Nov. 30, 2016

BTEC Standard 100 - 2016

Test Method

For

Measurement of Heating Efficiency and Emissions Performance

Of

Commercial, Biomass-fired, Hydronic Boilers

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1. Scope

This test method builds upon ASTM E2618-13 (Standard Test Method for Measurement of Particulate Emissions and Heating Efficiency of Solid Fuel-Fired Hydronic Heating Appliances) which is included as an authorized test method under the USEPA New Source Performance Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces published in the Federal Register on March 16, 2015.

This test method applies to commercial, biomass-fired, hydronic boiler systems that are comprised of either single or multiple boilers.

This test method applies to boilers that use either manual or automatic fuel feed.

This test method allows for testing of boiler operation with or without external thermal storage.

This test method allows for the use of manufacturer-specified operating principles for boiler temperature control, including continuous modulation of firing rate, slumber modes, and “stay alive” combustion air cycling strategies during off-cycle periods, so long as manual reset of the boiler control is not required.

This test method applies to boilers that are fired with woody biomass as well as other renewable, solid fuels made from grass-based or agricultural, waste-based feedstock.

2. Referenced Documents

ASTM Standards

E2618-13 Standard Test Method for Measurement of Particulate Emissions and Heating Efficiency of Solid Fuel-Fired Hydronic Heating Appliances

E2515-11 Test Method for Determination of Particulate Matter Emissions collected by a Dilution Tunnel

Other Standards

CSA B415.1-2010 Performance testing of solid-fuel-burning heating appliances

ASHRAE Standard 155P Method of Testing for Rating Commercial Space Heating Boiler Systems published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE Weather Data Viewer CD, which displays Climatic Design Information listed in the ASHRAE Handbook of Fundamentals.

3. Terminology

Definitions

Definitions are in accordance with E2618-13 unless otherwise indicated.

Definitions of Terms Specific to this Standard

Application Seasonal Efficiency - the calculated seasonal thermal efficiency of a single boiler or multiple boiler system, based on: the input/output efficiency graph determined for one or more individual boilers under this method; the capacity of the boiler(s); the peak heating load defined for a specific heating application; and, the annual distribution of temperature bin hours in accordance with ASHRAE weather data for a representative northern climate location.

Boiler Standby Loss (Btu/hr) - the loss of heat (Btu/hr) through jacket loss and off-cycle draft loss from a boiler when it is not firing.

Boiler Standby Loss (%) - the loss of heat (% of boiler rated capacity) through jacket loss and off-cycle draft loss from a boiler when it is not firing.

Condensing Boiler - a boiler which is designed to operate with return water temperatures at or below 120 deg F at design conditions, which condenses at least part of the water vapor in the flue gas, and which is equipped with a means of collecting and draining such condensate.

Jacket Loss (Btu/hr) - the loss of heat (Btu/hr) through convection and radiation from the surfaces of a boiler when the boiler is warmer than the surrounding ambient air.

Jacket Loss (%) - the loss of heat (% of boiler rated capacity) through convection and radiation from the surfaces of a boiler.

Multiple Boiler System - a boiler system, consisting of two or more boilers, installed with automatic, hydronic valves that can isolate individual boilers from each other, and from the hydronic distribution system, in regard to boiler water flow.

Positive Combustion Air Shutoff - a device, such as a sliding shutter or rotating damper, which blocks 90 percent or more of the flow path for combustion air or exhaust gas when in a closed position.

Stack Loss Method (SLM) Delivered Output - the average, delivered thermal output (Btu/hr) of a boiler, further defined as the Overall Heat Output (Btu), as determined using the Stack Loss Method described in Section 13 of CSA B415.1-10, divided by the duration (hrs) of the test, minus the jacket loss (Btu/hr) of the boiler.

Stack Loss Method (SLM) Delivered Efficiency - the average, delivered efficiency (%) of a boiler at a prescribed firing rate, further defined as the SLM Overall Efficiency, as determined using the Stack Loss Method described in Section 13 of CSA B415.1-10, minus the jacket loss (%) of the boiler.

Thermal Storage System Standby Loss (Btu/hr) - the loss of heat (Btu/hr) through convection and radiation from an external thermal storage system during operation when charged to a temperature of 160 degrees F.

Total Boiler-plus-Thermal Storage System Standby Loss (Btu/hr) – the sum of the boiler standby loss (Btu/hr) plus thermal storage system standby loss (Btu/hr)

4. Summary of Test Method

This test method incorporates efficiency and emissions measurement procedures as prescribed by ASTM 2618-13 and CSA B415.1-10 for solid fuel-fired, hydronic heating appliances, but with certain changes and additions as described further in this document.

This test method measures heating efficiency and fine particulate (PM 2.5) plus carbon monoxide (CO) plus includes an option for measurement of nitrogen oxide (NOx) emissions.

This test method requires the use of the CSA B415.1-10 Stack Loss Method (SLM) for measurement of boiler output, fuel consumption and efficiency.

This method allows the use of direct Btu metering only for manual feed boilers and for automatic feed boilers with rated heating capacities of 300,000 Btu/hr or less.

This test method allows for the testing of various configurations of external thermal storage.

This test method also allows for testing of boiler operation without external thermal storage.

This test method also allows for the testing of single or multiple boiler systems.

This test method requires boiler control and operation during testing to be in accordance with written instructions that are provided by the manufacturer to its customers.

This method also incorporates the measurement of boiler jacket losses and standby fuel consumption in accordance with procedures incorporated in ASHRAE Standard 155P as published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

This method incorporates the determination of boiler fuel input over the range of 0 to 100 percent of rated boiler capacity.

This method provides for the use of boiler temperatures of 180 deg F (non-condensing boilers), 140 deg F (non-condensing boilers with thermal post-purge) and 120 deg F (condensing boilers) for the measurement of boiler jacket loss and boiler standby loss, as further described in ASHRAE Standard 155P.

This method requires a fuel input vs thermal output graph to be plotted in accordance with ASHRAE Standard 155P.

The fuel input vs thermal output graph is then used to plot a graph of boiler efficiency over the range of 0 to 100 percent of rated boiler capacity.

Annexes A3 and A4 to this method provide for the optional calculation of Application Seasonal Efficiency.

ASHRAE bin hour weather data is used to determine the number of hours per year which occur at prescribed percentage fractions of the peak heating load.

Such weather data is then combined with fuel input data for each percentage load level to yield an estimated annual fuel consumption at each individual load level.

The estimated annual fuel consumption at each individual load level is then summed to provide an estimate of total annual fuel consumption for the boiler(s).

The calculation of annual efficiency is based on the assumption that the rated capacity of the single boiler or multiple boiler system is equal to the peak heating load.

Annex A3 (Informative) includes optional calculation procedures for estimating annual efficiency and total annual fuel consumption for single boiler systems.

Annex A4 (Informative) includes optional calculation procedures for estimating annual efficiency and total annual fuel consumption for multiple boiler systems.

5. Significance and Use

The measurement of PM 2.5, CO and NOx emissions is important for air quality purposes.

The measurement of boiler efficiency throughout the range of 0 to 100 percent of rated capacity is valuable in providing a uniform basis for comparison of annual product performance of commercial, biomass-fired boilers.

Standardized procedures for the calculation of multiple-boiler system performance can be important for the documentation of expected benefits and fuel savings of biomass-fired boilers compared to existing, fossil fuel-fired, boiler systems.

6. Apparatus

This test method incorporates the use of apparatus in accordance with Section 6 of ASTM E2618-13.

If it is impractical, however, for an entire boiler to be placed on a laboratory weigh scale, then this test method offers the option of weighing only the feed hopper or, alternatively, of weighing individual batches of fuel that are added to the hopper during testing.

For testing of boiler systems with external thermal storage, this test methods encourages the use of piping, control and tank configurations that are similar to those described in the publication entitled “Best Practices for Thermal Storage in Wood-fired Boiler Systems” published by the Biomass Thermal Energy Council.

7. Hazards

This test method requires that boilers meet the hazard requirements described in Section 7 of ASTM E2618-13, except that it offers the option of installing a non-ASME certified pressure vessel in such a manner that it is unpressurized and open to the atmosphere with a stand pipe (even if the manufacturer

instructions do not permit such type of installation for long-term use in actual customer applications) for the purpose of maintaining laboratory safety during testing.

8. Sampling, Test Specimens, and Test Appliances

This test method requires that boilers be supplied as complete appliances, and that design documents, as well as installation and operating instructions, be provided in accordance with Section 8 of ASTM E2618-13.

9. Preparation of Apparatus

This test method requires the preparation of apparatus in accordance with Section 9 of ASTM E2618-13 except that the installation of a recirculation loop between connections at the hydronic inlet and outlet of the boiler shall be mandatory in order to allow for testing of its standby heat loss. Additionally, the installation of a calibrated water flow meter on the cooling water inlet side of the heat exchanger shall be required only if the direct BTU metering option is used for determination of boiler capacity and efficiency. All temperature sensors as required by ASTM E2618-13 shall be included under this test method.

As described earlier in Section 6 of this test method, if it is impractical for an entire boiler to be placed on a laboratory weigh scale, then this test method offers the option of weighing only the feed hopper or, alternatively, of weighing individual batches of fuel that are added to the hopper during testing.

10. Calibration and Standardization

Calibration of all temperature sensors, the flow meter (if used), the weigh scale, and moisture meter shall be performed in accordance with Section 10 of ASTM E2618-13.

11. Conditioning

Conditioning of the boiler shall be performed in accordance with Section 11 of ASTM E2618-13.

12. Procedure

Testing of the boiler shall be conducted in accordance with Section 12 of ASTM E2618-13 but with the following additions and exceptions:

12.1 NOx Emissions

If NOx emissions are to be determined, then the test method specified in [test method to be determined at a later date] shall be used and results shall be included in the test records and reporting.

If NOx emissions are to be determined, then such emissions shall be measured during the efficiency testing that is prescribed in this standard to include each burn category as well as during standby testing.

12.2 Efficiency and Emissions Testing Under Categories I, II, III and IV

This test method is based upon ASTM E2618-13, which incorporates a requirement for the use of the Stack Loss Method (SLM), as described further in CSA B415.1-10, as a quality control measure.

Under this test method, manual feed boilers are allowed to use either direct Btu metering or the Stack Loss Method for measurement of boiler capacity and efficiency. Automatic feed boilers with rated heating capacities of less than 300,000 Btu/hr are also allowed to use either direct Btu metering or the Stack Loss Method.

For automatic feed boilers with rated heating capacities of 300,000 Btu/hr or higher, this test method requires the use of only the Stack Loss Method for determination of boiler capacity and efficiency. It is noted here that Section 13 of CSA B415.1-10 provides for the determination of burn rate through the measurement of mass and moisture content of fuel burned during testing.

This test method includes the determination of a new term entitled, *Stack Loss Method (SLM) Delivered Output (Btu/hr),* which is further defined as the Overall Heat Output (Btu), as determined using the Stack Loss Method described in Section 13 of CSA B415.1-10, divided by the duration (hrs) of the test, minus the jacket loss (Btu/hr) of the boiler. This term represents the net delivered thermal output of the boiler.

This test method also includes the determination of a new term entitled, *Stack Loss Method (SLM) Delivered Efficiency (%),* which is further defined as the SLM Overall Efficiency, as determined using the Stack Loss Method described in Section 13 of CSA B415.1-10, minus the jacket loss (%) of the boiler. This term represents the net thermal efficiency of the boiler.

Direct BTU metering of Manual Feed Boilers Without External Thermal Storage

For manual feed boilers, if the direct BTU metering option is used for determination of boiler capacity and efficiency, and if external thermal storage IS NOT used during testing, then the boiler shall be tested under the four burn categories and other requirements described further in ASTM E2618-13.

Under this test method, however, one exception from the requirements of ASTM E2618-13 shall be that if a manual feed boiler without external thermal storage experiences stopped combustion under Category I conditions, then it shall be considered as having failed the test. Such boiler would then need to be tested in accordance with one of the external thermal storage options described in ASTM E2618-13.

Direct BTU metering of Manual Feed Boilers With External Thermal Storage

For manual feed boilers, if the direct BTU metering option is used for determination of boiler capacity and efficiency, and if external thermal storage IS used during testing, then the boiler shall be tested in accordance with Annex A1 (Modified Test Method for Wood-fired Hydronic Appliances That Utilize Full Thermal Storage) or Annex A2 (Modified Test Method for Wood-fired Hydronic Appliances That Utilize Partial Thermal Storage) ASTM E2618-13.

Stack Loss Method Testing of Manual Feed Boilers Without External Thermal Storage

For manual feed boilers, if the CSA B415/1-10 Stack Loss Method is used for determination of boiler capacity and efficiency, and if external thermal storage IS NOT used during testing, then the boiler shall be tested under the four burn categories and other requirements described further in ASTM E2618-13.

Under this type of test, the recorded Stack Loss Method efficiency values shall be weighted according to the real-time firing rate of the boiler. The first option for accomplishing such weighting is to monitor the consumption of fuel through the use of a weigh scale on which the boiler is placed during testing.

The second option for accomplishing such weighting is to measure the total length of time elapsed during the burn cycle and then to apply the following weighting factors:

First 15% of burn cycle period:	0.10
Middle 60% of burn cycle period:	0.80
Final 25% of burn cycle period:	0.10

An example calculation table is offered here:

Burn cycle phase	Weighting Factor	Efficiency (%)	WF X Efficiency
First 15%	0.10	75	7.5
Middle 60%	0.80	80	64.0
Final 25%	0.10	60	6.0
Total weighted efficiency during burn cycle:			77.5

Under this test option, one exception from the requirements of ASTM E2618-13 shall be that if a manual feed boiler without thermal storage experiences stopped fuel combustion under Category I conditions, then it shall be considered as having failed the test. Such boiler would then need to be tested in accordance with one of the thermal storage options described in ASTM E2618-13.

Stack Loss Method Testing of Manual Feed Boilers with External Thermal Storage

For manual feed boilers, if the CSA B415.1-10 Stack Loss Method is used for determination of boiler capacity and efficiency, and if external thermal storage IS used during testing, then the boiler plus external thermal storage system shall be tested in accordance with Annex A1 (Modified Test Method for Wood-fired Hydronic Appliances That Utilize Full Thermal Storage) or Annex A2 (Modified Test Method for Wood-fired Hydronic Appliances That Utilize Partial Thermal Storage) ASTM E2618-13, except that in each case, the standby loss of both the boiler and the external thermal storage must be measured and included in the calculation of boiler plus external thermal storage system efficiency.

Under this type of test, the average weighted efficiency must be determined as described in the previous section above.

Direct BTU metering of Small Automatic Feed Boilers Without External Thermal Storage

For a small, automatic feed boiler with rated heating capacity of less than 300,000 Btu/hr, if the direct BTU metering option is used for determination of boiler capacity and efficiency, and if thermal storage IS NOT used during testing, then the boiler shall be tested under the four burn categories and other requirements described further in ASTM E2618-13.

Under this test method, however, an additional requirement shall be that if a small automatic feed boiler without thermal storage ceases operation under Category I, II or III conditions, and is unable to re-start automatically (without manual reset of the boiler control), then it shall be considered as having failed the test. Such boiler would then need to be tested in accordance with one of the thermal storage options described in ASTM E2618-13.

Direct BTU metering of Small Automatic Feed Boilers With External Thermal Storage

For a small, automatic feed boiler with rated heating capacity of less than 300,000 Btu/hr, if the direct BTU metering option is used for determination of boiler capacity and efficiency, and if thermal storage IS used during testing, then the thermal storage system shall be sized, pre-heated and operated in accordance with Annex A1 (Modified Test Method for Wood-fired Hydronic Appliances That Utilize Full Thermal Storage) or Annex A2 (Modified Test Method for Wood-fired Hydronic Appliances That Utilize Partial Thermal Storage) ASTM E2618-13.

During this test option, the ongoing consumption of fuel must be monitored in accordance with Section 12.3.2 of ASTM E2618-13.

Stack Loss Method Testing of Automatic Feed Boilers Without External Thermal Storage

For automatic feed boilers, if the CSA B415/1-10 Stack Loss Method is used for determination of boiler capacity and efficiency, and if thermal storage IS NOT used during testing, then the boiler shall otherwise be tested under the four burn categories and other requirements described further in ASTM E2618-13.

During this test option, the ongoing consumption of fuel must be monitored either: (1) in accordance with Section 12.3.2 of ASTM E2618-13, which incorporates the placement of the fuel hopper on a weigh scale; or (2) through the feeding of weighed quantities of fuel at least every 30 minutes to reach a prescribed level in the fuel hopper.

During the two hour, boiler pre-heat phase required by ASTM E2618-13, the circulating water flow rate through the boiler shall be adjusted, the fuel consumption shall be measured every 30 minutes, and efficiency shall be monitored to achieve the necessary firing capacity.

If the boiler goes into a standby mode, with no feeding of fuel or combustion air, but then automatically restarts operation, the start and end times of the standby mode shall be recorded.

Under this test option, an additional requirement shall be that if an automatic feed boiler without thermal storage experiences stopped combustion under Category I, II or III conditions, and is unable to re-start automatically (without manual reset of the boiler control), then it shall be considered as having failed the test. Such boiler would then need to be tested in accordance with one of the thermal storage options described in ASTM E2618-13.

Stack Loss Method Testing of Automatic Feed Boilers with External Thermal Storage

For automatic feed boilers, if the CSA B415.1-10 Stack Loss Method is used for determination of boiler capacity and efficiency, and if external thermal storage IS used during testing, then the thermal storage system shall be sized, pre-heated and operated in accordance with Annex A1 (Modified Test Method for Wood-fired Hydronic Appliances That Utilize Full Thermal Storage) or Annex A2 (Modified Test Method for Wood-fired Hydronic Appliances That Utilize Partial Thermal Storage) ASTM E2618-13.

During this test option, the ongoing consumption of fuel must be monitored either: (1) in accordance with Section 12.3.2 of ASTM E2618-13, which incorporates the placement of the fuel hopper on a weigh scale; or (2) through the feeding of weighed quantities of fuel every 30 minutes to reach a prescribed level in the fuel hopper.

12.3 Measurement of Jacket Loss

For all direct BTU metering and Stack Loss Method (SLM) testing options under this test method, the jacket loss of the boiler shall be determined in accordance with Sections 8.2 and 10.2 of ASHRAE Standard 155P. Such jacket loss measurements shall be made during operation of the boiler and shall be made at average boiler supply temperatures of either 180 deg F (non-condensing boilers) or 120 deg F (condensing boilers).

12.4 Measurement of Standby Losses of Boiler(s)and External Thermal Storage

Under all test method options that incorporate thermal storage, the standby loss factor of the thermal storage system, if used, and noted here as $Q_{s\text{-}b\ loss\ --\ thermal\ storage}$ (Btu/hr-deg F), shall be measured in accordance with Section A1.11 of Annex A1.

For a boiler intended to be installed in indoor locations with ambient temperatures in the range of 60 to 80 deg F, the standby loss factor of the thermal storage system shall then be used, together with a delta T of 85 deg F between the external thermal storage and surrounding ambient environment, to calculate a standby loss (Btu/hr) that represents the heat loss of the external thermal storage during operation.

For a boiler and external thermal storage system intended to be installed in an outdoor location, the standby loss factor shall then be used, together with a delta T of 150 deg F between the boiler and surrounding ambient environment, to calculate a standby loss (Btu/hr) that represents the heat loss of the external thermal storage system during operation. If the connected external thermal storage is intended to be installed in a heated, indoor location, however, the standard delta T of 85 deg F shall be used to calculate a standby loss for such thermal storage.

In a manner similar to that used under ASTM E2618-13 for measurement of the standby loss for thermal storage systems, the standby loss factor of the boiler (with or without thermal storage), noted here as $Q_{s\text{-}b\ loss\ –\ boiler}$ (Btu/hr-deg F) shall also be measured. Such measurement shall include the use of

recirculation pumping through the boiler for a minimum of one hour after the cessation of combustion, and prior to the measurement of boiler temperatures. Instead of then waiting four hours for temperature equilibration as specified for thermal storage tanks, however, the measurement of boiler temperatures shall be started immediately upon completion of the one hour of recirculation pumping.

For a non-condensing boiler, the boiler standby loss factor shall then be used, along with a delta T of 105 deg F between the boiler (at 180 deg F temperature) and surrounding ambient conditions, to calculate a standby loss (Btu/hr) that represents the heat loss of the boiler after the completion of a burn cycle.

For a non-condensing boiler with thermal post-purge function, in which the boiler control automatically provides, upon completion of a burn cycle, for continued pumping of supply water into the thermal storage tank, or into a low-temperature hydronic distribution zone, until the boiler temperature has dropped to 140 deg F, or to less than the thermal storage tank average temperature, then the required delta T for calculation of the boiler standby loss may be reduced to 65 deg F.

For a condensing boiler which operates at a temperature of 120 deg F, the required delta T for calculation of the boiler standby loss may be reduced to 45 deg F.

For boilers located in outdoor locations, the prescribed delta T shall be increased by 40 deg F for each of the scenarios described just above.

The total boiler-plus-thermal storage system (if applicable) standby loss (Btu/hr) shall be calculated as the sum of the boiler standby loss (Btu/hr) plus thermal storage system standby loss (Btu/hr).

Option for Use of Jacket Loss as Total Standby Loss Factor

This test method offers the option of using the measured boiler jacket loss of the boiler as the boiler standby loss value, for both manual feed and automatic feed boilers, where there is positive shutoff of exhaust or combustion air during a shutdown mode. This provision is based on the principle that the standby loss of a boiler will occur only through jacket loss if there is no combustion air flow through the boiler.

12.5 Measurement of Efficiency and Emissions of On-cycle Operation During Standby Mode

Manual Feed Boiler Without External Thermal Storage

For manual feed boilers without thermal storage, this test method includes the measurement of efficiency and emissions performance during a standby mode that might occur due to a low heating load. This procedure shall be performed after one hour of operation of the boiler under a Category IV load. The heating load shall be stopped and the boiler shall be allowed to go into a standby mode based on its control hardware and software. Boiler recirculation pumping shall be implemented and shall continue during the standby mode. Measurements of PM 2.5 emissions shall be performed during the standby mode and shall be reported in lb/hr units.

The boiler shall then be allowed to remain in the “off” mode until such time, to be determined by the boiler control system, that the boiler re-activates the blower(s) and/or exhaust/combustion air dampers to start a new combustion cycle.

It shall be permissible for a light heating load (less than 15% of boiler rated capacity) to be applied to the boiler, starting 30 minutes after the beginning of the "off" mode, in order to shorten the period that occurs before the boiler activates a new "on" cycle. Such heating load shall be stopped, however, as soon as the new "on" cycle begins.

The efficiency of the new "on" cycle shall then be determined using the Stack Loss Method, to include the determination of a Stack Loss Method (SLM) Delivered Efficiency, further defined as the Overall Efficiency (%) minus Jacket Loss (%) measured during the "on" cycle. The Overall Efficiency (%) of the "on" cycle, as determined under this procedure, shall be the simple average of efficiency measured during the "on" cycle, based on the simplified assumption of a constant burn rate during such "on" cycle.

Automatic Feed Boiler Without External Thermal Storage

For automatic feed boilers without thermal storage, this test method includes the measurement of efficiency and emissions performance during on/off standby operation due to a low heating load. This procedure shall be performed after one hour of operation of the boiler under a Category IV load. The heating load shall be stopped and the boiler shall be allowed to go into a standby mode. Boiler recirculation pumping shall be implemented and shall continue during the standby mode.

The boiler shall then be allowed to remain in the "off" mode until such time, to be determined by the boiler control system, that the boiler re-activates the blower(s) and/or exhaust/combustion air dampers to start a new combustion cycle.

It shall be permissible for a light heating load (less than 15% of boiler rated capacity) to be applied to the boiler starting 30 minutes after the beginning of the "off" mode, in order to shorten the period that occurs before the boiler activates a new "on" cycle. Such heating load shall be stopped, however, as soon as the new "on" cycle begins.

The efficiency of the new "on" cycle shall be determined using the Stack Loss Method, to include the determination of a Stack Loss Method (SLM) Delivered Efficiency, further defined as the Overall Efficiency (%) minus Jacket Loss (%) measured during the "on" cycle. The Overall Efficiency (%) of the "on" cycle, as determined under this procedure, shall be the simple average of efficiency measured during the "on" cycle, based on the simplified assumption of a constant burn rate during such "on" cycle.

Calculation of Standby Mode Fuel Input

The fuel input (Btu/hr) for standby mode operation of the boiler and thermal storage system shall be calculated as the Total Standby Loss (Btu/hr) divided by the Efficiency of Cyclic Operation (expressed as a decimal fraction) as determined above.

12.6 Calculation of Delivered Thermal Efficiency

Calculation of Direct BTU Metering-based Delivered Efficiency for Boilers Without External Thermal Storage

If the Direct BTU metering method is used for the determination of boiler efficiency, then the delivered efficiency shall be calculated for Burn Categories I, II, III and IV in accordance with ASTM E2618-13.

Calculation of Stack Loss Method (SLM) Delivered Thermal Efficiency for Boilers Without External Thermal Storage

If the Stack Loss Method (SLM) is used for the determination of boiler efficiency, then the Stack Loss Method (SLM) Delivered Thermal Efficiency shall be calculated for Burn Categories I, II, III and IV as the Overall Efficiency (%) minus the Jacket Loss (%).

Calculation of Delivered Thermal Efficiency for Boilers With Full External Thermal Storage

For boilers tested with full thermal storage, the combined boiler plus thermal storage efficiency for Burn Categories I, II, III and IV shall be determined as specified in Section A1.11.4 of Annex A1 of ASTM E2618-13 except that the standby loss of the boiler (Btu/hr), as described earlier in this test method, shall be added to the standby loss of the thermal storage system (Btu/hr) in calculating the combined boiler-plus- thermal storage heat output duration, efficiency and 8 hour heat output rate using equations A1.13, A1.14 and A1.21.

Calculation of Thermal Efficiency for Boilers With Partial External Thermal Storage

For boilers with partial thermal storage, the efficiency of the boiler plus thermal storage system for Burn Categories I, II, III and IV shall be calculated as specified in A2.13 except that 4 hours worth of thermal storage standby loss (Btu/hr) shall be subtracted from the useful output of the boiler and thermal storage system, using the same 85 deg F delta T (boiler temperature minus laboratory ambient temperature) as specified in equation A1.13.

12.7 Alternate Testing Procedure

[To be developed. An alternative testing procedure to be conducted in accordance with EN 303-5 with certain exceptions and additions.]

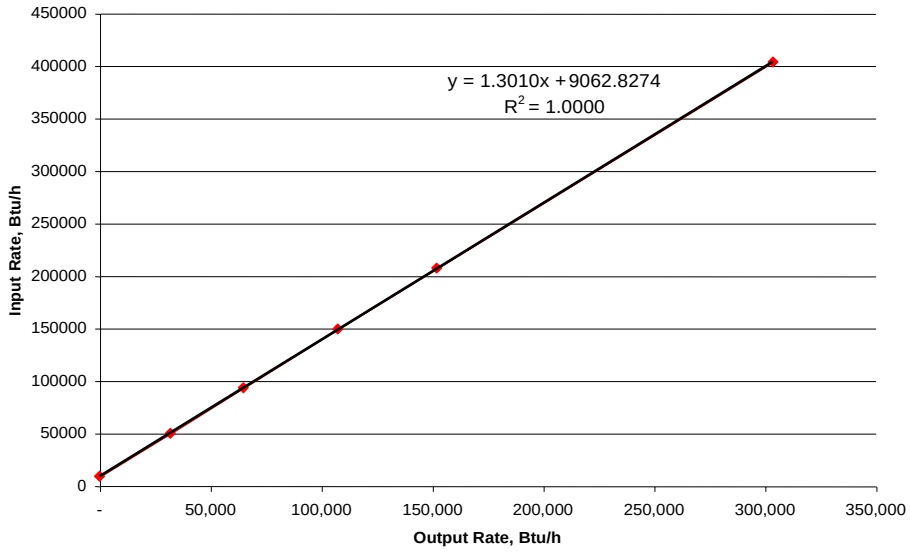
13. Compilation of Results

Input vs Output Graph for Boiler

The test method user shall prepare an Input vs. Output graph for the boiler (if without external thermal storage) or boiler-plus-thermal storage system in a manner similar to that prescribed by ASHRAE Standard 155P. The horizontal axis of the graph shall represent the output (Btu/hr) of the boiler or boiler-plus-thermal storage system over the range of 0 to 100 percent of rated boiler capacity. The vertical axis shall represent the fuel input (Btu/hr) for each burn category plus the standby mode.

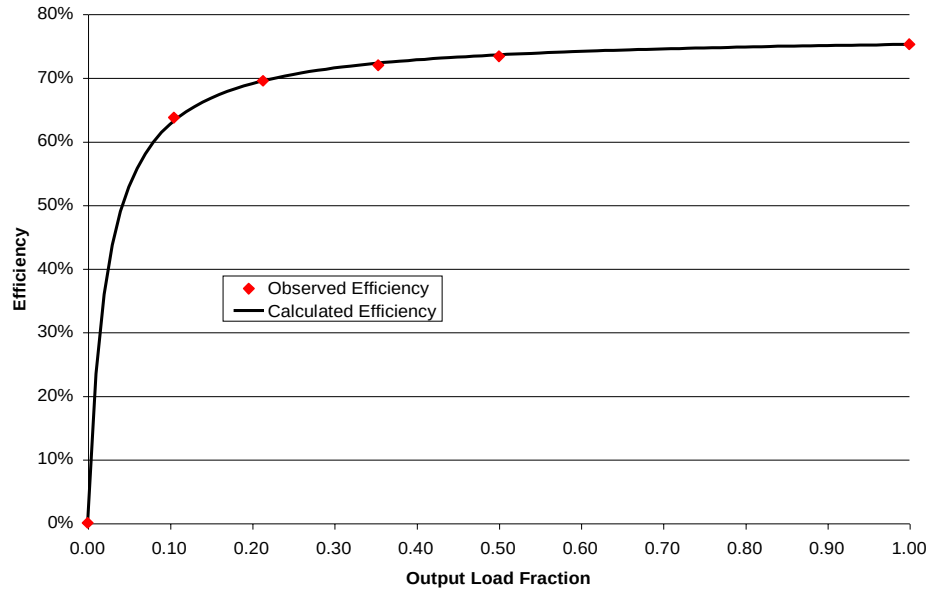
The graph shall include data points for Categories I, II, III and IV based on the test procedures described earlier. Curve fitting shall be used to create a smooth curve of input vs output with the requirement that the y-axis intercept shall be the total standby fuel input as determined earlier in this test method, and further defined again as the standby loss (Btu/hr) for the boiler (if without external thermal storage) or the standby loss (Btu/hr) for the boiler-plus-thermal storage, divided by the efficiency (decimal fraction) measured during on-off cyclic operation. The mathematical formula for the curve in the input vs output graph shall be used in calculating the corresponding input and output values for the table of temperature bins that is described further below.

An example Input vs Output graph from ASHRAE Standard 155P is shown below. The graph shows data for a 300,000 Btu/hr capacity boiler that has a delivered efficiency of 77% at full load and a standby fuel input of 9063 Btu/hr (or about 3% of rated capacity.)



Efficiency Graph for Boiler

The test method user shall then use the Input vs Output graph to plot a graph of efficiency vs load over the range of 0 to 100 percent of boiler rated capacity. The efficiency for each data point shall be calculated as the output divided by the input for such data point.



Annexes A3 and A4 provide optional calculation procedures for using the input vs output information to create tables that show boiler capacity and efficiency information, ASHRAE temperature bin data for the months of October through April in a typical northern US location, and calculated annual fuel consumption in each temperature bin. The tables in the annexes offer a choice of size ratios of boiler capacity to peak heating load ranging from 50% up to 200%. The resulting calculated efficiency value is referred to as the Application Seasonal Efficiency (%) which represents the ratio of thermal output to fuel input over the course of an entire heating season.

14. Report

The report shall have the same general format as that prescribed in Section 14 of ASTM E2618-13 except that the Tables 5 and 6 (Weighting) shall not be used. The primary result of the report shall be the Boiler Input vs. Output and Boiler Efficiency graphs required under Section 13 above. Optional calculations of Application Seasonal Efficiency performed in accordance with Appendix A3 or A4 may be included in the report.

15. Precision and Bias

Reference is made to the same precision and bias limitations that are described in Section 15 of ASTM E2618-13.

16. Keywords

Wood-fired commercial boilers, hydronic boilers, efficiency, emissions.

Annex A1.

Reference is made to Annex A1 of ASTM E2618-13 (Modified Test Method for Wood-fired Hydronic Appliances that utilize Full Thermal Storage) with the exception that the standby loss of the boiler shall be added to the standby loss of the thermal storage in determining efficiency for each output category.

Annex A2.

Reference is made to Annex A2 of ASTMI E2618-13 (Modified Test Method for Wood-fired Hydronic Appliances that utilize Partial Thermal Storage) with the exception that standby loss of the boiler shall be determined at 180 deg F and the standby loss of the external thermal storage shall be determined at the final average temperature observed during the test. The same capacity and efficiency calculations that are incorporated in Annex A1 shall then be used to determine output duration and efficiency values for the combined boiler plus thermal storage system under Category I and II operating conditions.

Annex A3.

Annex A3 includes efficiency calculations for single boiler systems. The pre-formatted calculation procedures include choices of 50%, 100%, 150% and 200% boiler oversizing ratios. The test method user may also use a custom format for other percentages of oversizing ratio.

The table below shows a sample table for a boiler with rated heating capacity of 300,000 Btu/hr used in an application with peak heating load of also 300,000 Btu/hr.

Boiler capacity Btu/hr	300000													
Boiler standby fuel input Btu/hr	9063													
Outdoor temperature deg F	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55
Percent peak heating load	100	92.4	84.7	77	69.3	61.6	53.9	46.2	38.5	30.8	23.1	15.4	7.7	0
Heating output Btu/hr in temp bin	300000	277200	254100	231000	207900	184800	161700	138600	115500	92400	69300	46200	23100	0
Fuel input Btu/hr in temp bin	399363	369700.2	339647.1	309594	279540.9	249487.8	219434.7	189381.6	159328.5	129275.4	99222.3	69169.2	39116.1	9063
Number of hours in temperature bin	10	21	52	86	141	222	346	453	636	798	669	540	427	299
Annual output in temperature bin	3000000	5821200	13213200	19866000	29313900	41025600	55948200	62785800	73458000	73735200	46361700	24948000	9863700	0
Annual fuel input in temperature bin	3993630	7763704	17661649	26625084	39415267	55386292	75924406	85789865	101332926	103161769	66379719	37351368	16702575	2709837
Efficiency in temperature bin	0.751196	0.749797	0.748129	0.746138	0.743719	0.740718	0.736893	0.731856	0.72491739	0.7147532	0.698432	0.6679273	0.59055	0
Annual heating output Btu/yr	4.59E+08													
Annual fuel input Btu/yr	6.4E+08													
Annual efficiency %	71.74975													

The table below shows example fuel input and efficiency values for each temperature bin when the boiler is oversized to a factor of 200% of peak heating load. It should be noted that the annual seasonal efficiency has dropped by several percentage points compared to the base case boiler that is matched to the peak heating load.

Boiler capacity Btu/hr	600000													
Peak heating load Btu/hr	300000													
Boiler standby fuel input Btu/hr	18000													
Outdoor temperature deg F	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55
Percent peak heating load	100	92.4	84.7	77	69.3	61.6	53.9	46.2	38.5	30.8	23.1	15.4	7.7	0
Heating output Btu/hr in temp bin	300000	277200	254100	231000	207900	184800	161700	138600	115500	92400	69300	46200	23100	0
Fuel input Btu/hr in temp bin	408300	378637.2	348584.1	318531	288477.9	258424.8	228371.7	198318.6	168265.5	138212.4	108159.3	78106.2	48053.1	18000
Number of hours in temperature bin	10	21	52	86	141	222	346	453	636	798	669	540	427	299
Annual output in temperature bin	3000000	5821200	13213200	19866000	29313900	41025600	55948200	62785800	73458000	73735200	46361700	24948000	9863700	0
Annual fuel input in temperature bin	4083000	7951381	18126373	27393666	40675384	57370306	79016608	89838326	107016858	110293495	72358572	42177348	20518674	5382000
Efficiency in temperature bin	0.7347539	0.732099	0.728949	0.725204	0.720679	0.715102	0.708056	0.698875	0.68641522	0.66853625	0.6407216	0.5915023	0.4807182	0
Annual heating output Btu/yr	459340500													
Annual fuel input Btu/yr	682201991													
Annual efficiency %	67.332037													

Annex A4.

Annex A4 includes calculation procedures for using test data for individual boilers in estimating the Application Seasonal Efficiency of multiple boiler systems.

[To be developed.]