



**Addendum to the report entitled “Verification of Emission Factors U.S. EPA Certified Wood Heaters” prepared by OMNI Environmental Services, Inc. for Environment Canada July 28, 2009**

**Comparisons of Overall Efficiencies as Measured by CAN/CSA B415.1-00 to the Draft Standard CAN/CSA B415.1-2009**

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## **1. Introduction**

Under contract with Environment Canada, OMNI Environmental Services, Inc. (OMNI) calculated the efficiencies from the report entitled “Verification of Emission Factors U.S. EPA Certified Wood Heaters” using the efficiency calculations in the newly released draft standard CAN/CSA B415.1-2009. Environment Canada provided the Excel spreadsheet used to calculate efficiencies by Section 13.6 (previously Section 13.9) in an email from Victor Li on July 22, 2009. The formulas in the provided Section 13.6 spreadsheet were not checked for accuracy against B415.1-2009. OMNI used the same spreadsheets created for the Verification of Emission Factors study, with appropriate changes to calculate the Annex B (previously Annex D), Total Combustible Carbon (TCC) efficiencies.

## **2. Results and Discussion**

Table 1 and 2 contain efficiency results per the calculations of B415.1-00 and Tables 3 and 4 contain efficiency results per the calculation of B415.1-2009. For comparison purposes, all results that changed from the original B415.1-00 calculations are bold and italicized in the results tables. Figures 1 and 2 show a comparison of overall efficiencies from each of the test runs calculated with B415.1-00 and Figures 3 and 4 shows a comparison of overall efficiencies calculated with B415.1-2009.

There were some characteristics of the data set that did not change by using B415.1-2009. All the low/cold test runs are still not applicable to the efficiency calculations due to multiple fuel additions. Additionally, all the efficiencies of Annex B (previously Annex D), TCC with measured fuel properties (in lieu of default values) did not change.

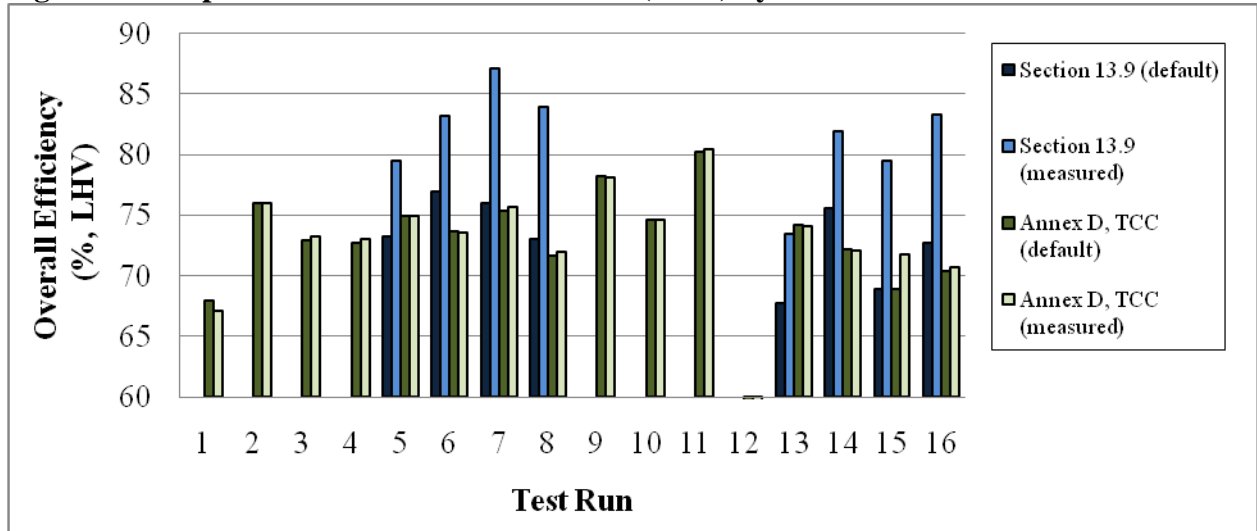
There were some characteristics of the data set that did change by using B415.1-2009. Efficiencies calculated by Section 13.6 (previously Section 13.9) with measured fuel properties changed the most with a change of over 10 percentage points. Others like Annex B (previously Annex D) with default fuel properties changed less than one percentage point.

There are a few details in B415.1-2009 worth discussing in reference to the Verification of Emission Factors study. In terms of the Annex B (previously Annex D), TCC efficiency calculations, the only change made to the efficiency calculations was the value of the default fuel property (carbon and hydrogen). In terms of Section 13.6 (previously Section 13.9) efficiency calculations, many changes were made. One major change is in Section 13.6.5 (previously Section 13.9.4) Fuel Constituents Ratio where the levels of carbon, hydrogen and oxygen are calculated during the intervals. B415.1-00 uses the initial default value of constituents plus an equation to estimate the changes to the constituents as the wood burned. B415.1-2009 uses only the initial value of the constituent and assumes it is constant throughout the burn cycle. This change appears to have made some progress on one of the major issues in B415.1-00 efficiencies, negative calculated “hydrocarbon” values. However, all but one of the tests still have negative interval “hydrocarbon” values and one of the total “hydrocarbon” losses (sum of the intervals) is still negative. The majority of the tests now have total “hydrocarbon” results with positive values (where as, in B415.1-00 many of the total losses were tens of thousands of KJ negative). There are a number of other changes made to the efficiency calculations of Section 13.6 (previously Section 13.9). However, a complete inventory of what changed and how those changes affect overall efficiencies is beyond the scope of this addendum.

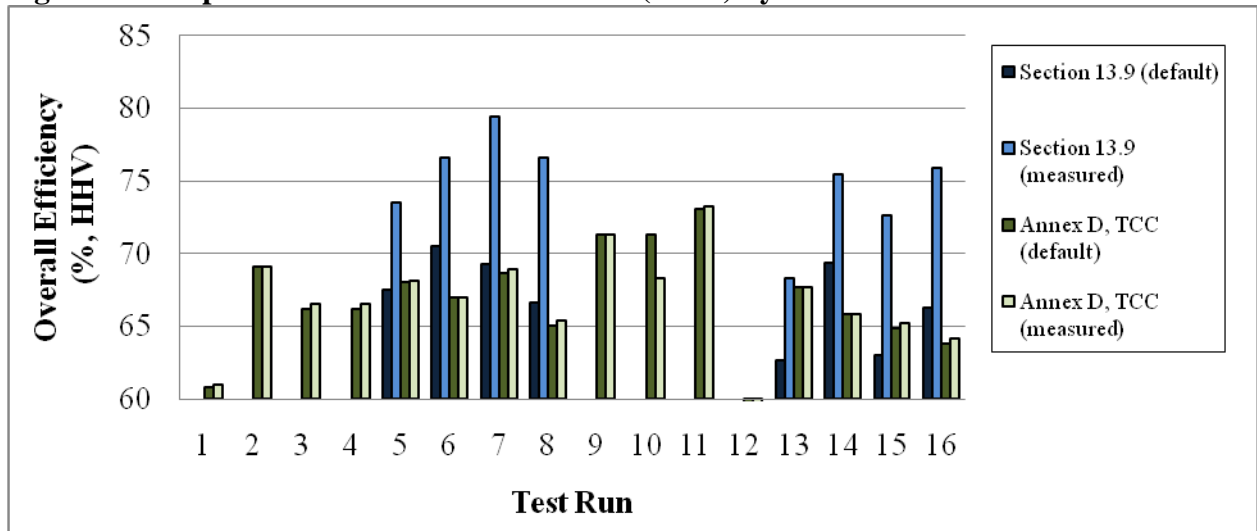
### 3. Summary

By applying the calculations in the draft standard B415.1-2009 to the Verification of Emission Factors data set, some overall efficiencies remained unchanged, while some changed moderately and some changed considerably. Overall, efficiencies considered the most realistic and reported in the average results tables, as well as, discussed in the summary section of the original study were unchanged. Therefore, all of the statements made in the summary section of original study concerning efficiencies are still valid with the changes made in B415.1-2009.

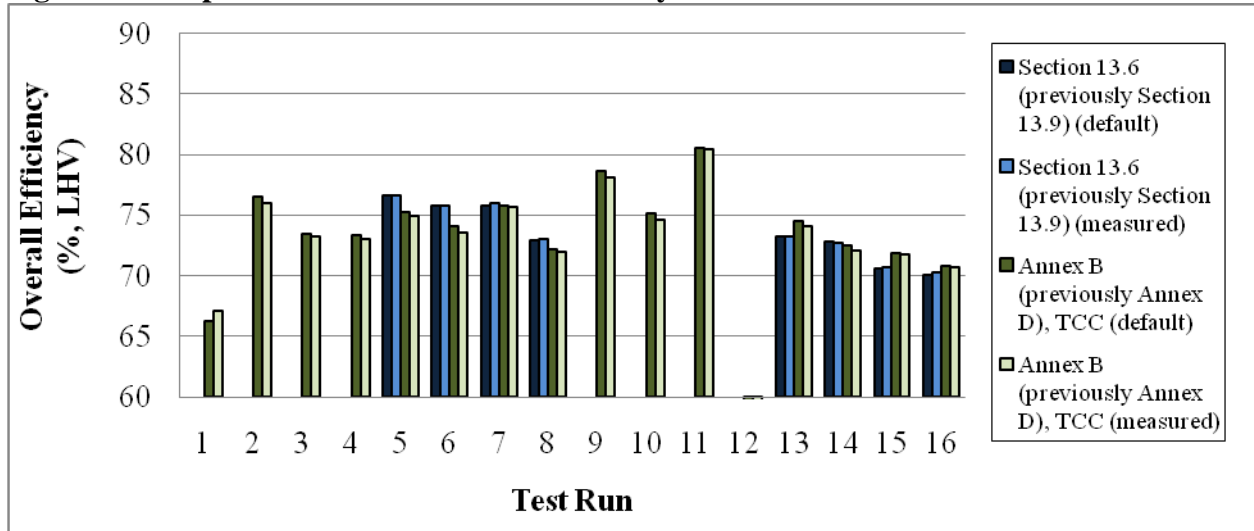
**Figure 1. Comparison of Overall Efficiencies (LHV) by CSA-B415.1-00.**



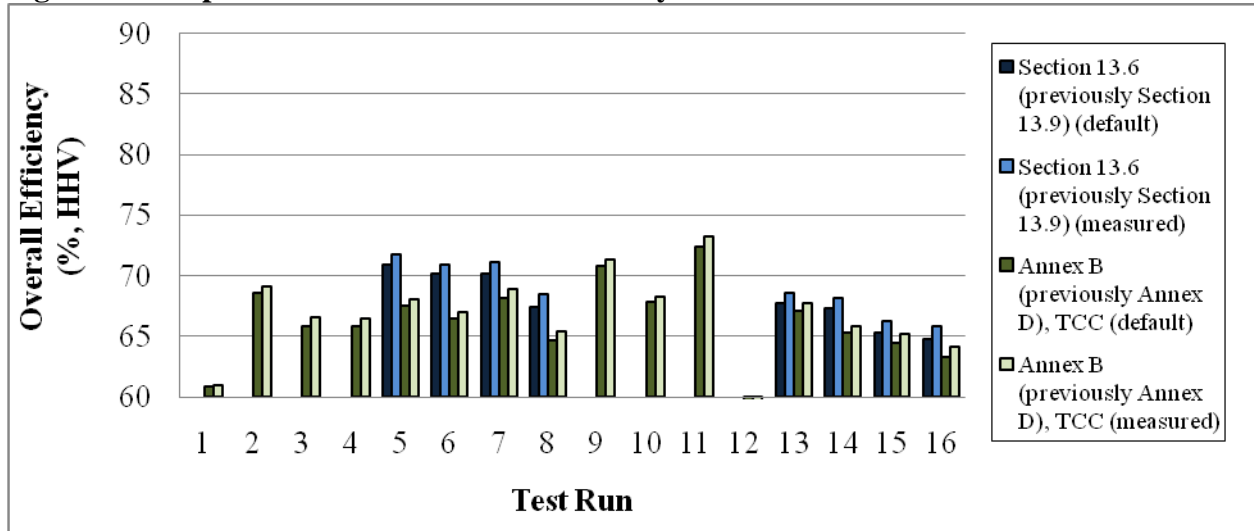
**Figure 2. Comparison of Overall Efficiencies (HHV) by CSA-B415.1-00.**



**Figure 3. Comparison of Overall Efficiencies by Draft Standard CSA-B415.1-2009.**



**Figure 4. Comparison of Overall Efficiencies by Draft Standard CSA-B415.1-2009.**



**Table 1. Wood Heater Efficiencies (%), Higher Emissions Heater**

Overall Efficiency per CSA B415.1-00	Softwood Low/Cold	Softwood Low/Cold Duplicate	Hardwood Low/Cold	Hardwood Low/Cold Duplicate	Softwood High/Hot	Softwood High/Hot Duplicate	Hardwood High/Hot	Hardwood High/Hot Duplicate
Test Run	1	2	3	4	5	6	7	8
Section 13.9 (HHV, default fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	67.50*	70.47*	69.25*	66.68*
Section 13.9 (LHV, default fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	73.30*	76.97*	75.98*	73.06*
Section 13.9 (HHV, measured fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	73.55*	76.58*	79.42*	76.62*
Section 13.9 (LHV, measured fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	79.49*	83.25*	87.14*	83.95*
Annex D, Total Combustible Carbon (HHV, default fuel properties)	61.01	69.12	66.21 <sup>†</sup>	66.18 <sup>†</sup>	68.09	67.02	68.66 <sup>†</sup>	65.09 <sup>†</sup>
Annex D, Total Combustible Carbon (LHV, default fuel properties)	67.18	76.04	72.91 <sup>†</sup>	72.75 <sup>†</sup>	74.95	73.64	75.37 <sup>†</sup>	71.66 <sup>†</sup>
Annex D, Total Combustible Carbon (HHV, measured fuel properties)	61.00	69.14	66.54	66.51	68.10	67.02	68.95	65.42
Annex D, Total Combustible Carbon (LHV, measured fuel properties)	67.12	76.01	73.22	73.07	74.92	73.59	75.66	71.99

\*Includes negative “hydrocarbon” and fuel moisture values, see Appendix J of the original study.

HHV-Higher Heating Value of the fuel used in the denominator of the efficiency calculation, assumes that the energy associated with water condensation is available for heating. Higher heating values for the fuel and combustion gases were used in the numerator of the efficiency calculation.

LHV-Lower Heating Values of the fuel was used in the denominator of the efficiency calculation, assumes that the energy associated with water condensation is not available for heating because the water is carried up and out of the stack in the vapor phase. Higher heating values for the fuel and combustion gases were used in the numerator of the efficiency calculation.

<sup>1</sup>na- not applicable, due to modifications in to the fueling protocol some of the interval calculations of Section 13.9 do not apply to the cold start scenarios with multiple fuel additions and therefore are not reported.

<sup>†</sup> Default fuel properties for Douglas Fir used in calculations

**Table 2. Wood Heater Efficiencies (%), Lower Emissions Heater**

Overall Efficiency per CSA B415.1-00	Softwood Low/Cold	Softwood Low/Cold Duplicate	Hardwood Low/Cold	Hardwood Low/Cold Duplicate	Softwood High/Hot	Softwood High/Hot Duplicate	Hardwood High/Hot	Hardwood High/Hot Duplicate
Test Run	9	8	11	12	13	14	15	16
Section 13.9 (HHV, default fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	62.67*	69.35*	62.99*	66.31*
Section 13.9 (LHV, default fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	67.79*	75.63*	68.93*	72.71*
Section 13.9 (HHV, measured fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	68.28*	75.42*	72.64*	75.93*
Section 13.9 (LHV, measured fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	73.51*	81.90*	79.48*	83.26*
Annex D, Total Combustible Carbon (HHV, default fuel properties)	71.33	71.33	73.05 <sup>†</sup>	nd	67.71	65.86	64.91 <sup>†</sup>	63.78 <sup>†</sup>
Annex D, Total Combustible Carbon (LHV, default fuel properties)	78.20	74.64	80.25 <sup>†</sup>	nd	74.17	72.16	68.93 <sup>†</sup>	70.37 <sup>†</sup>
Annex D, Total Combustible Carbon (HHV, measured fuel properties)	71.33	68.31	73.29	nd	67.70	65.85	65.24	64.12
Annex D, Total Combustible Carbon (LHV, measured fuel properties)	78.16	74.59	80.47	nd	74.12	72.11	71.78	70.72

\*Includes negative “hydrocarbon” and fuel moisture values, see Appendix J of the original study.

HHV-Higher Heating Value of the fuel was used in the denominator of the efficiency calculation, assumes that the energy associated with water condensation is available for heating. Higher heating values for the fuel and combustion gases were used in the numerator of the efficiency calculation.

LHV-Lower Heating Value of the fuel was used in the denominator of the efficiency calculation, assumes that the energy associated with water condensation is not available for heating because the water is carried up and out of the stack in the vapor phase. Higher heating values for the fuel and combustion gases were used in the numerator of the efficiency calculation.

<sup>1</sup>na- not applicable, due to modifications in to the fueling protocol, some of the interval calculations of Section 13.9 do not apply to the cold start scenarios with multiple fuel additions and therefore are not reported.

<sup>†</sup> Default fuel properties for Douglas Fir used in calculations

nd-no data due to results that did not pass quality control checks as specified in the method.

**Table 3. Wood Heater Efficiencies (%), Higher Emissions Heater**

<b>Overall Efficiency per CSA B415.1-2009</b>	<b>Softwood Low/Cold</b>	<b>Softwood Low/Cold Duplicate</b>	<b>Hardwood Low/Cold</b>	<b>Hardwood Low/Cold Duplicate</b>	<b>Softwood High/Hot</b>	<b>Softwood High/Hot Duplicate</b>	<b>Hardwood High/Hot</b>	<b>Hardwood High/Hot Duplicate</b>
<b>Test Run</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>
Section 13.6 (HHV, default fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	<b>70.95*</b>	<b>70.15*</b>	<b>70.14*</b>	<b>67.46*</b>
Section 13.6 (LHV, default fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	<b>76.68*</b>	<b>75.82*</b>	<b>75.81*</b>	<b>72.91*</b>
Section 13.6 (HHV, measured fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	<b>71.80*</b>	<b>70.94*</b>	<b>71.17*</b>	<b>68.44*</b>
Section 13.6 (LHV, measured fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	<b>76.66*</b>	<b>75.75*</b>	<b>75.96*</b>	<b>73.05*</b>
Annex B, Total Combustible Carbon (HHV, default fuel properties)	<b>60.85</b>	<b>68.62</b>	<b>65.83<sup>†</sup></b>	<b>65.82<sup>†</sup></b>	<b>67.49</b>	<b>66.53</b>	<b>68.17<sup>†</sup></b>	<b>64.72<sup>†</sup></b>
Annex B, Total Combustible Carbon (LHV, default fuel properties)	<b>66.23</b>	<b>76.52</b>	<b>73.46<sup>†</sup></b>	<b>73.33<sup>†</sup></b>	<b>75.31</b>	<b>74.07</b>	<b>75.77<sup>†</sup></b>	<b>72.16<sup>†</sup></b>
Annex B, Total Combustible Carbon (HHV, measured fuel properties)	61.00	69.14	66.54	66.51	68.10	67.02	68.95	65.42
Annex B, Total Combustible Carbon (LHV, measured fuel properties)	67.12	76.01	73.22	73.07	74.92	73.59	75.66	71.99

\*Includes negative “hydrocarbon” values (see results and discussion section).

HHV-Higher Heating Values of the fuel was used in the denominator of the efficiency calculation, assumes that the energy associated with water condensation is available for heating. Higher heating values for the fuel and combustion gases were used in the numerator of the efficiency calculation.

LHV-Lower Heating Values of the fuel was used in the denominator of the efficiency calculation, assumes that the energy associated with water condensation is not available for heating because the water is carried up and out of the stack in the vapor phase. Higher heating values for the fuel and combustion gases were used in the numerator of the efficiency calculation.

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<sup>†</sup> Default fuel properties for Douglas Fir used in calculations

**Table 4. Wood Heater Efficiencies (%), Lower Emissions Heater**

<b>Overall Efficiency per CSA B415.1-00</b>	<b>Softwood Low/Cold</b>	<b>Softwood Low/Cold Duplicate</b>	<b>Hardwood Low/Cold</b>	<b>Hardwood Low/Cold Duplicate</b>	<b>Softwood High/Hot</b>	<b>Softwood High/Hot Duplicate</b>	<b>Hardwood High/Hot</b>	<b>Hardwood High/Hot Duplicate</b>
<b>Test Run</b>	<b>9</b>	<b>8</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>
Section 13.6 (HHV, default fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	67.77*	67.34*	65.29*	64.81
Section 13.6 (LHV, default fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	73.25*	72.78*	70.57*	70.04
Section 13.6 (HHV, measured fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	68.59*	68.14*	66.26*	65.83
Section 13.6 (LHV, measured fuel properties)	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	na <sup>1</sup>	73.24*	72.75*	70.72*	70.26
Annex B, Total Combustible Carbon (HHV, default fuel properties)	70.79	67.87	72.38 <sup>†</sup>	nd	67.14	65.32	64.49 <sup>†</sup>	63.33 <sup>†</sup>
Annex B, Total Combustible Carbon (LHV, default fuel properties)	78.64	75.14	80.56 <sup>†</sup>	nd	74.48	72.50	71.88 <sup>†</sup>	70.78 <sup>†</sup>
Annex B, Total Combustible Carbon (HHV, measured fuel properties)	71.33	68.31	73.29	nd	67.70	65.85	65.24	64.12
Annex B, Total Combustible Carbon (LHV, measured fuel properties)	78.16	74.59	80.47	nd	74.12	72.11	71.78	70.72

\*Includes negative “hydrocarbon” values (see results and discussion section).

HHV-Higher Heating Values of the fuel was used in the denominator of the efficiency calculation, assumes that the energy associated with water condensation is available for heating. Higher heating values for the fuel and combustion gases were used in the numerator of the efficiency calculation.

LHV-Lower Heating Values of the fuel was used in the denominator of the efficiency calculation, assumes that the energy associated with water condensation is not available for heating because the water is carried up and out of the stack in the vapor phase. Higher heating values for the fuel and combustion gases were used in the numerator of the efficiency calculation.

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<sup>†</sup> Default fuel properties for Douglas Fir used in calculations

nd-no data due to results that did not pass quality control checks as specified in the method.