# STOVE TESTING TOOLBOX – DEFINITIONS AND METRICS

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1. Replications of a stove performance test

   1.1. The fuel consumption of a biomass burning stove is defined as the need to provide new fuel drawn from a supply that is sourced outside the system. Stoves generally do not completely consume all the fuel placed in them during a burn cycle. Some fuel in the form of unburned sticks, dry or torrefied wood and char remains after the completion of a burn cycle. Local practices vary so before making a comparative assessment of performance, the practices that will prevail after the adoption of a new product should be assessed and reproduced during testing.

   1.2. The calculation of the heat content of fuel remaining after a test has proven difficult. As a result the heat value of the partially burned fuel has historically been estimated as being the same as raw moist fuel. The heat value of char remaining has been assigned an arbitrary value based on a chart or experience. In a few cases the value has been measured. The changes in procedure contained herein largely obviate the need for such measurements or estimations and provides a simple yet accurate method of determining the energy in the fuel used to perform a test.

   1.3. When a stove test is conducted with biomass fuel the remaining fuel may not be able to be utilized in the next identical test. In such cases the fuel remaining is ignored and treated as a mechanical loss just as is carbon in the ash.

   1.4. When there is a quantity of partially burned fuel remaining after the test and the supplier claims that it can be used in subsequent fires, the test of performance should be conducted using such fuel remaining from a previous, identical burn cycle. The reference in the descriptions below to a series of identical replications of a burn cycle means that the test will consume, as part of the fuel for the test, that fuel remaining from an earlier cycle. The expectation is that the fuels condition and the amount of char remaining will be approximately the same for identical burns. The heat energy in the fuel and char remaining after each test is applied to a subsequent identical test. Thus the overall demand from the raw fuel supply, factored for the appropriate metrics – usually 'As Received' – is the additional raw fuel that is required to complete the burn cycle and constitutes the Fuel Consumption.

2. Energy content definitions and acronyms

   2.1. Energy content 1.1.0 – the energy content of fuel determined by a theoretical calculation of the net heat liberated by the combustion of the available[1] elements of a fuel from a fully dry condition to a completely oxidised state[2].

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[1] Some forms of the elements are not available, for example carbonates, and cannot be considered 'fuel'.

[2] Including Nitrogen burned to NO, not $NO_2$ because domestic stoves tend to produce very little $NO_2$.

2.2. Energy content 1.2.0 – the Higher Heating Value (HHV) of a fuel determined by a calculation based on the results of a bomb calorimeter test. It includes the latent heat of evaporation of combustion products and the cooling of the gases to 20° C.

2.3. Energy content 1.3.0 – the Lower Heating Value (LHV) of a fuel determined by subtracting from the HHV the latent heat of evaporation[3] of water vapour formed by the of combustion of hydrogen in the fuel.

2.4. Energy content 1.3.1 – the Potential Heating Value (PHV) is equal to the LHV of the dry fraction of a unit mass of damp fuel. At 0% moisture, the LHV = the PHV. It considers the LHV and the moisture in the fuel but not the energy needed to remove that moisture. It is the heat content of a given mass of damp fuel were it to be completely dried before use. It is calculated by factoring the LHV for moisture content only[4]: LHV * (1 - $H_2O$).

2.5. Energy content 1.3.2 – the As Received Value (ARV) is the heat content of a fuel considering the moisture level contained in that fuel. It assumes the fuel moisture will be heated, evaporated and not condensed on the heat receiving vessel. It is calculated by subtracting from the LHV the sum of heat needed to raise the fuel moisture from ambient to the local boiling point plus the latent heat of evaporation of that moisture.[5]

2.6. Energy content 1.3.3 – the As Received Ash-Free heating value (ARAF) is the ARV of a fuel factored for the ash content to give the energy liberated, net, by the complete combustion of one kg of combustible portion of the fuel[6]: ARV/(1 - Ash Content)[7].

2.7. Energy content 1.3.4 – the Condensing Heating Value (CHV) of a fuel is calculated by adding to the AR heat content the latent heat of condensation of the mass of moisture condensed on one or more heat exchangers[8].

3. Fuel Efficiency is a ratio of the heat energy usefully applied divided by the heat available from the raw fuel. There are several ways to report the fuel efficiency because the energy content of the fuel can be variously defined (see above). The stove may be heating a home as well as, or instead of, cooking food. A stove may heat a home directly or indirectly requiring different measurement tools.

3.1. Fuel efficiency 2.1.0 – the ratio, expressed as a percentage, of the heat energy delivered directly into a living space[9] divided by the LHV of all raw fuel consumed during any replication, save the first, in a series of identical burn cycles.[10]

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[3] 2257 Joules per gram of pure water is the latent heat of evaporation and also the latent heat of condensation

[4] Moisture content is the decimal fraction of the dry fuel mass expressed on a Wet Weight Basis.

[5] This is sometimes called the Net Heat available.

[6] It is the heat liberated by burning one kg of fuel when the combustor, retaining all the ash, is on a mass balance when such mass measurements are being taken.

[7] Ash content in this case is expressed as a decimal fraction of the fuel As Received.

[8] It means the hot water or hot air heat exchanger or the cooking vessel(s).

[9] This includes any heat that first passes through a cooking pot into the living space.

[10] In cases where the char produced by the fire can be used as part of the raw fuel in the next replication, the true heat value such char can be assessed. During the next replication, such char remaining must be loaded into the fire and consumed during that replication. Should the accumulation of char reach a point where some must be discarded, it shall be considered a mechanical loss and calculated on a mass per replication basis.

3.2. Fuel efficiency 2.1.1 – the ratio, expressed as a percentage, of the heat energy delivered directly into a living space[9] divided by the PHV[11] of all raw fuel consumed during any replication, save the first, in a series of identical burn cycles.[12]

3.3. Fuel efficiency 2.1.2 – the ratio, expressed as a percentage, of the heat energy delivered directly into a living space[13] divided by the ARV of all raw fuel consumed during any replication, save the first, in a series of identical burn cycles.[14]

3.4. Fuel efficiency 2.2.0 – the ratio, expressed as a percentage, of the heat energy delivered[15] directly or indirectly into one or more cooking vessels[16] on a stove divided by the LHV of all raw fuel consumed during any replication, save the first, in a series of identical burn cycles.[17]

3.5. Fuel efficiency 2.2.1 – the ratio, expressed as a percentage, of the heat energy delivered directly or indirectly into one or more cooking vessels on a stove divided by the PHV of all raw fuel consumed during any replication, save the first, in a series of identical burn cycles.[15]

3.6. Fuel efficiency 2.2.2 – the ratio, expressed as a percentage, of the heat energy delivered directly or indirectly into one or more cooking vessels on a stove divided by the ARV of all raw fuel consumed during any replication, save the first, in a series of identical burn cycles.[15]

3.7. Fuel efficiency 2.3.0 – the ratio, expressed as a percentage, of the sum of the heat energy delivered indirectly into a living space and directly or indirectly into one or more cooking vessels on a stove divided by the LHV of all raw fuel consumed during any replication, save the first, in a series of identical burn cycles.

3.8. Fuel efficiency 2.3.1 – the ratio, expressed as a percentage, of the sum of the heat energy delivered indirectly into a living space and directly or indirectly into one or more cooking vessels on a stove divided by the PHV of all raw fuel consumed during any replication, save the first, in a series of identical burn cycles.

3.9. Fuel efficiency 2.3.2 – the ratio, expressed as a percentage, of the sum of the heat energy delivered indirectly into a living space and directly or indirectly into one or more cooking vessels on a stove divided by the ARV of all raw fuel consumed during any replication, save the first, in a series of identical burn cycles.

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[11] The fuel may be dried before burning using the stove. In such a case assessing the fuel as it enters the home instead of as it enters the fire can give a misleading performance rating.

[12] Where the char produced by the fire cannot be used as part of the raw fuel in the next replication, such char is considered a mechanical loss. Where the char and partially burned fuel remaining are considered to be fuel for the subsequent replications, the initial replication is ignored and a subsequent test performed using the fuel remaining from the first. In all cases, the raw fuel drawn per cycle from the supply is the fuel consumption metric.

[13] This includes any heat that first passes through a cooking pot into the living space.

[14] When the char produced by the fire can be used as part of the raw fuel in the next replication, the true heat value of such char can be assessed and recorded. During the next replication, such char remaining must be loaded into the fire and consumed during that replication. Should the accumulation of char reach a point where some must be discarded, it shall be considered a mechanical loss and the heat value added to the fuel used on an average replication basis.

[15] The thermal mass of the pot and lid (Cp●mass) shall be considered in the 'heat received' metric.

[16] A cooking vessel might be a hot plate such as a 'plancha'.

[17] May be conducted simultaneously with Fuel efficiency 2.1.x

4. Energy efficiency is a ratio of the heat energy usefully applied divided by the net heat actually available. There are several ways to report the energy efficiency because the energy available can be variously defined. As with the Fuel Efficiency, the stove may be heating a home, cooking something, or both. A stove may heat a home directly or indirectly requiring different measurement tools. The energy efficiency metric is widely used to design stoves as it defines the performance of the fire in relation to the stove-pot combination.

    4.1. Energy efficiency 3.1.0 – the ratio, expressed as a percentage, of the heat energy delivered directly into a living space[18] divided by the ARV, factored for char burned and/or produced, of the fuel consumed during any replication, save the first, in a series of identical burn cycles.
    4.2. Energy efficiency 3.1.1 – the ratio, expressed as a percentage, of the heat energy delivered directly into a living space[18] divided by the ARV, factored for char burned and/or produced and for combustion inefficiencies[19] of the fuel consumed during any replication, save the first, in a series of identical burn cycles. This is the same as the space heating efficiency calculated using the Siegert Formula[20].
    4.3. Energy efficiency 3.2.0 – the ratio, expressed as a percentage, of the sum of the heat energy delivered directly or indirectly into one or more cooking vessels on a stove divided by the ARV, factored for char burned and/or produced, of the fuel consumed during any replication, save the first, in a series of identical burn cycles.
    4.4. Energy efficiency 3.2.1 – the ratio, expressed as a percentage, of the sum of the heat energy delivered directly or indirectly into one or more cooking vessels on a stove divided by the ARV, factored for char burned and/or produced and for combustion inefficiencies of the fuel consumed during any replication, save the first, in a series of identical burn cycles.[21]
    4.5. Energy efficiency 3.3.0 – the ratio, expressed as a percentage, of the sum of the heat energy delivered indirectly into a living space and directly or indirectly into one or more cooking vessels on a stove divided by the ARV, factored for char burned and/or produced, of the fuel consumed during any replication, save the first, in a series of identical burn cycles.
    4.6. Energy efficiency 3.3.1 – the ratio, expressed as a percentage, of the sum of the heat energy delivered indirectly into a living space and directly or indirectly into one or more cooking vessels on a stove divided by the ARV, factored for char burned and/or produced and for combustion inefficiencies of the fuel consumed during any replication, save the first, in a series of identical burn cycles.

    Special Cases

    4.7. Energy efficiency 4.1.0 – the hot stove, high power, water evaporation measurement is a proxy for the heat transfer efficiency. It is the ratio, expressed as a percentage, of the sum of the

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[18] This includes any heat that first passes through a cooking pot into the living space.

[19] Includes carbon-monoxide, hydrogen, $H_2S$, particulate matter or anything not fully combusted.

[20] The Siegert Formula calculates the loss of heat from a living space in which a stove in installed using fuel-specific constants, two temperatures and the CO concentration.

[21] Except for the use of fuel remaining from pervious fires, this is the closest to the 'efficiency' metric calculated by the GACC WBT 4.2.1.

heat energy delivered directly or indirectly into one or more cooking vessels on a hot stove divided by the ARV of the raw fuel consumed, factored for char burned and/or produced and for combustion inefficiencies of the fuel consumed during any replication, save the first, in a series of identical burn cycles. The rating gives the expected continuous cooking or heating power for a stove operated for extended periods without pause. It ignores the influence of the thermal mass of the stove. The heat transfer analysis commences when the stove body is hot, as shown by a constant calculated heat transfer value which may include part of the water heating portion of the cycle provided there is no evidence (reduced values) of the influence of the thermal mass. It is a sensitive test that measures the influence of changes in stove architecture or its relationship with the pot or method of operation.

4.8. Energy efficiency 4.2.0 – the cold start, high power, medium power and low power heat transfer efficiency is task-based. During the test a series of pots of cold water are replaced throughout the burn cycle as the water in each pot reaches 70° C. It is the ratio, expressed as a percentage, of the sum of the all the heat energy delivered directly or indirectly into all the pots divided by the ARV of the raw fuel consumed, factored for char burned and/or produced and for combustion inefficiencies of the fuel consumed during any replication, save the first, in a series of identical burn cycles. This method provides a heterogeneous test result for a range of power levels while simultaneously demonstrating the effect of the thermal mass of the stove. The power levels chosen for this test can be arbitrary or represent documented cooking or heating cycles.