Designation: ~~E3053 – 17~~ E3053 – 18

Standard Test Method for Determining Particulate Matter Emissions from Wood Heaters Using Cordwood Test Fuel[1]

This standard is issued under the fixed designation E3053; 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 covers the fueling and operating protocol for determining average particulate matter emissions from wood fires in wood-burning room heaters and fireplace inserts as well as options for determining heat output, efficiency, and carbon monoxide emissions.

1.2 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.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* Refer to 4.3.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D7438 Practice for Field Calibration and Application of Hand-Held Moisture Meters

E176 Terminology of Fire Standards

E631 Terminology of Building Constructions

E2515 Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel

E2780 Test Method for Determining Particulate Matter Emissions from Wood Heaters

2.2 *Other Standards:*

ANSI/UL-103 Standard for Factory-Built Chimneys for Residential Type and Building Heating Appliances[3]

CSA B415.1 Performance testing of solid-fuel-burning heating appliances[4]

NIST Monograph 175 Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90[5]

NIST 105-1: Specifications and Tolerances for Field Standard Weights (NIST Class F)[5]

2.3 *ASTM Adjunct:*[6]

Adjunct to ASTM E3053, Excel[7] Files for Cordwood Calculator and Wood Heater Cordwood Test Summary

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of general terms related to building construction used in this test method, refer to Terminology E631.

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[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.

[3] Available from Underwriters Laboratories (UL), 2600 N.W. Lake Rd., Camas, WA 98607-8542, http://www.ul.com.

[4] Available from Canadian Standards Association (CSA), 178 Rexdale Blvd., Toronto, ON, Canada M9W 1R3, http://www.csagroup.org.

[5] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

[6] Available from ASTM International Headquarters. Order Adjunct No. ADJE305317-EA. Original adjunct produced in 2017.

[7] Excel is a registered trademark of Microsoft Corporation.

3.1.2 For definitions of general terms related to fire testing used in this test method, refer to Terminology E176.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *burn rate, n*—the rate at which fuel is consumed in a wood heater.

3.2.2 *combustion air control, n*—an air control device that regulates air to the wood heater that is primarily intended to promote pyrolysis of the fuel load.

3.2.3 *cordwood, n*—conventional firewood, it is typically round wood 12 to 24 in. (300 to 600 mm) long that has been split into triangular, half-round, quarter-round, wedge-shaped, or trapezoidal segments.

3.2.4 *firebox, n*—the chamber in the wood heater in which the test fuel load is placed and combusted.

3.2.5 *firebox height, n*—unless otherwise specified in the manufacturer's written instructions included with the heater, firebox height is the vertical distance extending above the loading door, if fuel could reasonably occupy that space, but not more than 2 in. (50 mm) above the top (peak height) of the loading door, to the floor of the firebox, (that is, below a permanent grate) if the grate allows a 1-in. (25-mm) diameter piece of fuel to pass through the grate, or, if not, to the top of the grate.

3.2.5.1 *Discussion—*

Firebox height is not necessarily uniform. Variations are caused by internal baffles, air channels, or other permanent obstructions. A visible indicator or landmark within the firebox that will provide a clear indication to the heater user of the maximum height that fuel should be loaded, and is specifically referenced in the manufacturer's written instructions, may be used to determine firebox height for the purposes of calculating usable firebox volume.

3.2.6 *firebox length, n*—the longest horizontal firebox dimension where fuel pieces might reasonably be expected to be placed in accordance with the manufacturer's written instructions that is parallel to a wall of the chamber, in. (mm).

3.2.7 *firebox width, n*—the shortest horizontal firebox dimension where fuel pieces might reasonably be expected to be placed in accordance with the manufacturer's written instructions that is parallel to a wall of the chamber, in. (mm).

3.2.8 *fuel piece length, n*—the nominal length of the cordwood fuel pieces that comprise the test fuel load, in. (mm).

3.2.9 *kindling, n*—split cordwood fuel pieces used to ignite the start-up fuel and the test fuel load from a cold start condition. Applies to high fire test runs only.

3.2.10 *manufacturer's written instructions, n*—specific information regarding the fueling and operation procedures recommended by the heater manufacturer and included with the heater at the time of testing.

3.2.10.1 *Discussion—*

These instructions may include specific kindling and fueling instructions and recommendations such as kindling dimensions and placement (including newspaper) and ignition, dimensions of start-up fuel pieces, addition and placement of the start-up fuel, addition and placement of the main fuel load, position of the load door(s), and setting heater controls (including bypass dampers, if applicable) during start-up and subsequent operation. Instructions for refueling a hot heater when residual fuel and charcoal are present in the firebox also may be included. These instructions must be consistent with information provided to the heater end-user in the owner's manual but also may include information that will be useful only during testing and not to the end-user.

3.2.11 *owner's manual, n*—written information provided to the wood heater end-user regarding the proper installation and operation of the wood heater.

3.2.11.1 *Discussion—*

Includes recommended kindling, fueling, and operating procedures that will help the heater user to achieve the best heater emissions and efficiency performance. It also is referred to as the installation and operation guide or other equivalent title.

3.2.12 *particulate matter (PM), n*—all gas-borne matter resulting from combustion of solid fuel, as specified in this test method, which is collected in accordance with Test Method E2515.

3.2.13 *primary combustion air control(s), n*—an air control device (s) that regulates airflow to the wood heater that is primarily intended to regulate the rate of fuel consumption and heat output.

3.2.13.1 *Discussion—*

There may be single, multiple, or automatic primary air controls.

3.2.14 *residual start-up fuel, n*—leftover fuel present in the firebox at the time the test fuel load is added during high fire test runs.

3.2.14.1 *Discussion—*

May include charcoal and partially burned or unburned kindling and/or start-up fuel.

3.2.15 *secondary combustion air control(s), n*—an air control device(s) that regulates airflow to the wood heater that is primarily intended to provide the additional oxygen needed to promote secondary combustion of the combustible materials released during pyrolysis of the fuel.

3.2.15.1 *Discussion—*

There may be single, multiple, or automatic secondary combustion air controls.

3.2.16 *single burn rate heater, n*—wood heater without user-adjustable primary combustion air control(s).

3.2.17 *start-up fuel, n*—split cordwood pieces intended to provide residual fuel (charcoal or partially burned wood) for ignition of the test fuel load. Applies to high fire test runs only.

3.2.18 *test facility, n*—the area in which the wood heater is installed, operated, and sampled for emissions and efficiency.

3.2.19 *test fuel load, n*—a specified grouping of test fuel pieces.

3.2.20 *test fuel loading density, n*—the weight of the as-fired test fuel load per unit volume of usable firebox, lb/ft^3(kg/m^3).

3.2.21 *test fuel pieces, n*—the individual cordwood pieces that comprise the test fuel load.

3.2.22 *test fuel specific gravity, n*—the nominal dry basis (oven dry weight and oven dry volume) specific gravity of test fuel load, kindling, and start-up fuel.

3.2.23 *test fuel sub-load, n*—a division of the test fuel load for the sole purposes of specifying the test fuel pieces that comprise the test fuel load.

3.2.24 *test run, n*—an individual emission/efficiency test.

3.2.25 *test series, n*—a group of test runs on the same wood heater which includes at least one test run in each burn rate category.

3.2.26 *usable firebox volume, n*—the volume of the firebox determined using its height, length, and width as defined in this section, ft^3 (m^3).

3.2.27 *wood heater, n*—an enclosed, wood burning appliance capable of, and intended for, space heating and/or domestic water heating. This includes wood heaters designed for installation in a fireplace cavity, that is, fireplace inserts, and wood heaters that are built into a wall. Includes adjustable burn rate and single burn rate wood heaters.

3.2.28 *wood heater empty weight, n*—the weight of the cleaned, dry wood heater with or without dry ash or sand added consistent with the manufacturer's written instructions, lb (kg).

4. Summary of Test Method[8]

4.1 This test method is used in conjunction with Test Method E2515. The wood heater under evaluation is fueled by cordwood test fuel loads. Test runs employ either a hot-to-hot cycle or a cold-to-hot cycle depending on the burn rate category of the test run. The test fuel pieces must be within the allowable range of specific gravity. The test fuel load weight and composition is determined based on the usable firebox volume of the heater. For low and medium fire test runs, a charcoal bed is established by conducting a full high fire test run. That high fire test run may be an actual test run or may be just for the purpose of establishing the charcoal bed for a low or medium fire test run. The test fuel load is placed on the charcoal bed and given time to ignite before the air control(s) is (are) set to the test run condition.

4.1.1 For the low and medium fire test runs, particulate emission sampling and efficiency measurements begin immediately prior to addition of the test fuel load to the firebox and end when the test run is terminated in accordance with the specifications in the method.

4.1.2 For the high fire test runs, the test run for the purposes of determining emission rate or emission factor begins with a cold (see 8.5.1) empty (see 8.2.1) firebox. Kindling (and crumpled newspaper, if specified) are used to ignite start-up fuel pieces which, in turn, are used to ignite the test fuel load following manufacturer's written instructions. Particulate emission sampling begins before the kindling is ignited and ends when the test run is terminated in accordance with the specifications in the method.

4.1.3 For low fire, medium fire, and high fire test runs, efficiency is determined on a hot-to-hot cycle and efficiency parameter measurements begin when the test fuel load is added to the firebox and end when the test run is terminated in accordance with the specifications in the method.

[8] This method supersedes Test Method E2780 Annex A1.

4.1.4 For low fire, medium fire, and high fire test runs, average burn rate is determined on a hot-to-hot basis and is based on the weight of the portion of the test fuel load burned during the test run divided by the duration of the test run beginning when the test fuel load is added to the firebox and ending when the test run is terminated. Burn rate for all test runs is adjusted to a dry fuel weight basis.

4.1.5 The total particulate emissions are determined over the test run duration. The particulate emissions rate is then determined from the total particulate emissions divided by the duration of the test run and is reported in grams of particulate per hour. The test run duration for the high fire test for purposes of determining particulate emission rate includes the kindling and start-up fuel period before the test fuel load is added to the firebox. The particulate emission factor lb/lb (g/kg) also may be determined from the total particulate emissions divided by the dry basis weight of the total fuel weight burned and is reported in pounds of particulate per dry pound of fuel (grams of particulate per dry kilogram of fuel). For high fire test runs, the total test fuel weight when determining emission factor includes any kindling and start-up fuel consumed before the test fuel load is added less any fuel remaining at the end of the test run.

4.1.6 This test method also may be used in conjunction with Annex A1 and CSA B415.1 for determining heat output and efficiency. If heat output and efficiency are determined, particulate emissions per unit of heat output also may be calculated and is reported in pounds of particulate per million Btu of heat output (grams of particulate per megajoule). For low and medium fire test runs, the efficiency, heat output, and particulate emissions per unit of heat output are determined on a hot-to-hot cycle. For high fire test runs, particulate emissions are determined for the entire test run, including the cold start (kindling and start-up) portion. However, the kindling and start-up portions of the test run are excluded from the efficiency and heat output determination. For the determination of particulate emissions per unit of heat output, a different approach must be taken. The hot-to-hot efficiency value is applied to the total fuel burned, including kindling and start-up fuel, to determine the heat output that corresponds to the measured emissions.

4.2 This test method may be used to measure emissions and efficiency from wood heaters with adjustable heat output rates (user-adjustable primary air combustion controls) or "Single Burn Rate" wood heaters (no user adjustable primary combustion air controls). A test series for wood heaters with adjustable primary combustion air controls shall include at least one test run from each of the three burn rate categories: high fire, medium fire, and low fire. For single burn rate wood heaters, a test series shall include at least one test in the high fire category and at least one test in the low fire category. In the case of the low fire test, all references to use of primary combustion air controls, burn duration, and burn rate shall be disregarded since single burn rate heaters have no user-adjustable primary air controls.

4.3 **Warning—**This test method may involve hazardous materials, operations, and equipment.

5. Significance and Use

5.1 This test method is used for determining particulate matter (PM) emission rates and emission factors for wood heaters.

5.2 This method is used in conjunction with Annex A2 for determining particulate matter (PM) emissions for Single Burn Rate heaters.

5.3 Use of this test method in conjunction with Annex A1 and CSA B415.1 allows overall thermal efficiency, carbon monoxide emission rate, and particulate matter per unit of heat output to be determined.

5.4 The fuel load specified in this test method is cordwood that is representative of the fuel actually burned in homes. The intent is that the results from this test method will be more predictive of in-home performance than other test methods using a lumber crib of uniform dimensions.

6. Equipment and Supplies

6.1 *Wood Moisture Meter*—Calibrated electrical resistance meter capable of measuring test fuel moisture content with an accuracy of ±2 % moisture content dry basis. Must meet the calibration requirements specified in 7.1.

6.2 *Test Fuel Scale*—A scale capable of weighing test fuel to within ±0.01 lb (0.005 kg). Must meet the calibration requirements specified in 7.3.

6.3 *Platform Scale*—A scale capable of weighing the test wood heater and attached chimney, including the weight of the test fuel, to within ±0.1 lb (0.05 kg). Must meet the calibration requirements specified in 7.2.

6.4 *Wood Heater Flue Gas Temperature Measurement Device*—A 0.125-in. (3.2-mm) diameter sheathed, non-isolated junction Type K thermocouple capable of measuring flue gas temperature with an accuracy of ±4.0 °F (2.2 °C) or ±0.75 % of the reading, whichever is greater. Must meet calibration requirements specified in 7.4.

6.5 *Wood Heater Surface Temperature Measuring Device*—A temperature sensor capable of measuring surface temperatures with an accuracy of ±4.0 °F (2.2 °C) or ±0.75 % of the reading, whichever is greater. Must meet calibration requirements specified in 7.4.

6.6 *Catalytic Combustor Exit Temperature Measuring Device*—A temperature sensor capable of measuring the temperature of the gases exiting the catalytic combustor in a catalyst equipped heater with an accuracy of ±4.0 °F (2.2 °C) or ±0.75 % of the reading, whichever is greater. Must meet calibration requirements specified in 7.4.

6.7 *Insulated Solid Pack Chimney*—Chimney used for installation of wood heater in the test facility. Solid pack insulated chimneys shall have a minimum of 1 in. (25 mm) solid pack insulating material surrounding the entire flue and possess a label demonstrating conformance to ANSI/UL-103 Standard for Factory-Built Chimneys for Residential Type and Building Heating Appliances.

7. Calibration and Standardization

7.1 *Wood Moisture Meter*—Calibrate in accordance with the manufacturer's instructions before each certification test run. Additional information regarding wood moisture meter calibrations can be found in Practice D7438.

7.2 *Platform Scale*—Perform a multipoint calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test run, audit the scale with the test wood heater in place by weighing at least one calibration weight ~~(Class~~ (NIST 105-1 Class F) that corresponds to between 20 and 80 % of the expected test fuel load weight. If the scale cannot reproduce the value of the calibration weight within 0.1 lb (0.05 kg) or 1 % of the expected test fuel load weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

7.3 *Test Fuel Scale*—Perform a multipoint calibration (at least five points spanning the operational range) of the test fuel scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test run, audit the scale by weighing at least one calibration weight ~~(Class~~ (NIST 105-1 Class F) that corresponds to between 20 and 80 % of either the expected test fuel piece weight or test fuel load weight. If the scale cannot reproduce the value of the calibration weight within 0.01 lb (0.005 kg) or 1 % of the expected test fuel load weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

7.4 *Temperature Sensors*—Temperature measuring equipment shall be calibrated before initial use and at least semi-annually thereafter. Calibrations shall be in compliance with NIST Monograph 175 Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90.

8. Procedure

8.1 *Pre-conditioning of the Wood Heater*—The wood heater must be pre-conditioned before a test series begins according to the following steps:

8.1.1 Set up the wood heater in accordance with the manufacturer's written instructions. This includes adding dry sand or dry ash to the bottom of the firebox, if applicable.

8.1.2 The total height of chimney when measured from the floor or top of the platform scale (if the wood heater is on the platform scale) shall be 15 ± 1 ft (4.6 ± 0.3 m).

8.1.3 Install a flue-gas temperature measurement device at the center of the flue, 8.0 ± 0.5 ft (2.44 ± 0.15 m) above the floor or top of the platform scale. For catalyst-equipped heaters, install a catalytic combustor exit temperature measurement device at the centroid of the catalytic combustor exit face and within 1 in. (25 mm) downstream of the catalytic combustor exit face. The centroid of catalytic combustor exit is a 2-in. (50-mm) diameter area around the geometric center of the catalytic combustor exit face. For circular shapes, the geometric center is the center of the circle. For rectangular shapes, the geometric center is the intersection of the two diagonal lines from opposite corners.

8.1.4 Operate the wood heater for at least 50 h at a medium combustion air setting using fuel meeting the specifications in 8.4 or with any type of untreated wood with a moisture content between 18 and 28 % dry basis. Untreated wood is wood fuel that has never been chemically treated (including pressure treating, painting, or staining) or that has not been exposed to salt water. The hours of operation do not need to be continuous. The conditioning may be conducted at the manufacturer's facility as long as full documentation for 8.1.5 – 8.1.7 is provided to the laboratory for inclusion in the test report. The manufacturer's test equipment must meet the applicable requirements in Sections 6 and 7.

8.1.5 Record the time, weight, and moisture content for all fuel added.

8.1.6 Record the flue-gas temperature at least once during each hour of operation.

8.1.7 For catalyst-equipped wood heaters, record the hourly catalytic combustor exit temperature.

8.1.8 Allow the wood heater to cool to room temperature and remove all unburned wood, charcoal, ash, or other debris from the firebox.

8.1.9 Clean the chimney using a standard chimney brush appropriately sized for the chimney.

8.2 Install the wood heater in the test facility.

8.2.1 Set up the wood heater in accordance with the manufacturer's written instructions. This includes adding dry sand or dry ash to the bottom of the firebox, if applicable.

8.2.2 Place the wood heater centrally on the platform scale.

8.2.3 The venting shall consist of single wall steel flue pipe extending to 8.5 ± 0.5 ft (2.6 ± 0.1 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ± 1 ft (4.6 ± 0.3 m) above the platform scale, and of the size specified in the manufacturer's written instructions. This applies to both freestanding and fireplace insert type wood heaters. Do not install a chimney cap.

8.2.3.1 Other chimney types (for example, solid pack insulated pipe or double wall flue pipe) shall be used in place of the steel flue pipe if the wood heater manufacturer's written appliance specifications require such chimney for home installation. The flue pipe and chimney used for testing shall be documented in the test data and test report.

8.2.4 Locate wood heater surface temperature measuring devices at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, on two sidewall surfaces, and on the bottom and back surfaces. Position the monitor sensing tip on the firebox exterior surface inside of any heat shield, air circulation walls, or other wall or shield separated from the firebox exterior surface.

8.2.4.1 The wood heater firebox surface temperature sensors may be wired together in a parallel circuit that provides a single reading of the average firebox surface temperature in lieu of recording individual readings. To get a true average temperature, the thermocouples must be the same length or have the same resistance.

8.2.5 Center the flue outlet (chimney) under the dilution tunnel hood. Refer to Test Method E2515 for specific requirements including positioning the flue outlet to meet induced draft and smoke capture requirements.

8.2.6 Install a flue-gas temperature measurement device at the center of the flue, 8.0 ± 0.5 ft (2.44 ± 0.15 m) above the top of the platform scale.

8.2.7 Photograph or video the completed test installation (including venting) showing front, rear, and side views.

8.3 *Usable Firebox Volume Determination*—Determine the firebox volume, ft^3 (m^3), using the definitions for firebox height, width, and length in Section 3. Follow the manufacturer's written instructions for where fuel should or should not be placed in the firebox when determining usable firebox volume.

8.4 *Fuel:*

8.4.1 *Test Fuel Load Requirements:*

8.4.1.1 The nominal test fuel load weight shall be determined by multiplying the Usable Firebox Volume (UFV) per 8.3 times the specified nominal load density for the applicable test run (Low, High, or Medium Fire) per 8.5 or 8.6.

8.4.1.2 For the sole purpose of determining the overall composition of the test fuel load, the test fuel load shall be considered to be comprised of two sub-loads. Once determined and assembled, the two sub-loads are combined to form the test fuel load that will be added to the firebox during the test run in accordance with the requirements of 8.5.9.3 or 8.6.5.

8.4.1.3 The core sub-load is comprised of three fuel pieces with a combined weight between 45 and 65 % of the nominal test fuel load weight. The allowable weight range for each core sub-load fuel piece shall be 15 to 25 % of the nominal test fuel load weight. Each of the three core sub-load fuel pieces shall fall within that calculated core fuel piece weight range.

8.4.1.4 For the low fire test and medium fire tests, the remainder fuel sub-load shall be comprised of two or three fuel pieces for heaters with UFVs ≤3.0 ft^3 (0.08 m^3) or three or four fuel pieces for heaters with UFVs >3.0 ft^3 (0.08 m^3). The total remainder sub-load weight shall be between 35 and 55 % of the nominal test fuel load weight. The allowable weight for each remainder sub-load fuel piece shall be 10 to 30 % of the nominal test fuel load for heaters with UFVs ≤3.0 ft^3 (0.08 m^3) and 10 to 20 % of the nominal test fuel load weight for heaters with UFVs >3.0 ft^3 (0.08 m^3).

8.4.1.5 For the low and medium fire tests, the smallest fuel piece in the remainder sub-load shall not exceed 67 % of the weight of the largest fuel piece in the remainder sub-load.

8.4.1.6 For the high fire test, the remainder fuel sub-load shall be comprised of up to three fuel pieces for all heaters. The total remainder sub-load weight shall be between 35 and 55 % of the nominal test fuel load weight. The minimum allowable weight for each remainder sub-load fuel piece shall be 10 % of the nominal load weight.

8.4.1.7 The maximum allowable weight for each remainder sub-load fuel piece shall be 55 % of the nominal load weight.

8.4.1.8 Record the total test fuel load weight. The total test fuel load weight (core sub-load plus remainder sub-loads) shall be between 95 and 105 % of the nominal test fuel load weight for all test runs.

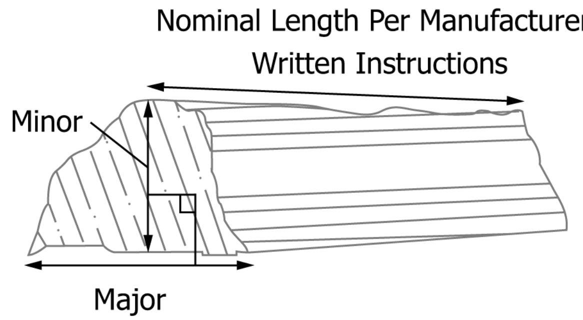
8.4.1.9 All test fuel load and piece weight determinations shall be on the as-fired or wet basis.

8.4.1.10 The test fuel piece minor dimension shall be ≥40 % of the major dimension for each piece of test fuel. See Fig. 1A and Fig. 1B. The major dimension is the longest cross-sectional dimension that can be measured on either end of the test fuel piece. The minor dimension is the longest dimension of the test fuel piece measured on a line perpendicular to the major dimension. Dimensional measurements must be made within the perimeter of the ends of the fuel piece. A MS Excel[7] Spreadsheet fuel load calculator is available as an adjunct to this standard.[6]

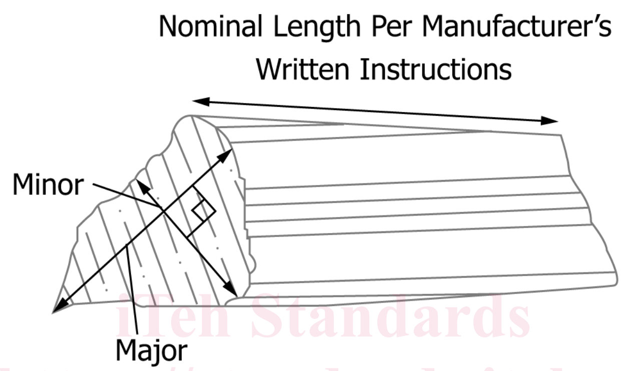
8.4.2 *Fuel Properties:*

8.4.2.1 *Fuel Species and Properties*—Test fuel load, kindling, and start-up fuel pieces shall be species of cordwood with a specific gravity range of 0.48 to 0.73 on a dry basis (oven dry weight/oven dry volume). See Fig. 2 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.

8.4.2.2 *Test Fuel Load Moisture Content*—Using a fuel moisture meter as specified in 6.1 of the test method, determine the fuel moisture content for each test fuel piece used for the test fuel load by averaging at least three fuel moisture meter readings



(**A**)



(**B**)

FIG. 1 A and 1B Dimensions of Test Fuel Pieces

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
Douglas fir (coast, Int. West, Int. North)	0.51
Douglas fir (Interior South)	0.49
Elm, Rock	0.67
Elm, Soft	0.57
Gum, Red	0.53
Larch, Western	0.55
Maple, Hard	0.60
Maple, Sugar	0.67
Oak, Red	0.66
Oak, White	0.71
Pine, Southern	0.55
Pine, Southern Long Leaf	0.64

Source: Wood Structural Design Data - 1970 Edition, Page 4, National Forest Products Association, Washington, DC.

FIG. 2 Specific Gravity of Commercially Imported Species of Wood Based on Oven-Dry Weight and Oven-Dry Volume

measured parallel to the wood grain for each test fuel piece. One measurement each from two different sides shall be made at approximately 3 in. (75 mm) from opposite ends of the fuel piece. One additional reading shall be made at approximately the center of a third side. Penetration of the moisture meter insulated electrodes for these three readings shall be ⅕ to ¼ of the thickness of the fuel piece. For fuel pieces with tightly adhered thick bark (defined as more than ⅛ in. (3.2 mm) thick), the thickness of the bark shall be added to the electrode penetration depth or the bark shall be locally removed in the area where the moisture readings are taken. If more than three moisture readings are taken on any test fuel piece, the additional readings shall be dispersed as evenly as practicable among all fuel piece sides and in proportion to the locations of the three required readings. Holes for the moisture meter pins may be pre-drilled to the measurement depth minus at least ¼ in. (6.4 mm). For half-round fuel pieces, the curved side shall be considered to be comprised of two equal sides and moisture readings taken accordingly. For fuel pieces with geometries that do not directly allow application of the measurement location criteria, measurements should be taken at locations that best meet the intent of this section. The average moisture content for each test fuel piece shall be in the range of 18 to 28 % on a dry basis. The average moisture content of the test fuel load shall be in the range of 19.0 to 25.0 % on a dry basis. Moisture shall not be added to previously dried fuel pieces except by storage under high humidity conditions and temperature up to 100 ºF (38 °C). Test fuel load moisture content shall be determined within 4 h of using the fuel for a test.

8.4.2.3 *Start-up Fuel Moisture Content*—Start-up fuel pieces may be split from larger fuel pieces that have had average moisture content determined using the procedure in 8.4.1.2. Moisture content for individual start-up fuel pieces also may be determined using the procedure per 8.4.1.2. Average start-up fuel moisture content shall be in the same allowable range as the test fuel load. Start-up fuel moisture content shall be determined within 4 h of using the fuel for a test.

8.4.2.4 *Kindling Moisture Content Determination*—Kindling that is stored under ambient conditions of 70 ± 10 °F and Relative Humidity of 50 ± 10 % for at least 48 h may be assumed to have a moisture content of 10 % dry basis.

8.4.2.5 *Alternative Kindling Moisture Content Determinations*—Kindling moisture content may be determined by measurement. The average moisture content for each kindling piece shall be between 6 and 12 % dry basis. Kindling moisture content shall be determined within 4 h of using the kindling for a test unless the kindling has been stored under cover and under ambient conditions per 8.4.2.4 for at least four months before use. In that case, the kindling moisture may be measured within 24 h of the start of the test run. There are two alternative methods for determining kindling moisture content:

(1) Measure the moisture content of each kindling piece. One moisture meter reading for each kindling piece, measured parallel to the wood grain, is sufficient. Penetration depth for the moisture meter pins shall be in accordance with 8.4.2.2. In lieu of the insulated pins required for measuring moisture in typical cordwood fuel pieces, uninsulated pins may be used when measuring individual kindling piece moisture. All readings from all kindling pieces shall be averaged to determine the average kindling moisture.

(2) Measure the moisture content of each piece of fuel that is split into kindling. The average moisture content for kindling split from a larger fuel piece may be assumed to be the same as the average moisture content of the larger piece measured in accordance with the procedure in 8.4.2.2.

8.4.2.6 *Fuel Conditioning*—Cordwood, including that to be used for start-up fuel, may be partially dried at an elevated temperature up to 140 °F until the average dry basis moisture content reaches ~30 % (dry basis). Cordwood dried in this manner must be allowed to equilibrate after drying for at least three weeks before use. See Note 1 for guidance on achieving and maintaining more uniform moisture distribution.

NOTE 1—Once split cordwood pieces have dried to an average moisture content that is near the top of the allowable moisture content range, to maintain fuel within the allowable moisture content range, storage at a relative humidity of 95 % or higher and temperature of 90 to 100 ºF (32 to 38 °C) is necessary. An air circulation means within the storage area will reduce the likelihood of fungus or mold growth on the fuel pieces. In addition, storage at these conditions for a period of several weeks or longer generally results in more uniform moisture content distribution throughout the fuel pieces and thus improves the accuracy of the moisture content measurement.

8.4.2.7 *Fuel Temperature*—The test fuel piece temperature shall be within the allowable test facility temperature range as per Test Method E2515. The fuel temperature may be determined by measuring the temperature of the room where the test fuel has been stored for at least 24 h prior to the fuel moisture determination.

8.4.2.8 *Cordwood Test Fuel Piece Length*—The nominal test fuel piece length used shall be in accordance with the manufacturer's written instructions. All test fuel pieces shall be the nominal length ±1 in. (25 mm). See Fig. 1A and Fig. 1B.

8.5 *High Fire Test Category:*

8.5.1 *Start-up Conditions*—Appliance operation for the high fire test category employs a cold start. The average heater surface temperature per 8.2.2 and flue-gas temperature per 8.2.4 at the start of the test run shall be less than 10 °F (5 °C) above ambient.

8.5.2 *High Fire Test Primary Combustion Air Control Setting*—The primary combustion air control(s) shall be at the highest setting(s) at all times during the high fire test run.

8.5.3 Other manual air control(s) shall be set at the position(s) in accordance with the manufacturer's written instructions. Automatically operated controls shall be allowed to operate as designed.

8.5.4 The nominal test fuel load density for the high fire test runs shall be 10 lb of test fuel per ft^3 (161 kg/m^3) of usable firebox volume.

8.5.4.1 *Exception*—Every effort shall be made to achieve the required test fuel load density including adjustment of the sizes of individual test fuel pieces (within the ranges allowed in 8.4.1), starting the test run within 0.2 lb (0.1 kg) of the minimum allowed

residual start-up fuel bed weight per 8.5.8 and with a test fuel load weight within 0.5 lb (0.2 kg) of the minimum allowable test fuel load weight per 8.5.4 and 8.4.1.8. However, if the minimum test fuel load density per 8.4.1.8 cannot be achieved due to insurmountable firebox loading problems (for example, there is no room for the last fuel piece no matter what combination of allowable fuel piece sizes, minimizing residual start-up fuel weight, and/or minimizing test fuel load weight is tried), the nature of the loading problem shall be documented including: photographs, the weight of the fuel piece(s) that could not be added to the firebox, the actual load density that was achieved for the test run, and any other information that can help justify employment of the exception.

8.5.5 Follow the manufacturer's written instructions for kindling size, placement in the firebox (including crumpled newspaper), and ignition for the addition and placement of the start-up fuel, for addition and placement of the test fuel load, for position of the load door(s), and for setting heater controls (including bypass dampers, if applicable) during start-up with the following conditions:

8.5.5.1 If the manufacturer's written instructions recommend or allow the use of a portable hand-held homeowner-type gas torch for ignition purposes, the use of the torch is allowed but limited to a total of 60 s.

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

8.5.5.3 For wood heaters that include an automatic ignition system (such as a gas ignition burner or electric ignition heating element) or other supplemental energy input system, the ignition system or other supplemental energy system shall be operated in accordance with the manufacturer's written instructions. The energy input value from the ignition system or other supplemental energy system after the test fuel load is added shall be measured and added to the total energy input for the purpose of determining overall efficiency. For gas ignition systems or for gas supplemental energy systems, the impact on the determination of heat output and efficiency using the CSA B415.1 stack loss method per Annex A1 shall be accounted for in the efficiency determination and reported.

8.5.6 *Kindling*—The kindling to ignite the start-up fuel pieces and test fuel load may be up to 20 % of the test fuel load weight on a wet basis.

8.5.7 *Start-up Fuel*—The start-up fuel is in addition to the test fuel load and may be up to 30 % of the test fuel load weight on a wet basis. Start-up fuel pieces may be positioned or repositioned as needed to ensure good ignition. Start-up fuel may be added with the kindling or after the kindling is ignited in accordance with the manufacturer's written instructions.

8.5.8 *Residual Start-up Fuel Bed Weight*—The residual start-up fuel weight when the test fuel load is added shall be 10 to 20 % of the actual test fuel load weight–wet basis. For purposes of this test method, the moisture content of the residual start-up fuel when the test fuel load is added shall be assumed to be 0 %.

8.5.9 *High Fire Test Run:*

8.5.9.1 Record the weight of the cleaned, dry wood heater (including the chimney per 8.2.3) within 5 min before adding the kindling to the firebox.

8.5.9.2 Before igniting the kindling, record all wood heater individual surface temperatures (or the average of the individual surface temperatures) and the flue gas temperature (see 8.5.1), catalyst temperature, if applicable, initial sampling method measurement values, photograph the kindling/start-up fuel configuration in the firebox, and begin the particulate emission sampling in accordance with Test Method E2515. Ignition of the kindling shall begin within 30 s after starting emission sampling.

(1) Follow the manufacturer's written instructions for the position of the load door during the kindling and/or start-up portion of the test run. Document the position or positions with a linear measurement from the fully closed position.

8.5.9.3 When the kindling and start-up fuel have been consumed to leave a residual start-up fuel bed weight as specified in 8.5.8, the residual start-up fuel bed may be adjusted in accordance with the manufacturer's written instructions. In the absence of written instructions, the residual start-up fuel bed may be leveled, if necessary, to allow room for the test fuel load. Provide a detailed written description and photograph or video of the residual start-up fuel bed before and after any adjustments. Record the weight of the fuel remaining, photograph or video the residual fuel bed, tare the platform scale, or record the starting weight, begin CSA B415.1 sampling and add the test fuel load in accordance with the manufacturer's written instructions. Record the weight after the test fuel load is added. Because some fuel weight may be consumed during the allowable test fuel load time, the initial recorded test fuel load weight shall be the weight determined per 8.4.1.8. Photograph or video the test fuel load before and after it is placed in the firebox. The maximum allowable time for loading the test fuel load into the wood heater is equal to 30 s/ft^3 (1060 s/m^3) of usable firebox volume but not less than 60 s.

NOTE 2—If the default procedure for residual start-up fuel adjustment is employed, examples of residual start-up fuel adjustments that are not allowed include creating furrows or ridges or angling.

8.5.9.4 The fuel load door may be placed in a position other than fully closed in accordance with the manufacturer's written instructions (for example, open 1 in.) for up to 5 min after the maximum load time. Fuel load adjustments may be made as needed during that same 5-min period to ensure that fuel load ignition is achieved.

8.5.9.5 Additional test fuel load adjustments may be made. The time used to make any fuel adjustment shall be less than 30 s for each adjustment. Any fuel adjustments must be documented and justified in the test report.

(1) The test fuel load pieces may be adjusted once (that is, repositioned) until 15 min after the maximum load time or until 15 % of the test fuel load weight (wet basis) has been consumed, whichever is less. Provide a detailed written description or photograph or video of the fuel load in the firebox before and after it is adjusted.

(2) The test fuel load pieces also may be adjusted once (that is, repositioned) during a test run if more than 60 % of the initial test fuel load weight has been consumed and more than 10 min have elapsed without a measurable (<0.1 lb (0.05 kg) or 1.0 % of the test fuel load weight, whichever is greater) weight change. Provide a detailed written description or photograph or video of the fuel load in the firebox before and after it is adjusted.

8.5.9.6 *Data Recording*—Data shall be recorded at intervals sufficient to produce a minimum of 50 data points based on the anticipated test run duration for fuel weight, flue gas temperature, flue gas CO and CO_2 concentrations and ambient temperature for CSA B415.1 efficiency determination, heat output, and CO emissions calculations. All other data shall be collected at intervals not exceeding 10 min.

8.5.9.7 *Air Control(s) Adjustment*—Air control(s) other than primary air control(s) may be adjusted once at any time during the test run in accordance with the manufacturer's written instructions. Automatically operated controls shall be allowed to operate as designed.

8.5.9.8 *Test Run Completion*—The test run is completed when 90 ± 1 % of the test fuel load weight is consumed. At the end of the test run, stop the particulate sampling per Test Method E2515 and CSA B415.1 sampling, and record the final fuel weight, the run time, and all final measurement values. The total test run duration for purposes of determining emission rate equals the time from ignition of the kindling per 8.5.5 to the test run completion. For purposes of determining the emission factor, the total weight of fuel burned includes kindling weight, start-up fuel weight, and test fuel load weight, less the ending fuel bed weight at the test run completion, all on a dry basis. For purposes of this test method, the moisture content of the remaining fuel at the end of the test run shall be assumed to be 0 %.

NOTE 3—The test fuel load weight excludes the residual start-up fuel weight per 8.5.8.

8.5.9.9 *Auxiliary Wood Heater Equipment Operation*—Heat exchange blowers sold with the wood heater, whether as standard equipment or offered as an option, shall be operated during the test run in accordance with the manufacturer's written instructions. Automatically operated blowers shall be operated as designed. Shaker grates, by-pass controls, or other auxiliary equipment may be adjusted only one time during the test run in accordance with the manufacturer's written instructions. All adjustments shall be recorded on the wood heater operational written record. The test report and the owner's manual shall include a statement that the overall efficiency of the heater may be lower if the heater is operated without a heat exchange blower or with the heat exchange blower turned off.

8.5.9.10 *High Fire Test Run Efficiency, Heat Output, and Carbon Monoxide Emission Rate Determination*—The high fire test run overall efficiency, heat output, and carbon monoxide emission rate shall be determined in accordance with Annex A1.

8.6 *Low and Medium Fire Test Runs:*

8.6.1 *Starting Charcoal Bed Preparation*—A low or medium fire test run may be conducted after a high fire test run is completed and the remaining high fire charcoal bed used for a low or medium fire test run. If a low or medium fire test run is not being run after completion of a high fire test run, the starting charcoal bed for a low or medium fire test run shall be prepared using the high fire test run procedure per 8.5.2 through 8.5.9.8 except Test Method E2515 and CSA B415.1 data per 8.5.9.5 is not required. The charcoal bed used for low and medium fire test runs shall be the result of a single high fire test fuel load only.

8.6.1.1 Adjustment of the combustion air control(s) and coal bed adjustments in accordance with the manufacturer's written instructions are allowed up to the start of the low or medium fire test run. In the absence of such written instructions, coal bed adjustments are limited to the use of a metal tool (poker) to level the coal bed to make room for the test fuel load, and coal bed adjustments other than leveling are not allowed. Record all adjustments made to the combustion air control(s). Provide a detailed written description and document any coal bed adjustments with before and after photographs or video.

NOTE 4—If the default procedure for coal bed adjustments is employed, examples of coal bed adjustments that are not allowed include creating furrows or ridges or angling.

8.6.2 *Charcoal Bed Weight*—The weight of charcoal bed remaining at the start of the test run is determined as the difference between the weight of the wood heater (including the chimney per 8.2.3) with the remaining charcoal bed and the tare weight of the cleaned, dry wood heater (with or without dry ash or sand added in accordance with the manufacturer's instructions) including the chimney per 8.2.3. The tare weight of the wood heater must be determined with the wood heater (and ash or sand, if added) in a dry condition.

8.6.3 *Low and Medium Fire Test Run Nominal Fuel Load Density* shall be 12 lb/ft^3 30 (194 kg/m^3) of usable firebox volume.

8.6.3.1 *Exception*—Every effort shall be made to achieve the required test fuel load density including adjustment of the sizes of individual test fuel pieces (within the ranges allowed in 8.4.1), starting the test run within 0.2 lb (0.1 kg) of the minimum allowed charcoal bed weight per 8.6.4 and with a test fuel load weight within 0.5 lb (0.2 kg) of the minimum allowable test fuel load weight per 8.6.3 and 8.4.1.8. However, if the minimum test fuel load density per 8.4.1.8 cannot be achieved due to insurmountable firebox loading problems (for example, there is no room for the last fuel piece no matter what combination of allowable fuel piece sizes, minimizing residual start-up fuel weight, and/or minimizing test fuel load weight is tried), the nature of the loading problem shall be documented including: photographs, the weight of the fuel piece(s) that could not be added to the firebox, the actual load density that was achieved for the test run, and any other information that can help justify employment of the exception.

8.6.4 *Low and Medium Fire Test Run Starting Charcoal Bed Weight Range* is 10 to 20 % of the actual total test fuel load weight–wet basis.