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RE: Efficiency and Lower vs. Higher Heating Value of Fuel.

Dear Tom:

I'm am writing to provide information that I hope will clarify the issue of efficiency as it relates to solid fuel appliances and eligibility for tax rebates based on heating efficiency. As I understand the recently enacted legislation, there is a requirement that eligible appliances be at least 75% efficient. I also understand that this efficiency was selected based on rated efficiencies of European appliances. Since Europe uses the "Lower" or "Net" heating value of the fuel in calculation of efficiencies, and in North America we use the "Higher" or "Gross" heating value, the limit specified needs to be fully understood in determining what specific appliances should be eligible for the incentive.

First, efficiency is defined as Heat Output divided by Heat Input.

$$\varepsilon = \frac{\text{Output}}{\text{Input}} \bullet 100$$

Output is generally determined by a stack loss process or direct measurement which yields identical results regardless of whether the Higher or Lower Heating Value of the fuel is used to determine the input.

The difference between the Higher and Lower Heating value of a fuel is essentially the heat involved in converting water that is created in combustion from liquid to gaseous state. This "heat of vaporization" is about 1030 Btu/lb[1]. Lower heating value does not include this energy while the higher heating value does. In determining efficiency the Input is derived by multiplying the dry weight of the fuel burned by its heating value. Obviously, if the higher heating value is used, the fuel weight is

[1] Literature sources for "heat of vaporization of water" report varying values in a range of 970 to 1060 Btu/lb. 1030 Btu/lb is equivalent to the value specified in ASTM E711.

multiplied by a larger number than when lower heating value is used and thus the denominator in the efficiency equation is larger and the efficiency is therefore lower.

The standard method for determining solid fuel heating value is ASTM E711. This test directly measures the fuels Higher Heating Value. Per this test method, the Lower Heating Value is determined by calculation based on the hydrogen content of the fuel. Since the hydrogen is converted to water in combustion, this is a straight forward process. The formula (in inch-pound units) is:

$$\mathrm{LHV} = \mathrm{HHV} - 10.3\left(\%\mathrm{H} \bullet 9\right)$$

Where %H is the hydrogen content of the fuel by weight.

In wood fuels, hydrogen content typically averages about 6.5% with a range of 6 to 7%. Higher heating values are around 8500 to 8700 Btu/lb of dry wood for commonly used fuel woods. Thus, for a typical efficiency test, the Higher and Lower Heating Values are: HHV = 8600 Btu/lb and LHV = 8600 – 10.3 (6.5 x 9) = 7997 Btu/lb.

Thus the efficiency calculated using the Higher Heating Value is always about 93% of the efficiency calculated from the Lower Heating Value. That is:

Efficiency HHV = Efficiency LHV X 0. 93

Example: An appliance produces a total heat output of 75,000 Btu's through consumption of 12.5 dry pounds of wood. The efficiency based on Lower Heating Value is:

$$\varepsilon = \frac{75{,}000}{12.5 \bullet 7997} \bullet 100 = 75\%$$

The efficiency based on Higher Heating Value is:

$$\varepsilon = \frac{75{,}000}{12.5 \bullet 8600} \bullet 100 = 69.8\%$$

This means that since the intent of the wood stove incentive is that appliances be at least 75% efficient based on the Lower Heating Value, this is mathematically identical as requiring at least 69.8% efficiency based on the Higher Heating Value.

Why is this discussion important? In North America virtually all fuel burning heating appliances have their efficiencies determined based on Higher Heating Values. The use of Lower Heating Values carries an implicit assumption that the latent heat of water from combustion is unrecoverable. This effectively defines 100% efficiency as recovery of all sensible heat (that is, the energy required to heat products of combustion from the ambient temperature to the temperature at which they exit the heated space) without recovering any latent heat through condensation of water. Since it is technically feasible – and, in fact, common in gas fired appliances – to recover a significant portion of this latent heat, the use of Lower Heating Value in efficiency calculations inevitably leads to the potential to claim efficiencies of greater than 100%. This is an obvious violation of one of the fundamental laws of thermal dynamics. No energy conversion process can produce more heat as an output than is available as an input.

Practically speaking, it is generally undesirable to recover latent heat from wood burning appliances since this would require capture and drainage of liquid water. Further, naturally drafted appliances (those that depend on draft created by relatively hot flue gases to draw combustion air and exhaust products of combustion) cannot be operated with flue gas temperatures low enough to condense water and recover latent heat. This results in an effective upper limit of approximately 82%[2] on heating efficiency based on the Higher Heating Value of the fuel.

Conclusion:

Since it seems clear that the intent of the solid fuel appliance incentive program recently enacted by congress is to apply to appliances with efficiencies of **75%** or higher based on **Lower Heating Values**, the program eligibility requirement should be restated based on the **Higher Heating Value** of the fuel to require a minimum of **69.8%** efficiency. This does not in any way constitute a reduction of the intended minimum efficiency requirement. It will allow for efficiency ratings to be consistent with existing North American practice and consistent with the laws of physics and accepted definitions of 'heating efficiency'. It will also eliminate an "apples-to-oranges" comparison issue when efficiencies of appliances are compared across fuel types such as wood-to-gas, wood-to-oil or wood-to-coal.

Sincerely,
Rick Curkeet, PE
Chief Engineer – Hearth Products

[2] This value includes additional latent heat losses from fuel moisture content and sensible losses required to maintain flue gas temperatures above the dew point.