Outdoor Wood Boilers – New Emissions Test Data and Future Trends

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ABSTRACT

Outdoor Wood Boiler (OWB) Particulate Matter (PM) emissions were measured with EPA Method 5G in 48 tests done in 2005/2006. The average of the test results are within 10% of the results from eight EPA tests on two OWBs done in 1995. A comparison of the OWB test data to EPA tests of certified woodstoves as actually used by residential owners show that: 1) current OWB PM emissions are in the same range as certified woodstove emissions on a g/kg or lb/MMBtu basis and average 22 to 25 percent higher, and 2) operation of an OWB, which has a larger firebox than a woodstove, at a reduced firing rate approximating that of a woodstove does not produce high emissions. A comparison of polycyclic aromatic hydrocarbon (PAH) data reveals OWB emission rates are similar to, and lower than PAH emission rates for certified woodstoves. Mass emissions from the OWB tests were analyzed with dispersion modeling and the results demonstrate a properly installed OWB can operate year-round next to a residence and fully comply with the new $PM_{2.5}$ air quality standards. OWB manufacturers have worked with EPA to develop a voluntary Outdoor Wood-fired Heater (OWH) Program with a Phase 1 emissions target of 0.6 lb/MMBtu, representing a 60% PM emissions reduction. The Program uses EPA Draft Method 28-OWHH that incorporates EPA Method 5G. The Phase 1 emissions goal is more stringent than the current NSPS for non-catalytic woodstoves. Manufacturers will offer OWH Phase 1 Qualified Models later in 2007, and those units will have lower emissions, lb/MMBtu basis, than certified woodstoves and OWBs now in use.

INTRODUCTION

Concerns have been in by NESCAUM[1] about the emissions from Outdoor Wood Boilers (OWBs). These residential furnaces are designed to heat an entire home and in many cases replace multiple indoor wood stoves, which are typically sized to a heat a single room. Both certified woodstoves and OWB are bulk-loaded with cordwood. In both, an air damper regulates the combustion process (manual in a woodstove, automatic in an OWB tied to a thermostat), and heat transfer is through the firebox surface to either the surrounding room (in the case of a woodstove) or a surrounding water reservoir (in the case of an OWB). The usable heat produced by a stove or furnace is related to the quantity of wood burned and the heat provided to a home, thus the appropriate measure of emissions is the mass of PM per unit of fuel burned (g/kg-dry) or heat input (lb/MMBtu). Emission limits stated in lb/MMBtu are common in stationary source air permits and regulations, and reflect the fact that sources that burn more fuel produce more energy and do more work. By contrast, NESCAUM[2] compares OWB to woodstoves using g/hr emissions, an incorrect approach that fails to recognize the fact an OWB delivers 3-10 times more heat than a woodstove. An analogy to this comparison is if someone compared the hourly emissions (g/hr) of a Honda that drove 40 miles to those of a Cadillac that drove only 4 miles and complained that the Honda had 10 times the emissions of the Cadillac without disclosing that the Honda had traveled 10 times farther. In this paper, emissions data are presented using all three measures: g/kg, lb/MMBtu heat input and g/hr.

Particulate Matter (PM) and Polycyclic Aromatic Hydrocarbon (PAH) emission test data for OWB and EPA-certified woodstoves as they are actually operated in people's homes were collected and compared. The objectives were: 1) to compare OWB and woodstove emissions on a comparable heat input basis, 2) to examine the variation in OWB emissions over a wide range of burn rates and during unit cycling, and 3) to analyze the mass emissions from the OWB tests with EPA's AERMOD dispersion model to determine if a properly installed OWB, from those now available on the market, will comply with the new 24-hour $PM_{2.5}$ air quality standard of 35 $\mu g/m^3$. The maximum $PM_{2.5}$ ground-level concentrations for a properly-installed OWB meeting the EPA Phase 1 emissions target of 0.6 lb/MMBtu are also determined. All of the test data presented in this paper were collected using EPA Method 5G or other comparable EPA test methods. The one OWB emission test published by NESCAUM[3] is reviewed and compared to the other test data.

BODY

Particulate Matter Emissions Data for OWBs

The Particulate Matter (PM) emissions from six current-model OWBs were measured with EPA Method 5G in 48 tests done in 2005/2006[4,5,6.7]. These emissions are compared to eight Method 5G tests done on two OWBs in 1995 by U.S. EPA[8], and to tests done on 16 woodstoves performed in 1999 by EPA[9]. The goal was to use PM test data that represent how wood-burning appliances are actually used in a residential setting. The test data are compared in Figures 1 through 6. The mean PM emission rate for the 56 OWB tests is 12.2g/kg (1.44 lb/MMBtu).

A woodstove is designed to heat a single room and provides an average heat output of 11,000 Btu/hr.[9] By contrast, OWBs are sized to provide heat output in the rate of 25,000 to 100,000 Btu/hr, with a typical heat output rate around 50,000 Btu/hr. The "rated" heat output of these outdoor wood furnaces listed by manufacturers are often much higher, and the units are seldom used for an extended period of time at the rating. The peak heating-load on a cold January day (-20 F) for a 2,800 square foot home in a Northern State with good insulation would be approximately 55,000 Btu/hr. Thus, a typical OWB is designed to heat an entire home under all weather conditions. Dairy farmers use larger sized OWBs to heat their barns or other buildings.

Test Data for Wood Furnaces A, B and C

In the OMNI-Test Laboratories report[4], three OWBs from three different manufacturers (labeled A, B and C in Figures 1,2 and 3) were tested twice for emissions at each of two heat draw rates, corresponding to 11,000 Btu/hr ("low fire rate"), the average heat output of a wood stove, and 22,000 Btu/hr ("high fire rate"), twice that of a woodstove. These test points represent the condition where an OWB is fired at a reduced firing rate relative to its design capacity. The heat input rates during the tests varied from 23,000 to 54,000 Btu/hr. A total of 12 tests were done. Emissions were measured using EPA Method 5G (dilution tunnel sampling) with dual glass fiber filter trains, and the OWB were fired with a mixture of hard and soft cordwood having moisture contents of 20-25% (dry basis). The water circulation rate through the appliance was controlled to target the heat withdrawl rate, and mimic the cycling on and off of the air damper in a residential installation that controls the fire in the OWB.[11]

An examination of Figures 1 and 2 show the 12 test points labeled A, B and C are clustered around the previously-stated average emission rate for all 56 OWB tests of 12.1 g/kg and 1.44 lb/MMBtu, and thus very low firing of an OWB does not produce higher than normal emission rates. In Figure 3, mass emissions on a g/hr basis are at the lower of the scale reflecting the low firing rate during these tests and the fact less heat is being output. The mass emission rates from the low fire (11,000

Btu/hr) output) averaged 20.4 g/hr and the 22,000 Btu/hr output rate averaged 32.4 g/hr. The overall average on these lower output tests was 26.4 g/hr and is in the range of emissions from indoor wood stoves as tested by EPA in the home (discussed below).

Test Data for Wood Furnaces D, E and F

In the series of three Intertek Testing Services emission tests,[5,6,7] EPA Method 5G with dual filter trains was also used, and each of the three OWBs were fired with either dimensional oak wood or cordwood having moisture contents of 20-30% (dry basis). The test results are labeled D, E and F in Figures 1-3, where D represents the OWB named Rick in the test report, E represents Brian, and F is the OWB called Dan. For each OWB, 12 emission tests were done, six each at a target "low fire rate" and a "high fire rate". Within each group of six tests, three were done using cordwood and three with dimensional oak. The test results reveal no significant difference in emissions related to the two types of wood fuel. The water circulation rate through the appliance was controlled to target the heat withdrawl rate. While it is assumed that the units were cycled on and off to maintain the target heat withdrawl rate, this could not be confirmed with Intertek.

OWB Rick[6] was operated at higher than normal heat output rates, and the "high fire rate" is thought to be close to 100% of rated capacity with heat output centered on 100,000 Btu/hr, and the "low fire rate" targeting 50,000 Btu/hr heat output, the usual upper limit for consumer operation. The test points for OWB Rick (labeled D in Figures 1-3) stand out in Figures 1-3 because of the high heat input rate (124,000 to 241,000 Btu/hr) and consequently high mass emissions (42 to 116 g/hr). While the PM emission rates at these very high firing rates, 7 to 14 g/kg, are in the same range as emission tests at lower firing rates, operation of an OWB at close to its rated capacity for an extended period of time is unusual. The wood load was consumed in 4.3 hours or less in these tests. Consumers normally do not operate at this high burn rate; thus, the D-high fire rate data points should not be viewed as representative of OWB operation.

The Intertek tests on OWB Brian[5] resulted in the fuel load lasting from 5 to 6 hours at the "high fire rate" targeting 50,000 Btu/hr output; the mass emissions averaged 69.1 g/hr. The fuel load for the "low fire rate" representing 25,000 Btu/hr output lasted 9 to 10 hours and resulted in mass emissions averaging 58 g/hr. Excluding the one significant outlier, the emissions averaged 47.4 g/hr. The test points for OWB Brian (labeled E in Figures 1-3) show relatively consistent emission results in the 7 to 15 g/kg range except for one outlier with an emission rate of 25 g/kg (2.98 lb/MMBtu) and mass emissions of 111 g/hr that occurred under the lower firing rate with dimensional oak wood. The two identical tests of this unit (same fuel and heat input rate) recorded half this emission rate. No explanation for the outlier could be found in the test report.

The Intertek tests on OWB Dan[7], a smaller sized OWB, was operated more consistent with consumer use and the fuel load lasted 7 to 8 hours for the high burn rate and 9 to 11 hours for the low burn. The "high fire rate" targeted 24,000 Btu/hr heat output and the "low fire rate" produced 12,000 Btu/hr, a rate similar to that from a woodstove. The test points for OWB Dan (labeled F in Figures 1-3) reveal slightly higher emissions ranging from the 9 to 17 g/kg, and the average mass emissions were 43.8 g/hr for the high fire rate and 39.4 g/hr for the low fire rate.

Test Data for Wood Furnaces G and H

EPA performed PM emission tests[8] on two OWBs using Method 5G and a XAD sorbent trap on the sampling trains to capture PAH (discussed below). The low and high fire rates for the two OWBs labeled G and H in Figures 1-3 represent target heat outputs of 17,000 and 25,000 Btu/hr. The furnaces were fueled with cordwood having moisture contents of 10-25% (dry basis). The water circulation rate through the appliance was controlled to target the heat withdrawl rate, and mimic the cycling on and off of the air damper in a residential installation. For furnace G, the cycle was typically 8 minutes with the damper open followed by 30-60 minutes with it closed.

The PM emission rates for OWB G ranged from 9 to 13 g/kg and averaged 10.7 g/kg. EPA notes "several data quality problems" with the tests of furnace H that "may have compromised the data quality"[12]. The PM emission rates for OWB H were higher than those for OWB G and ranged from 15 to 17 g/kg except for one outlier with an emission rate of 25 g/kg (2.96 lb/MMBtu) and mass emissions of 143 g/hr. Despite the fact the EPA test report provides reasons for excluding this data point, it has been included in the Figures and overall emission statistics.

Analysis of all 56 Tests

In total, the 56 Method 5G emission tests on eight OWBs provide data for a very wide range of heat outputs from 11,000 to 110,000 Btu/hr and corresponding heat input rates of 23,000 to 242,000 Btu/hr (1.3 to 13 kg-dry/hour of wood firing). These data represent the wide variety of consumer uses and firing rates for OWBs. The mean PM emission rate for the 56 tests is 12.1 g/kg (1.44 lb/MMBtu heat input), and the mean mass emissions are 53 g/hr with a typical heat input rate of 93,000 Btu/hr. Figures 1 and 2 reveal that PM emission rates (g/kg or lb/MMBtu) do not vary for wood burn rates that span an entire order of magnitude, and that the average emission rate of 12 g/kg applies across the full range of heat inputs. These figures also show that operation of an OWB, which has a larger firebox than a woodstove, at a reduced firing rate approximating that of a woodstove does not produce high emissions. Figure 3 establishes that OWBs with higher mass emissions in g/hr emit more PM simply because of a greater fuel firing rate and not because the emission rate (g/kg) is higher.

Comparison to NESCAUM Emission Test

NESCAUM claims that a typical OWB has mass emissions of 161 g/hr from a single test done in June 2005.[21] Two significant errors were made by NESCAUM that invalidate their test results. First, the OWB was improperly fueled with green wood[22], and thus it produced excess smoke. Second, NESCAUM did not use the designated EPA test methods for PM emissions from wood heaters (Method 5G or 5H). Instead, they used a light-scattering monitor survey instrument, a DataRAM 4000, which erroneously measured water in the flue gas as PM. The Thermo Electron DataRAM 4000 uses light scattering to determine the size and number of particles in an air sample, and assumes a particle density of 2.6 g/cm^3 corresponding to surface dirt; it then estimates the particle mass in the air sample. This type of field survey instrument cannot be used for wood combustion PM measurements for two reasons. First, the density of wood combustion PM in any given test is unlikely to be 2.6 g/cm^3 and NESCAUM made no attempt to correct for this fact. EPA Methods 5G and 5H, by contrast, are gravimetric and measure particle mass directly. Second, and this is the greater error, wood combustion particles are saturated with water vapor when the gas is cooled to "near-ambient temperatures" as NESCAUM did before introducing the sample gas into the DataRAM 4000[21], and above 50% relative humidity (RH) solid particles swell due to accretion of water. Above 70% RH, this growth in particle size is so significant that the majority of the "particle mass" is water according to instrument manufacturer.[23] NESCAUM failed to use an MIE Temperature Conditioning Heater (DR-TCH) that could have removed the excess water. Thus, most of the "particle mass" NESCAUM measured with the DataRAM 4000 in their test was water, and it is not surprising that this poorly designed test produced emission estimates three times higher than the other emission tests done with EPA test methods and proper fuel.

Particulate Matter Emissions for EPA-Certified Woodstoves

Test Data for 16 Certified Woodstoves

A very comprehensive study of emissions from EPA-Phase 2 certified woodstoves, as they are operated in homes was done in Klamath Falls and Portland, Oregon in the late 1990s[9]. In that EPA study, emission sampling was done for up two months on 16 woodstoves while consumers operated the woodstoves conducting their "normal" heating practices. EPA devised an Automated Wood Emissions Sampling system for this study in which flue gas was drawn off and passed through a glass filter and then through a XAD cartridge. The test results reveal certified woodstoves emit an average of 9.7 g/kg (1.18 lb/MMBtu), with non-catalytic stoves averaging 9.2 g/kg and catalytic stoves averaging 10.8 g/kg.[13] Mass emissions for these stoves covered a wide range from 2 to 32 g/hr and averaged 11.1 g/hr, which is significantly above the certification limits for Phase 2 woodstoves of 4.1 g/hr (catalytic design) and 7.5 g/hr (non-catalytic design). A comparison of the actual PM emissions to each stove's hang-tag certification value is provided in this same EPA study and shows that actual in-use emissions from certified stoves are on average 3.3 times the certification value.[14] The two reasons for this discrepancy are: 1) EPA's stove certification Method 28 allows the air controls to be manipulated during the test to achieve lower emissions, as discussed below, and 2) in the case of the catalyst stove, the catalyst is not replaced by the homeowner as the stove ages.

Comparison of all OWB and Woodstove Test Data

The test data for the 16 certified woodstoves are graphed with the 56 tests for OWBs in Figures 4, 5 and 6 and reveal that at the low heat input rates characteristic of woodstoves, PM emission rates from OWBs and certified woodstoves are very similar. The mean values for the set of OWB and woodstove tests are separately noted by larger symbols in Figures 4, 5 and 6. The average OWB emission rate of 12.1 g/kg is 25% above the average woodstove emission rate of 9.7 g/kg. Expressed in units of heat input, the average OWB emission rate of 1.44 lb/MMBtu is 22% above the average woodstove emission rate of 1.18 lb/MMBtu. The mean heat input values represented in the two sets of test data are 93,000 Btu/hr for the OWBs and 19,000 Btu/hr for the woodstoves. This ratio of 5:1 in heat input explains most of the difference in the 5:1 ratio of mass emissions (g/hr) between OWBs and woodstoves seen in Figure 6.

One Reason Why Actual Woodstove Emissions are 3 Times Hang-Tag Certification Values

PM emissions increase dramatically when a new load of wood is added to a woodstove unless the primary air control is left wide open for 5-15 minutes to bring the internal temperature back up to the high level required for secondary combustion of pollutants.[15] Tests by EPA of one of its "cleanest" non-catalytic woodstoves found that the stove achieved low PM emissions (2 to 4 g/hr) if the air supply control was left wide open for 10-15 minutes each time wood was loaded into the stove. When the air control was turned down for a slower burn rate before 5 minutes had elapsed, however, emissions soared 5 to 10 times higher into the 15-20 g/hr range.[16] Because of this emissions spiking characteristic of woodstoves, Method 28 allows the test operator to leave the air damper wide open for the first 5 minutes of the test to artificially raise the stove temperature and then turn it down to match the test's prescribed burn rate (see Section 8.12.1.4 in Method 28). Method 28 also allows the air control to be manipulated during the test to minimize PM emissions (see Sections 8.12.4 and 8.10). A leading woodstove manufacturer confirmed to EPA that many stoves are designed to pass the test and have higher emissions in actual in-home use.[17]

Homeowners do not do the air control manipulations employed during a Method 28 test, adjustments that are crucial to a woodstove passing the EPA certification. When a stove is refueled in the home, the wood is added, the air control might be adjusted, and the homeowner walks away. Thus, actual in-home use of a woodstove produces substantially higher emissions than the hang-tag certification value, as documented in the EPA woodstove study.[14]

PAH Emissions for OWBs and Woodstoves

The previous-cited EPA OWB study[8] also produced test data on PAH emission rates and compared these to PAH emission rates for EPA-certified woodstoves, on a g/MJ heat input basis. The EPA test data reveal that OWBs labeled G and H in this paper produce 16.1 and 15.6 mg/MJ of PAH, respectively, and those values are similar to, and lower, than emission rates EPA gives for certified woodstoves of 24-28 g/MJ.[18]

Dispersion Modeling Analysis of OWB PM Emissions

Air dispersion modeling was performed with the EPA AERMOD model and following EPA guidance to determine whether a properly installed and operated OWB complies with the new, more stringent 24-hour $PM_{2.5}$ National Ambient Air Quality Standard of 35 $\mu g/m^3$. Persons who buy an OWB typically have an ample and inexpensive wood supply and the land on which to split and store the wood fuel, and hence OWBs are most often found in rural areas. The air dispersion modeling assumed the OWB was located in flat terrain at a typical distance of 50 feet from a house (50' x 40' footprint) with an 18-foot roof peak and the OWB stack was 20 feet above grade, or two feet above the roof peak of the nearest structure, following manufacturer installation instructions and industry guidelines.[19] Five years of hourly meteorological data for Burlington, Vermont were utilized in the modeling and the AERMOD model considered the wake cavity effects from house and the OWB firebox on the furnace stack.

The OWB that was modeled is a Central Boiler Model 6048, a popular model sold by the leading manufacturer. The test data presented in this paper for OWB G are for a similar Central Boiler furnace that EPA tested and the average emission rate for that unit was 10.7 g/kg-dry. Assuming a 5.6 kg-dry/hr firing rate (7.4 kg/hr of wood with 24% moisture), which corresponds to a heat input rate of 99,600 Btu/hour, the emission rate is 60 g/hr of PM. The dispersion modeling assumed this as a 24-hour average emission rate because the air concentrations being predicted were for a 24-hour time period. This emission rate is slightly higher than the mean value of 52 g/hr for the shorter time period OWB emission tests presented in Figure 3. Two emission rates were analyzed for the OWB: 1) 60 g/hr of PM (1.33 lb/MMBtu) representing typical winter operation of an OWB now on the market, and 2) 27 g/hr of PM (0.60 lb/MMBtu) corresponding to the new EPA Phase 1 guideline for OWBs, some of which will be available to consumers later in 2007. As a conservative assumption, all PM emissions were assumed to be $PM_{2.5}$, even though EPA data suggest only 76% of the total PM mass has a mass mean diameter of 2.5 microns or less.[20] Following the latest EPA guidance, the five-year average of the highest, 8^{th}-highest 24-hour $PM_{2.5}$ concentrations were predicted as the design concentrations for compliance assessment.

The modeling results reveal a single peak concentration of 8.4 $\mu g/m^3$ for the 60-g/hr-emission rate with most concentration values in the range of 1 to 3 $\mu g/m^3$ at distances up to 150 meters from the OWB. For the lower 27-g/hr-emission rate representing the new EPA Phase 1 emissions goal, the modeling results show a peak concentration of 3.8 $\mu g/m^3$ with concentrations below 1 $\mu g/m^3$ at distances over 150 meters from the OWB. In a rural area where OWBs are typically found, background levels of

$PM_{2.5}$ are sufficiently low that the sum of background and OWB concentrations will definitely comply with the new 24-hour NAAQS of 35 μg/m^3 for both existing OWBs (60 g/hr) and the new EPA Phase 1 models (27 g/hr). Note that the peak concentration for the EPA Phase 1 OWB of 3.8 μg/m^3 is below the 5-μg/m^3 EPA significance threshold for 24-hour Particulate Matter.[24] Thus, it can be concluded that a properly installed and operated OWB that meets the new EPA Phase 1 guideline of 0.6 lb/MMBtu will have an insignificant effect on local air quality.

New OWBs Meeting the EPA Phase 1 Guideline Are Cleaner Than Certified Woodstoves

In January, EPA announced a partnership agreement with OWB manufacturers to make lower-emission OWBs. Under the EPA Outdoor Wood-Fired Heater Program Phase 1, manufacturers are building units to meet an emission goal of 0.6 lb/MMBtu and will be certified at that level with the EPA Test Method 28 OWHH. Some manufacturers expect to have at least one model available for purchase by consumers this fall that meets the Phase 1 limit. The Phase 1 OWBs with PM emissions of 0.6 lb/MMBtu will have 60% less emissions than the typical OWB in use today (1.44 lb/MMBtu, see Figure 5) and will have 50% less emissions than the typical woodstove (1.18 lb/MMBtu average as operated, see Figure 5). In a recent letter, EPA stated that "most current EPA-certified woodstoves emit 0.8 – 1.5 lb/million BTU heat input [particulate matter]"[25], which confirms that the new Phase 1 OWBs will have an emission rate that is 25% to 60% less than a certified woodstove. In addition, the Phase 1 emissions goal of 0.6 lb/MMBtu is more stringent than the current NSPS for non-catalytic woodstoves of 7.5 g/hr, which equates to 0.74 lb/MMBtu.[26]

CONCLUSIONS

Concerns have been raised by NESCAUM about the emissions from Outdoor Wood Boilers (OWB). These residential furnaces are designed to heat an entire home and in many cases replace multiple indoor wood stoves, which are typically sized to a heat a single room. To properly compare OWB and woodstove emissions, the measure is emissions per unit of fuel burned (g/kg-dry) or heat input (lb/MMBtu). To meet an emissions goal on a g/kg or lb/MMBtu basis requires the furnace to have good combustion efficiency. By contrast, use of a mass-per-time limit (g/hr) does not impose this requirement because the firing rate can simply be limited, an approach taken by some wood stove manufacturers in gaining EPA certification.

Particulate Matter (PM) emissions from six current-model OWB were measured with EPA Method 5G in 48 tests done in 2005/2006. The results reveal PM emission rates do not vary over a wide range of burn rates (1.3 to 13 kg-dry/hour) and operation of an OWB with larger firebox than a woodstove at a reduced firing rate, when heat demand is low, does not produce high emissions. The average of the test results are within 10% of the results from EPA tests on two OWBs done in 1995. A comparison of the OWB test data to EPA tests of certified woodstoves as actually used by residential owners show that: 1) current OWB PM emissions are in the same range as certified woodstove emissions on a g/kg basis and average 22 to 25 percent higher, and 2) cycling of the OWB fire by the thermostat in a home does not produce high emissions. A comparison of polycyclic aromatic hydrocarbon (PAH) data reveals OWB emissions are similar to, and lower than PAH emissions from certified woodstoves.

Mass emissions from the OWB tests were analyzed in a dispersion modeling analysis to produce contour maps of maximum 24-hour $PM_{2.5}$ concentrations for two OWB emission rates representing current models and lower emission models meeting the EPA Phase 1 emissions goal. The results demonstrate that: 1) a properly installed OWB can operate year-round next to a residence and fully comply with the new $PM_{2.5}$ air quality standards, and 2) a properly installed and operated OWB that meets the new EPA Phase 1 guideline of 0.6 lb/MMBtu will have an insignificant effect on local air quality. OWB manufacturers have worked with EPA to develop a voluntary Outdoor Wood-fired Heater (OWH) Program with a Phase 1 emissions target of 0.6 lb/MMBtu, representing a 60% reduction in PM emissions from existing OWB. The Program uses EPA Standard Test Method 28 OWHH that incorporates EPA Method 5G. The Phase 1 emissions goal is more stringent than the current New Source Performance Standard (NSPS) for wood stoves. Manufacturers will be bringing OWH Phase 1 Qualified Models to market starting in 2007, and those units will have lower emissions, lb/MMBtu, basis than certified woodstoves now in use.

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KEY WORDS

Particulate matter
PM
Outdoor Wood Boilers
Outdoor Wood Hydronic Heaters
Outdoor Wood Furnaces
PAH
Certified Woodstoves
Emission Factors

Figure 1. PM emissions (g/kg) vs heat input rate of eight outdoor wood boilers (56 tests)

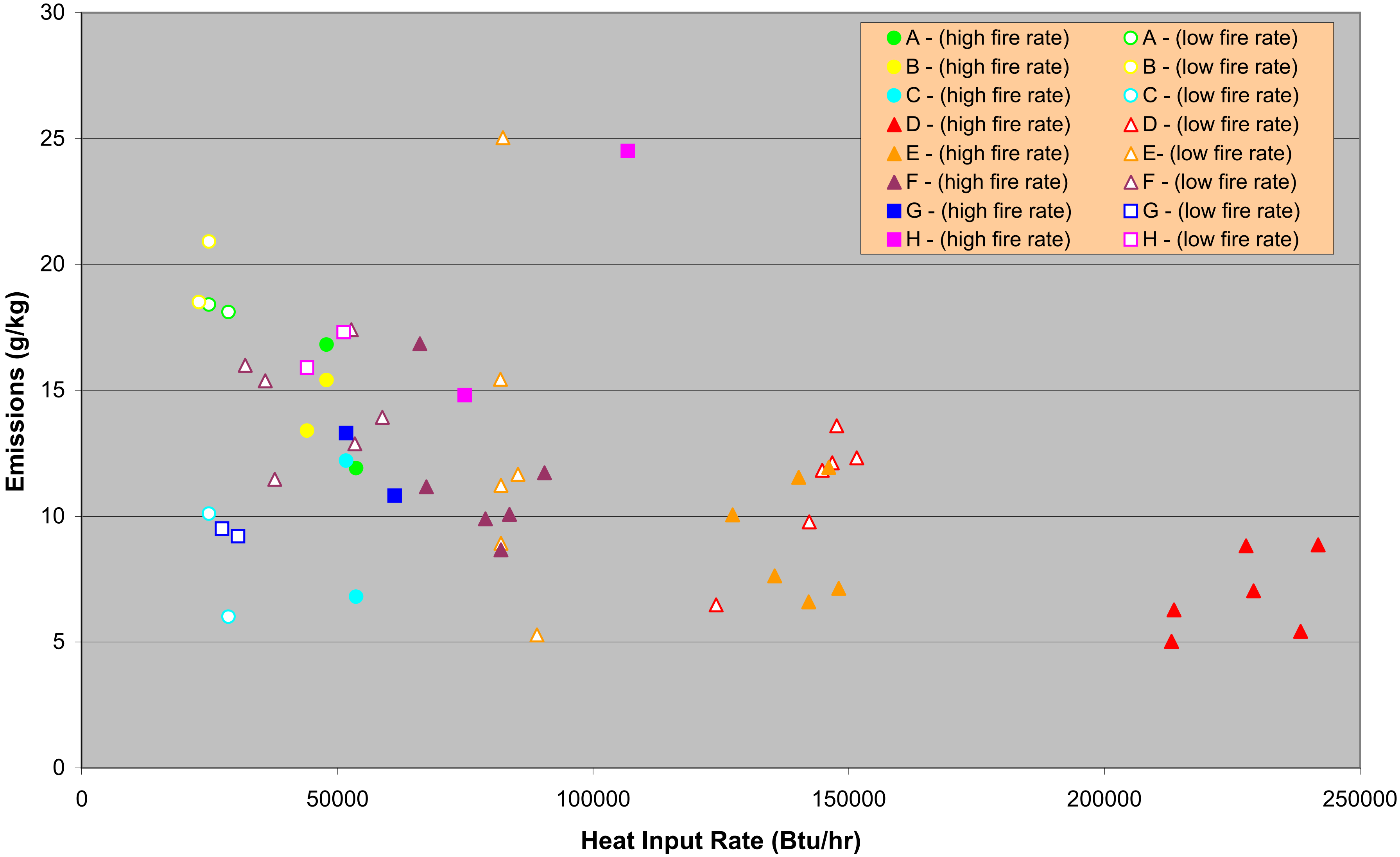

Figure 2. PM emissions (lb/million Btu) vs heat input rate of eight outdoor wood boilers (56 tests)

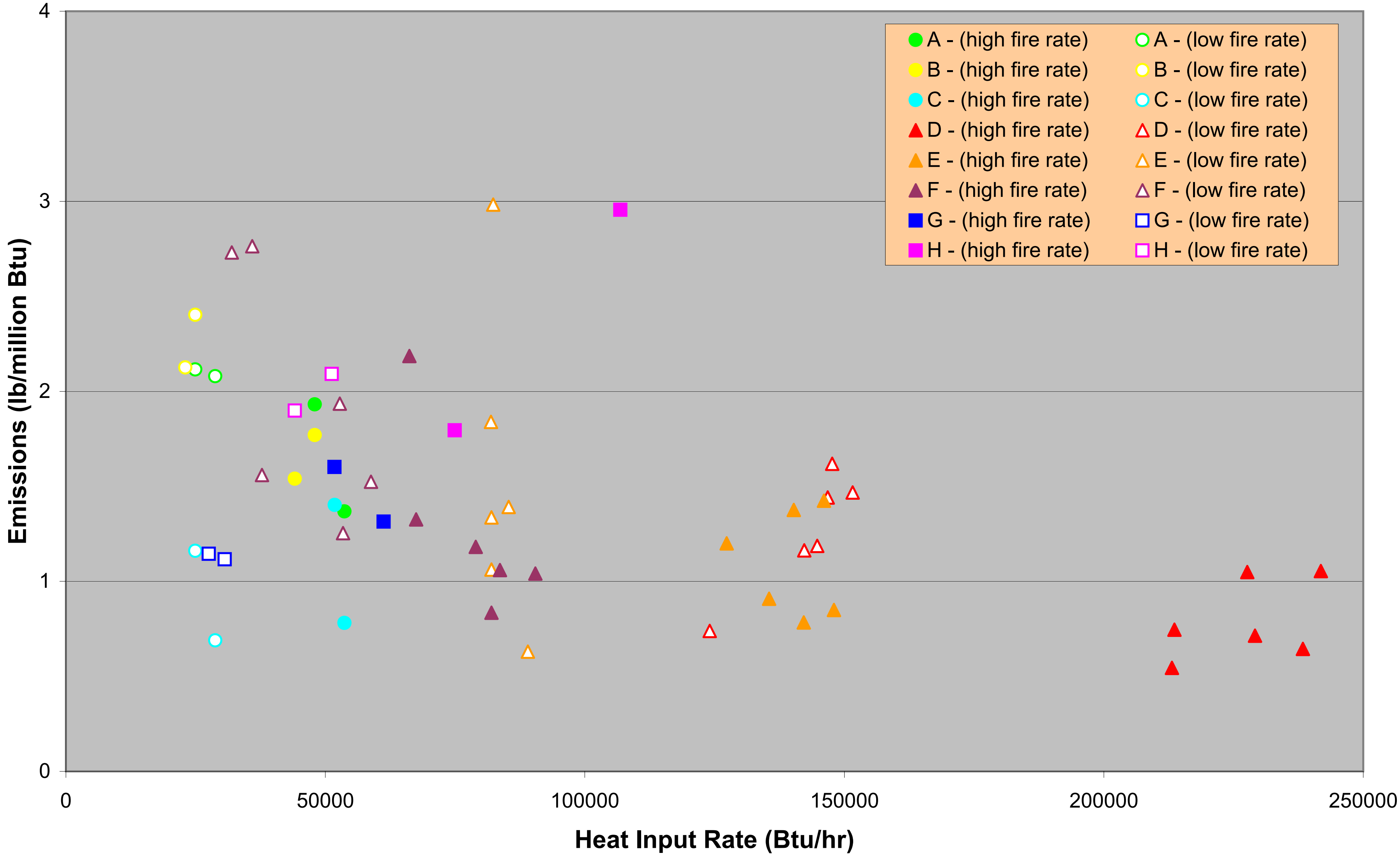

Figure 3. PM emissions (g/kg) vs emissions (g/hr) of eight outdoor wood boilers (56 tests)

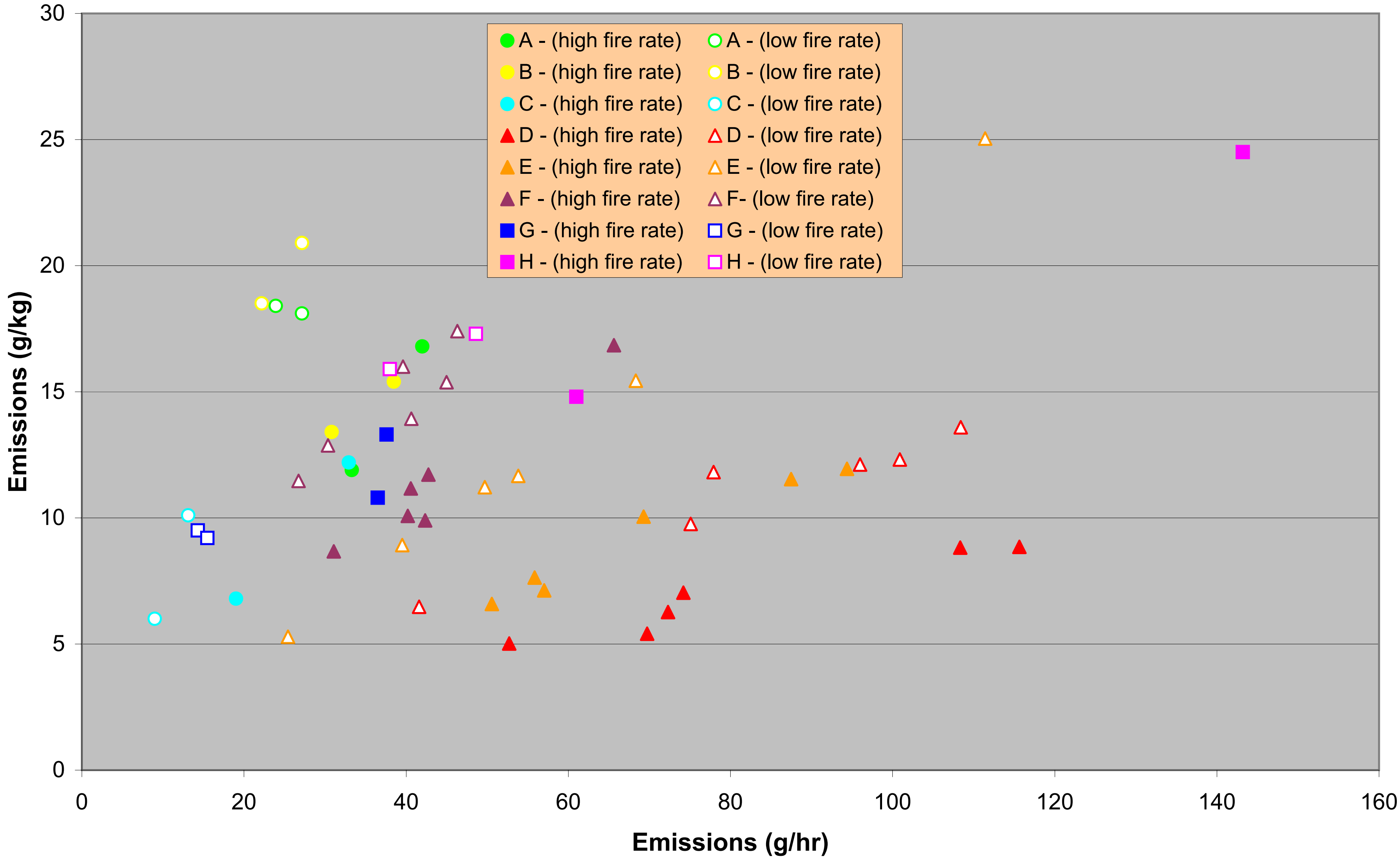

Figure 4. PM emissions (g/kg) vs heat input rate of outdoor wood boilers vs. certified woodstoves

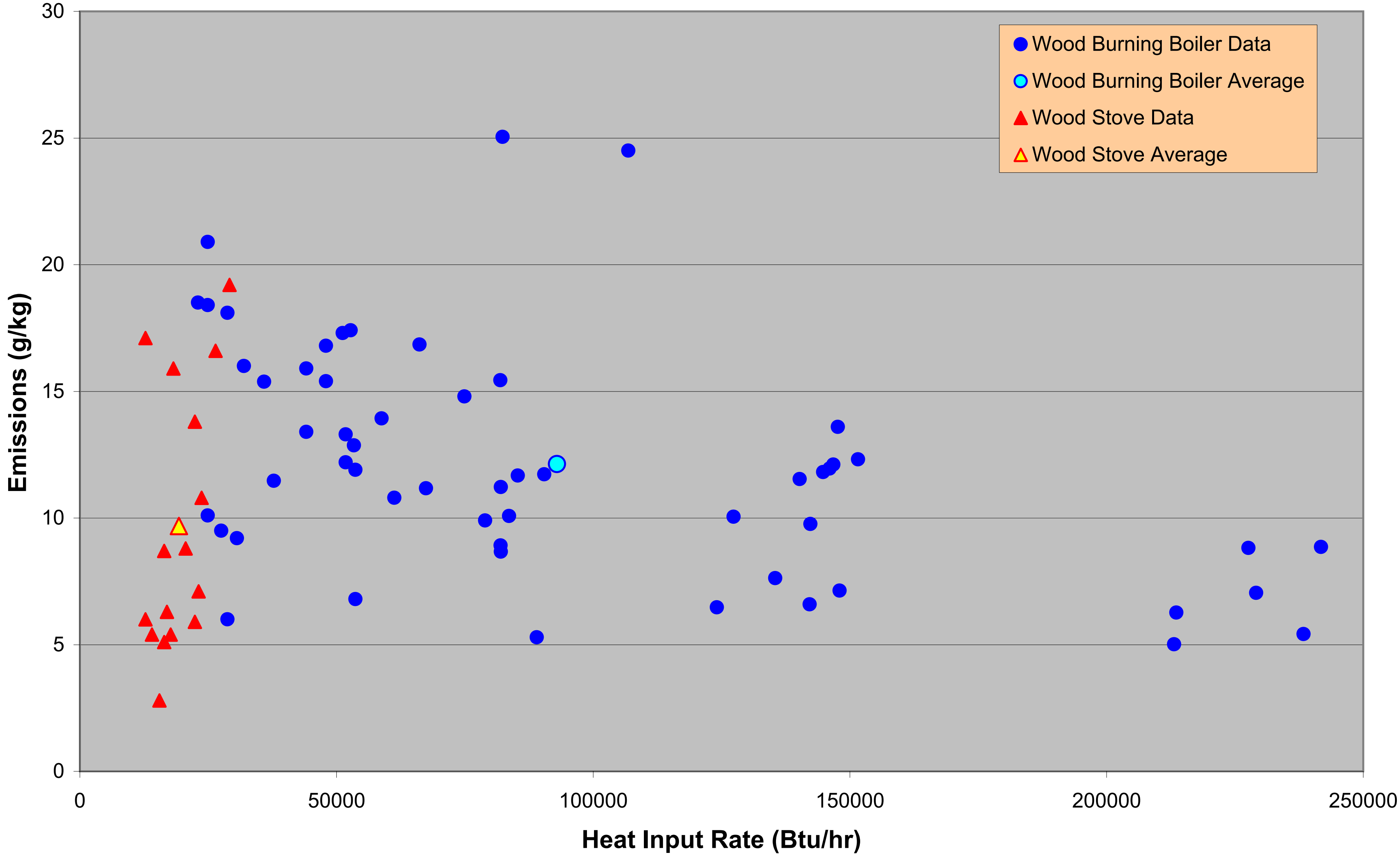

Figure 5. PM emissions (lb/MMBtu) vs heat input rate of outdoor wood boilers vs. certified woodstoves

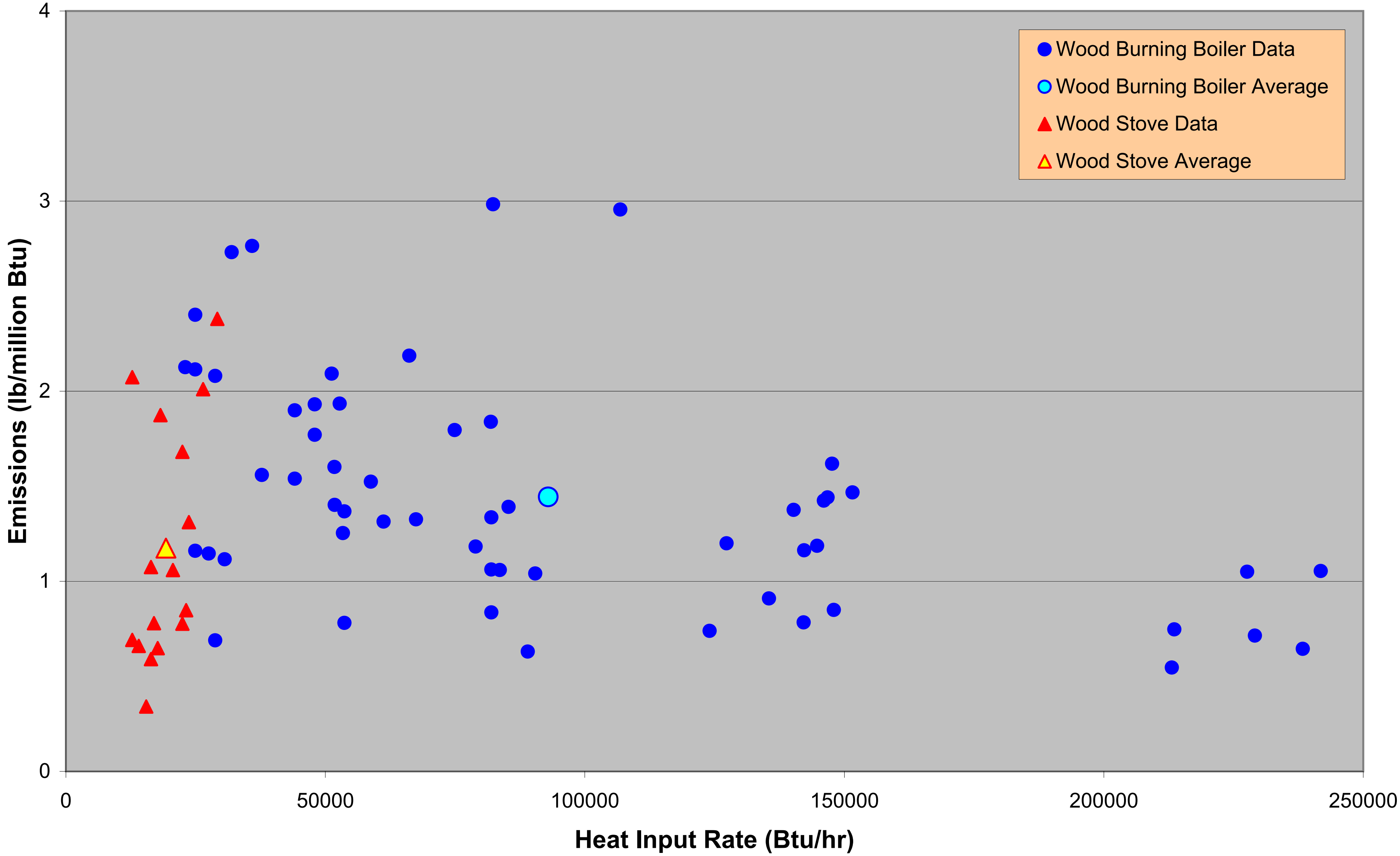

Figure 6. PM emissions (g/kg) vs emissions (g/hr) of outdoor wood boilers vs. wood stoves

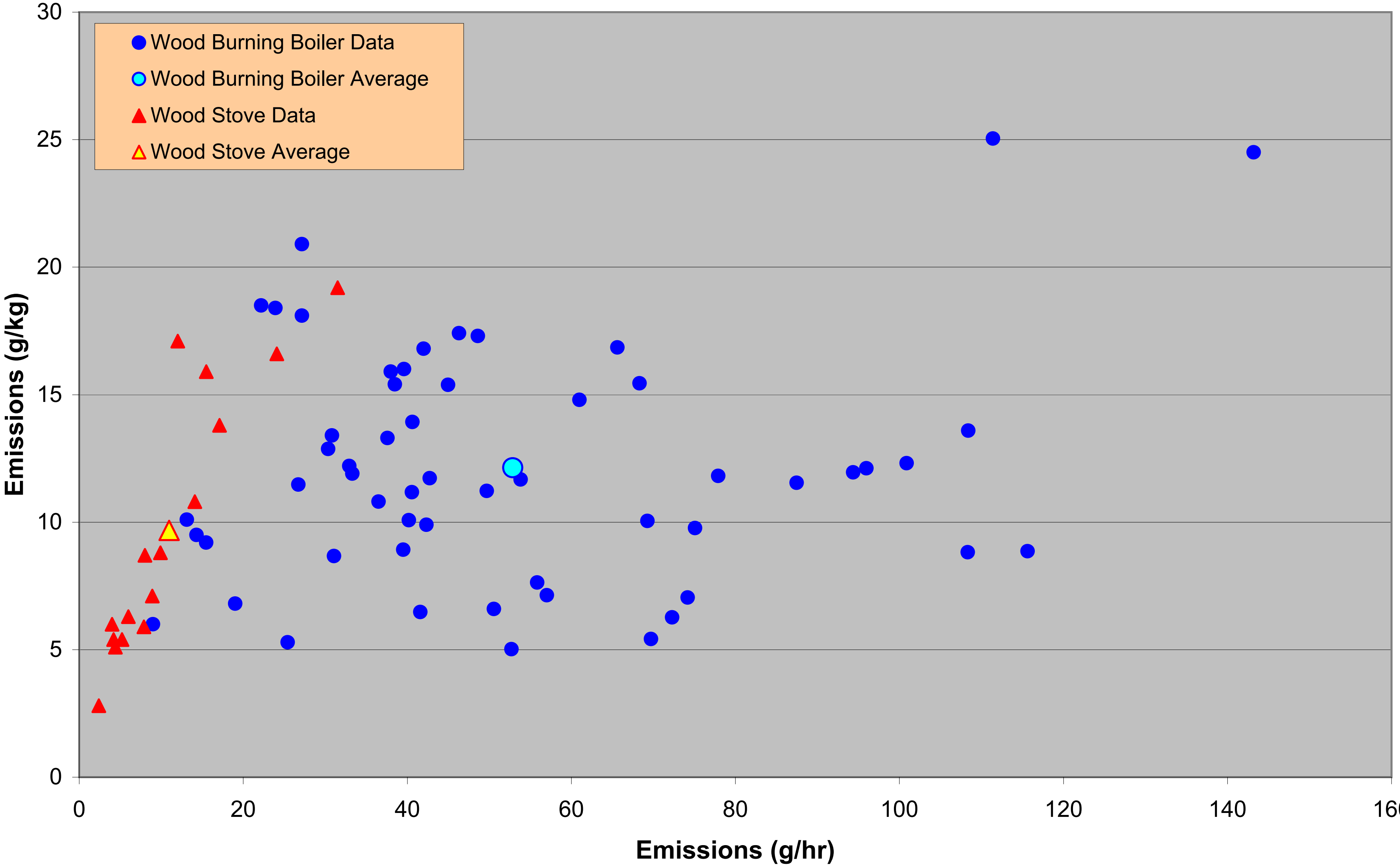

Figure 7. Five-year Average 24-Hour H8H $PM_{2.5}$ Concentrations (ug/m^3) For An OWB With A 20-Foot Stack Emitting 60 g/hr

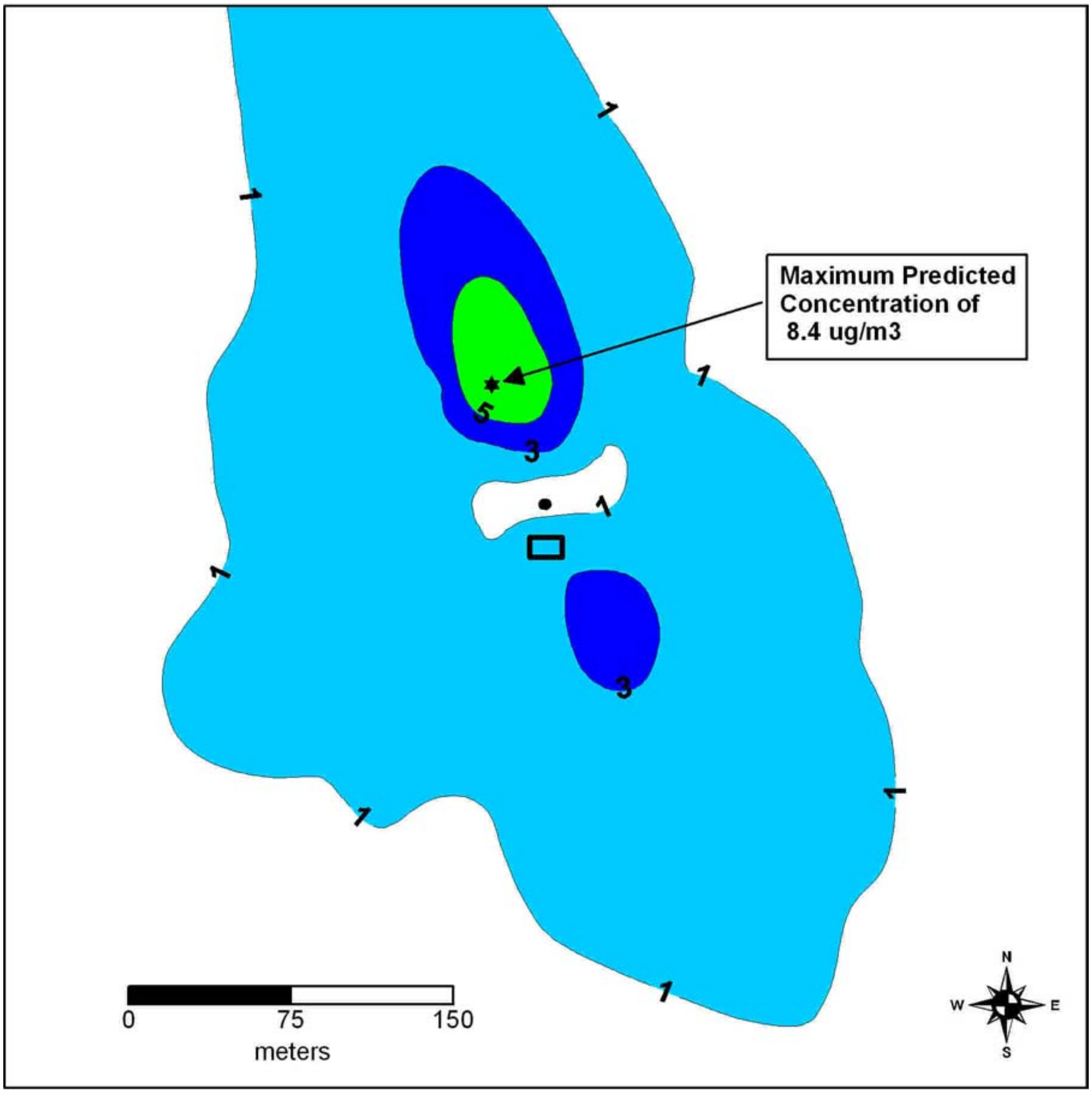

Figure 8. Five-year Average 24-Hour H8H $PM_{2.5}$ Concentrations (ug/m^3) For An OWB With A 20-Foot Stack Emitting 27 g/hr