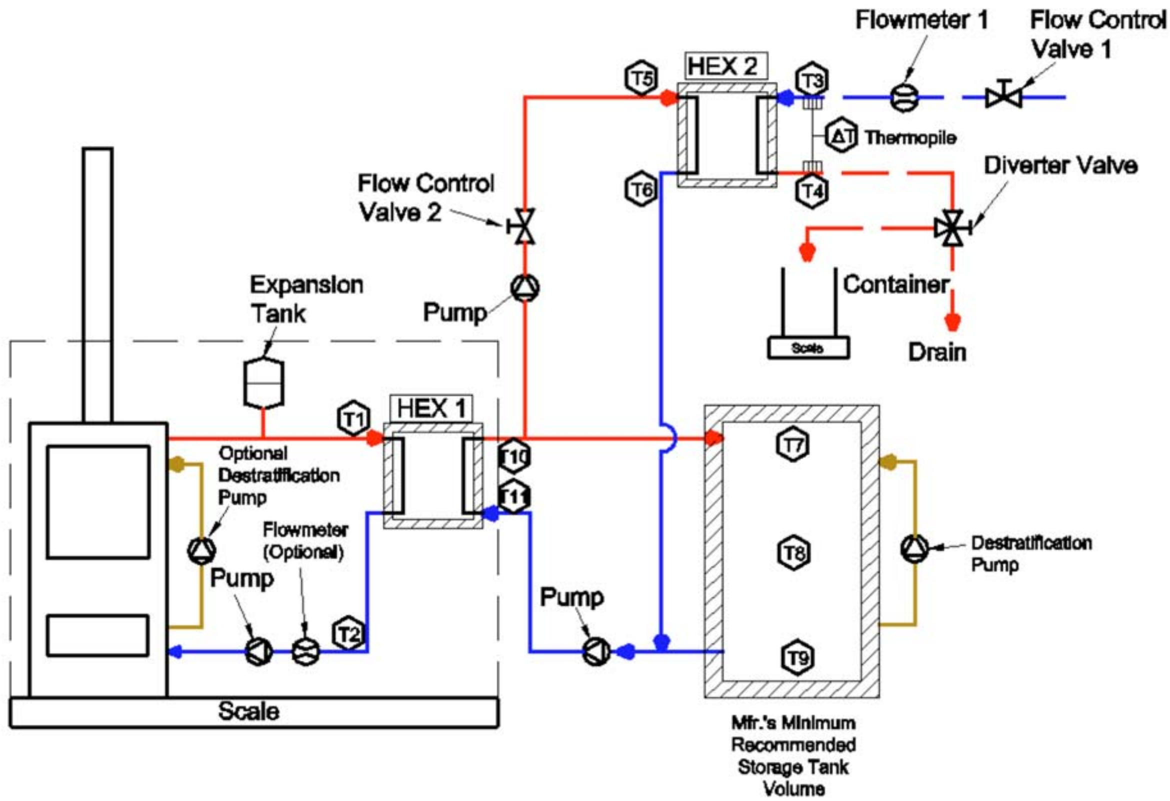


FIG. A2.1 Test Apparatus Schematic

intermediary heat exchanger and associated plumbing when the water is circulating. Verify that the scale indicates a stable weight under operating conditions. Make sure air is purged properly.

A2.9.3.2 Use a totalizing water flow meter to determine the mass of water in the remote storage, or determine total storage mass by calculation if the volume can be accurately determined.

A2.10 Calibration and Standardization

A2.10.1 Refer to Main Test Method, Section 10, except:

A2.10.2 *Scales*—The scales used to weigh the appliance and remote storage tanks(s) and test fuel charge shall be calibrated using NIST Traceable Methods at least once every six months.

A2.11 Conditioning

A2.11.1 Refer to Main Test Method, Section 11.

A2.12 Procedure

A2.12.1 Refer to Main Test Method, Section 12, except:

A2.12.2 *Test Fuel Moisture*—Refer to Main Test Method, 12.2.1.2, except:

A2.12.2.1 Kindling may have any moisture content equal to or greater than 7 % dry basis.

A2.12.3 *Test Fuel Load:*

A2.12.3.1 For the Category IV, Category III and Category II test runs, determine the test fuel load weight and piece sizes in accordance with 12.2.3 in the main test method.

A2.12.3.2 For the Category I test run, the test fuel load may be a partial test fuel load if a full test fuel load cannot be fully consumed during a Category I test run without a shut down or lock out that requires user intervention to restart the appliance. The nominal weight of a partial test fuel load, if used, shall be determined per the following equation:

$$PTL = 10\ lb/ft^3 \cdot \frac{\text{Target Category I Heat Output}}{\text{Actual Category II Heat Output}} \qquad (A2.1)$$

where:

PTL = Nominal Partial Test Fuel Load Weight (Wet Basis).

A2.12.3.3 For the Category I and II test runs only, kindling with a weight of up to 10 % of the test fuel load weight may be used to ignite the main test fuel load. The kindling weight is in addition to the test fuel load weight. The test fuel load weight may include up to 10 % start-up fuel. Start-up fuel may be comprised of fuel pieces with cross-sections of at least 2 in. (51 mm). Kindling and start-up fuel shall be placed in the firebox in accordance with the manufacturer's written instructions. The remainder of the test fuel load, comprised of pieces meeting the sizing requirements in Table 2 in the main test method except 60 % of the fuel pieces shall fall in the weight ranges specified in the column labeled "80 % piece weight range," is added after the start-up fuel in accordance with the manufacturer's written instructions. Fig. A2.2 provides a graphic example of the test fuel composition and adjustment of total fuel burned per A2.12.9.2(1). Weigh and determine the moisture content of all kindling that is used. Record all other fuel piece weights

<table>
<tr><td colspan="6">Total Test Fuel Burned</td></tr>
<tr><td colspan="4">Total Test Fuel Weight Placed in Firebox</td><td rowspan="4">-</td><td rowspan="2">Residual Charcoal</td></tr>
<tr><td>Kindling</td><td rowspan="3">+</td><td colspan="2">Test Fuel Load</td></tr>
<tr><td rowspan="2">≤ 10% of Test Fuel Load Weight.</td><td>Start-Up Fuel</td><td rowspan="2">Remainder of Test Fuel Load</td><td rowspan="2">≤ 5% of Test Fuel Load Weight.</td></tr>
<tr><td>≤ 10% of Test Fuel Load Weight.</td></tr>
</table>

FIG. A2.2 Category 1 and 2 Test Fuel Composition Graphic

(start-up fuel pieces and remainder of test fuel load pieces) and moisture contents per 12.2.1.2. The test fuel load and kindling are to be weighed within 3 h prior to loading on a scale with an accuracy of ±0.1 lb (±0.05 kg) or ±0.5 % of the load weight, whichever is greater. Newspaper may be used to ignite the kindling in accordance with the manufacturer's written instructions. Newspaper shall be weighed with the kindling.

A2.12.3.4 For hydronic heaters that include an automatic ignition system (such as a gas ignition burner or electric ignition heating element), the ignition system shall be operated in accordance with the manufacturer's written instructions. The energy input value from the ignition system shall be measured and added to the total energy input for the purpose of determining overall efficiency.

A2.12.3.5 No fuels or energy source other than natural wood, newspaper, natural gas, propane gas or electricity shall be used for ignition of the heater.

A2.12.4 *Appliance Start-Up*—The appliance shall be fired with wood fuel of any species, size and moisture content at the laboratory's discretion to bring it up to operating temperature. When the appropriate temperature has been achieved, remove all unburned fuel and ash, zero the scale, and verify the scales' accuracy using dead weights.

A2.12.5 *Pre-Test Burn Cycle*—For the Category IV and Category III test runs, refer to the main test method, 12.2.6 – 12.2.8.

A2.12.5.1 The Category II and Category I test runs begin with an empty firebox (no charcoal bed). Adjust the load heat exchanger (Fig. A2.1, HEX 2) load side water flow rate as needed to bring the return water temperature to the heater and the average temperature of any remote storage down to 125 ± 5ºF (52 ± 2.8°C) prior to starting the test run. Prior to recording the average temperature of the remote thermal storage at the beginning of the test run per A2.12.6.2, operate the storage tank(s) destratification pump(s) until all the tank water temperatures per A2.6.3 are within 1°F (0.5°C) of the average storage water temperature. The load draw on the heat exchanger should be at the target load draw for the Category being tested for at least 1 h prior to starting the test run.

A2.12.6 *Test Run Start:*

A2.12.6.1 For the Category IV and Category III test runs, refer to the main test method, 12.2.9.1.

A2.12.6.2 For the Category II and Category I test runs, tare the scale, start all sampling systems, and record the time and all initial temperatures including the average heat storage media temperature before beginning the fuel ignition sequence.

(1) The manufacturer shall provide written operating instructions that must include kindling and fueling instructions when starting with an empty firebox. Follow the manufacturer's written instructions for kindling placement (including newspaper, if used) and ignition, for the addition of the start-up fuel, for addition of the remainder of the test fuel load and for setting heater controls (including bypass dampers, if applicable) during start-up except:

(2) All test fuel must be placed in the firebox within 30 min of the ignition of the kindling.

(3) The fuel load door(s) shall remain closed during the Category II and Category I kindling and fueling process except when placing and igniting the newspaper and kindling, adding the start-up fuel and adding the remainder of the test fuel load or when adjusting the fuel load during the first 30 min of the test run, and,

(4) the total time the load door may be open during the first 30 min of the test is 10 min.

(5) All heater controls must be at their final run settings within 30 min of the ignition of the kindling.

(6) A portable hand-held homeowner-type gas torch may be used for ignition purposes if the manufacturer's written instructions recommend or allow its use. The use of the torch is limited to a total of 3 min.

(7) Every effort shall be made to minimize smoke spillage from the fuel load door(s) when open.

A2.12.7 *Minimum Water Temperature Exemption*—After the test run starts, the return water temperature to the heater may fall below the specified minimum per A2.12.5.1 for Category I and Category II test runs.

A2.12.8 *Test Fuel Load Adjustment*—To help ensure the test fuel load is fully consumed, as defined in A2.12.9, the test fuel load may be adjusted (that is, repositioning of fuel and charcoal) once during a test run, if 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. The time used to make this adjustment shall be less than 60 s.

A2.12.9 *Test Run Completion*—At the end of the test run, stop the particulate sampling and record the run time and all final measurement values. The test run is completed when either:

A2.12.9.1 The remaining weight of the test fuel load is less than or equal to 1 % of the total test fuel weight (kindling plus test fuel load weight (wet basis) or,

A2.12.9.2 The remaining unburned fuel and ash weight is greater than 1 % of the total test fuel weight (test fuel load plus kindling) and the scale has indicated no measurable test fuel weight loss (1 lb (0.5 kg) or 1 % of the test fuel load weight, whichever is greater), for more than 10 min.

(1) Shovel all remaining unburned fuel and ash from the heater and extinguish in an air-tight container. Separate the ash from the unburned fuel by sifting using a 0.125 in. (3.2 mm) mesh screen. Weight the unburned fuel portion on a scale with an accuracy of ±0.1 lb (±0.05 kg). The maximum weight of unburned fuel must be less than 5 % of total test fuel weight for the test run to be valid. See Fig. A2.2 and Eq A2.3.

A2.12.9.3 Prior to recording the average temperature of the remote thermal storage at the end of the test run, operate the storage tank(s) de-stratification pump(s) until all the tank water temperatures per A2.6.3 are within 1°F (0.5°C) of the average storage water temperature.

A2.12.10 *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 A2.4.2.5. It is not required to run these tests in any particular order.

A2.13 Calculation of Results

A2.13.1 Refer to Main Test Method, 13.1 and 13.2, except:

A2.13.2 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 gross heat input. Also, include the equivalent heat input from any automatic ignition system if used.

$$Q_{in_{gross}} = \left[\left(\frac{W_{kindling}}{1 + (MC_{kindling} / 100)} \right) + \left(\frac{W_{fuel}}{1 + (MC_{fuel} / 100)} \right) \right] \cdot \text{HHV} + Q_{ign} \quad \text{(A2.2)}$$

where:

HHV = the assumed higher heating value of the fuel, 8600 Btu/lb (19 990 Mj/kg),
MC_{fuel} = average fuel moisture content, percent dry basis,
MC_{kind} = average kindling moisture content, percent dry basis,
W_{fuel} = weight of main test fuel load, lb (kg),
W_{kind} = weight of kindling, lb (kg), and
Q_{ign} = heat input from ignition source, Btu (MJ).

A2.13.3 If the weight of the remaining test fuel is greater than 1 % of the total test fuel weight at the end of the test run, adjust the total heat input using the following equation:

$$Q_{in_{net}} = \left[Q_{in_{gross}} - (W_{Res} \cdot HHV_{Res}) \right], \text{Btu (MJ)} \quad \text{(A2.3)}$$

where:

$Q_{in_{net}}$ = Net Heat Input, Btu (MJ),
W_{Res} = Mass of residual unburned fuel after ash is sifted out, lb (kg), and
HHV_{Res} = Assumed HHV of unburned fuel - 12 000 Btu/lb (27 890 MJ/kg).

$$Q_{Unit} = (W_{app} \cdot C_{Steel} + C_{pa} \cdot W_{water}) \cdot (TF_{avg} - Ti_{avg}) \quad \text{(A2.4)}$$

$$Q_{Load} = \Sigma \left(C_{pi} \cdot \Delta T_i \cdot \dot{M}_i \cdot t_i \right) \quad \text{(A2.5)}$$

$$Q_{Storage} = (W_{Tank} \cdot C_{Tank} + C_{pa} \cdot W_{water}) \cdot (TF_{Tank\_avg} - TI_{Tank\_avg}) \quad \text{(A2.6)}$$

$$Q_{Out\_Total} = Q_{Load} + Q_{Unit} + Q_{Storage} \quad \text{(A2.7)}$$

where:

C_{Tank} = Specific heat of storage tank material,
W_{Tank} = Weight of storage tank(s),
TF_{Tank_avg} = Final average storage tank temp,
TI_{Tank_avg} = Initial average storage tank temp,
Q_{Load} = Total heat delivered to simulated load,
Q_{Unit} = Net energy content change of appliance and on-board water,
$Q_{Storage}$ = Net energy content change in storage, and
Q_{Out_Total} = Total heat output.