Contribution of Wood Smoke to Particle Matter Levels in Connecticut

Source Characterization of Outdoor Wood Furnaces

Prepared by
NESCAUM
September 9, 2008

Members of Northeast States for Coordinated Air Use Management

Arthur Marin, Executive Director
Northeast States for Coordinated Air Use Management

Paul Miller, Deputy Director
Northeast States for Coordinated Air Use Management

Anne Gobin, Bureau Chief
Connecticut Department of Environmental Protection, Bureau of Air Management

James P. Brooks, Bureau Director
Maine Department of Environmental Protection, Bureau of Air Quality

Barbara Kwetz, Director
Massachusetts Department of Environmental Protection, Bureau of Waste Prevention

Robert Scott, Director
New Hampshire Department of Environmental Services, Air Resources Division

William O'Sullivan, Director
New Jersey Department of Environmental Protection, Office of Air Quality Management

David Shaw, Director
New York Department of Environmental Conservation, Division of Air Resources

Stephen Majkut, Chief
Rhode Island Department of Environmental Management, Office of Air Resources

Richard A. Valentinetti, Director
Vermont Department of Environmental Conservation, Air Pollution Control Division

Contribution of Wood Smoke to Particle Matter Levels in Connecticut

Source Characterization of Outdoor Wood Furnaces

Prepared by
NESCAUM

September 9, 2008

CONTRIBUTION OF WOOD SMOKE TO PARTICLE MATTER LEVELS IN CONNECTICUT

SOURCE CHARACTERIZATION OF OUTDOOR WOOD FURNACES

Project Manager

George Allen, NESCAUM

Principal Contributors

Executive Summary: George Allen, NESCAUM

Chapter 1: George Allen, Lisa Rector

Chapter 2: George Allen

Chapter 3: George Allen

Chapter 4: Lisa Rector, George Allen

Acknowledgments

NESCAUM gratefully acknowledges the funding support provided by the Connecticut Department of Environmental Protection, Bureau of Air Management, and the United States Environmental Protection Agency. NESCAUM is an association of the eight northeast state air pollution control programs that provides technical guidance and policy advice to its member states.

We also acknowledge CT DEP staff that provided assistance with the OWB testing field work:
Peter Babich
Joseph Kowalczyk
Mark Spiro

NESCAUM also thanks the following individuals for providing comments on this report:
Mark Spiro, Aileen Matta, and Anne Gobin – CT DEP
Paul Miller – NESCAUM

Printed: September 10, 2008

Executive Summary

This report was undertaken by the Northeast States for Coordinated Air Use Management (NESCAUM) for the Connecticut Department of Environmental Protection (CT DEP) as part of an effort to assist policymakers at the national, state, and local levels in better understanding the contribution of the biomass burning sector to air pollution problems and to investigate control options for reducing wood smoke emissions from outdoor wood furnaces.

ES-1. Introduction

Outdoor wood furnaces (commonly called outdoor wood boilers or OWBs) are a growing concern as large sources of wood smoke in residential areas in the Northeast. NESCAUM, under contract to CT DEP, performed several particulate mass (PM) stack emission (source) tests on a typical OWB (approximately 500,000 Btu per hour input capacity, a common size for residential use) under a range of burn conditions. These tests allow us to gain a better understanding of how "burn practices" can effect stack PM emissions and determine the range of particle emissions that could be expected to be found from an in-use uncontrolled OWB. In-use here means an existing OWB installation that was routinely being used for space heating during the cold weather season. PM measurements were made using a continuous method (TEOM®) to allow us to observe short-term variations in PM emissions and segregate damper open from damper closed emissions.

ES-2. OWB Testing Protocols

A total of eleven test burn days were performed during four different weeks; two in October 2007, one in March and one in April, 2008. Week one used a full load of the wood (600 pounds) from the OWB owner's woodpile. During the first test day, the unburned wood was removed after the day's tests. During the second and third days of week one, a new 600 pound load was burned for two successive days. A limited number of speciated total (gas and particle phase) poly-aromatic hydrocarbon (PAH) samples were collected during week one of testing. Week two consisted of two test days burning the same Owb user's wood but samples were collected downstream of an early prototype oxidation catalyst. Weeks three and four (six test days total) focused on evaluation of PM emissions over a wide range of burn practices. Burn practices evaluated include the type of wood (hard or soft cord-wood), the moisture content (seasoned or "green" wood), and the size (weight) of the load relative to the volume of the burn chamber. To give some context of our tests to laboratory emission tests, an EPA method 28 "crib" was used for one of the test days. A crib is a structure assembled from seasoned dimensional oak lumber in a predefined way to provide optimal burn conditions.

ES-3. Summary of OWB Testing Results

During testing, it became clear that on a PM grams per hour basis, nearly all the emissions occurred when the OWB damper was open. Therefore, the table of emissions presented here shows the average emissions constrained to times when the OWB damper was open over the course of each day's burn. All data are at standard temperature and pressure (STP), and are not corrected for water vapor or differences between TEOM and Teflon filter gravimetric samples (the TEOM data are different by approximately ± 25percent). In the case of the week two catalyst tests, results are also constrained to when the catalyst was operating properly (i.e., self-firing).

Table ES-1. Summary of OWB Test Results: Emissions with Damper Open

Date of Test	PM emissions, grams/hour STP	Wood Load Description	Wood Moisture Content Range (%)
10/2/07	71	611 lb user’s hardwood, split	14-29
10/3/07	55	614 lb user’s hardwood, split	14-29
10/4/07	24	continued burn of 10/3 load	n/a
10/10/07 (Catalyst)	12	610 lb user’s hardwood, split	14-29
10/11/07 (Catalyst)	1.5	continued burn of 10/10 load	n/a
3/11/08	221	300 lb wet Hemlock Slab, 48" lengths	21-35
3/12/08	265	300 lb “kiln dry” white Pine split	11-28
3/13/08	147	300 lb “wet” mixed hardwood split	26-36
4/8/08	81	300 lb EPA Crib	14-29
4/9/08	96	300 lb seasoned hardwood, split	13-39
4/10/08	81	150 lb seasoned hardwood, split	15-37 (same woodpile as 4/9)

Not including data from the catalyst test days, PM “damper open” emissions varied by an order of magnitude, ranging from 24 to 265 grams per hour for the same OWB. The difference in emissions on each test day was driven by burn practices and how long the wood had been in the OWB (day two of a two-day load burn is cleaner than day one).

ES-4. Findings Summary

The work completed indicates several issues that may require development of or revisions to existing policy to assure public health protections. The issues include:

• EPA test methods for OWBs may under-represent real-world emissions by a factor of four;

• Fuel specifications may be necessary in the future to ensure lowest possible emissions from wood burning;

• There may be additional pollutants of concern, including sulfur dioxide, naphthalene, and mercury from wood burning that may depend on the harvest location;

• Add-on control technologies could significantly reduce emissions if and when they become commercially available.

4.1 Testing Protocols

EPA Method 28 OWHH should be re-evaluated to more closely approximate a worst case scenario. This would harmonize emission results from indoor woodstoves and OWBs and provide a better method for comparing emissions from residential wood burning devices. The difference in emissions from different fuels is significant, so more attention should be focused on developing fuel requirements.

4.2 Fueling Protocols

This work suggests that the species of wood and moisture content play critical roles in determining the extent of emissions from wood burning. It is possible that these parameters will play a critical role in emission outcomes in all wood burning devices.

4.3 Other Pollutants than PM

Emissions other than PM should be investigated further. Wood smoke contains many PAH species, especially naphthalene. $SO2$ emissions, at least for eastern wood, are significant. It is likely that significant amounts of mercury are present in wood smoke emissions.

4.4 Recommendations on Retrofit Technologies

Little to no action has been focused on add-on technology to reduce the emissions from existing units, which are a significant portion of the wood smoke related air quality problem. Based on the data obtained in this project, reducing emissions from existing units is technically feasible, but at this time there are no commercial retrofit products available.

1. INTRODUCTION

1.1 Background and Need for Stack Testing

Due to the high cost heating fuels many people are turning to the use of wood for residential and commercial heating. Outdoor wood boilers (OWBs), water-stoves or outdoor hydronic heaters (OWHH) create the greatest concern for public health. OWBs have been a controversial form of wood heating in the northeastern and mid-western US and Canada for several years. The controversy is caused largely by the smoke and health impacts the emissions from OWBs have on neighbors, but there has also been concern about the use of the units when burning various types of wood or for burning materials other than natural wood.

OWBs can be used in both residential and commercial applications. These units are primarily used for space heating and providing domestic hot water. They are also used to heat swimming pools and hot tubs, and in agricultural operations such as dairy and greenhouse operations. They come in a variety of sizes and shapes but most look like small, freestanding metal tool sheds with stacks. Commonly, they have large fireboxes (20 cubic feet up to 150 cubic feet), which are surrounded by water jackets. The water is heated by the fire and is circulated underground via insulated pipes from the OWB to the house or other operation. The units are designed to burn large amounts of wood over long periods of time.[1] OWBs vary in size ranging from 115,000 Btu per hour up to 3.2 million Btu per hour, although residential OWBs tend to be less than 1 million Btu per hour. According to sales data, the size of the most commonly sold unit is 500,000 Btu per hour. OWBs heat buildings ranging in size from 1,800 square feet to 20,000 square feet.

These units are different than typical heating devices for the following reasons:

- Year Round Operation – OWBs are designed to provide heat and hot water year round. Owners often use them in the warmer months not only for domestic hot water but also to heat their swimming pools and/or spas.

- Cyclic Operation - The cyclic nature of OWB operations does not allow for complete combustion and creates an environment conducive to increased toxic and particulate emissions, unlike EPA certified wood stoves.

- Short Stack Heights – Stacks from OWBs, as per manufacturer's installation instructions, are usually less than 12 feet from the ground, resulting in poor dispersion of smoke and are more likely to cause fumigation within surrounding areas.

- Oversized Firebox – An OWB's large firebox is built such that a user could burn a variety of inappropriate materials that could not be burned in wood stoves or fireplaces. Enforcement programs have discovered OWBs burning tires, large bags of refuse, and

---

[1] Schreiber, Judith et al. *Smoke Gets in Your Lungs: Outdoor Wood Boilers in New York State*. Office of the Attorney General; Albany, New York, 2005. Available at http://www.oag.state.ny.us/press/2005/aug/August 2005.pdf

railroad ties. Even when used properly, overall OWBs emissions are greater than other residential wood burning devices.

Many states have seen a significant increase in the use of these units while air emissions from them remain relatively un-characterized. The current vendor sponsored certification test data set represents new, cleaner units using a dimensional red oak within a specific moisture content range. The limited vendor independent data available indicates that OWBs may pose a significant public health impact. Until this current emissions test program, there has been no analysis to determine how fueling and use patterns can affect emissions. Emission standards have been developed to protect public health based upon the above referenced certification test. However, questions remain as to how the certification tests may represent real world conditions.

In general, wood burning in residential or small commercial situations emits hundreds or even thousands times more particulate than burning oil or gas. While wood is a renewable local resource and is considered by some to be global warming neutral, more and more people choose to burn wood. The devices they use need to be more and more efficient in order to maintain the current air quality. Some long term effects of an increasing population that chooses poor wood burning technologies will be increased health care costs, premature deaths and a decreasing quality of life.

The information obtained through this project will be valuable in developing control strategies and emission inventories while gaining a better understanding of the OWBs contribution to Connecticut's $PM_{2.5}$ levels. In addition, the information developed under this project is meant to assist in assessing the impacts of OWBs on air quality and public health. Currently, Connecticut and several other states are assessing the need to develop regulations that would require emission controls on these units. Gaining a better understanding of OWB emissions should direct further action.

1.2 Project Design

This OWB stack test project was limited to a single uncontrolled OWB that was in-use for heating a building. The OWB size was typical of many installations, with a heat input of approximately 500,000 Btu per hour. The OWB was located near the building, allowing us to run measurement instrumentation in a controlled environment and still sample from the stack without excessive sample line length. Constraining tests to a single unit allowed us to evaluate only the effect of burn practices on PM stack emissions. Variables included the type of wood (hard or soft, slab), the moisture content (green or seasoned), the amount (weight) of the load used, damper status or duty cycle, and fresh load versus aged load emissions.

There were some limitations to this work that are a result of testing an in-use field OWB. We could not measure the weight of wood actually burned, only the weight of the initial load and a visual inspection of the remainder of the load at the end of the test burn. We could not measure actual heat output due to the complexity of the load plumbing used on the system. Therefore, we can not report emissions in units of mass of wood burned for a given heat input or output. We did not make measurements of stack water vapor, so results represent "wet" emissions. Stack water vapor is generally between 8 and 12 percent in OWBs, so this is not a large uncertainty given the very wide range of emissions observed during the tests.

2. METHODS

2.1 Introduction

Based on early experience during the OWB testing phase of this project, we realized that it was more practical to focus testing on a single OWB while varying the burn conditions instead of testing multiple OWBs. A 500,000 Btu per hour uncontrolled OWB was used for all tests. The OWB we tested was heating only a portion of building. This aspect of the building's plumbing prevented an accurate measurement of heat output. The damper was thermostatically controlled based on OWB water jacket temperature, but was manipulated manually for these tests. This facility also had an optional add-on prototype catalytic after-burner available. This configuration allowed us to run tests with the catalyst for one of the four test weeks to assess its performance.

The burn-box volume of this OWB was measured as 60.5 cubic feet, slightly different than the manufacturer's specification. Various wood types (hard vs. soft, seasoned vs. green) and loads (150, 300, and 600 lb hardwood, EPA Method 28 crib) were used to vary the "burn practices" while keeping the OWB hardware constant. Wood moisture content was measured for each load of wood. Several moisture samples were performed on each of a few pieces of wood from each load. The original work plan was to perform two days of tests for each of the four weeks. Working at a fixed facility reduced the overall effort and allowed us to do three days of tests for each week except the week when the catalytic converter was tested. This approach also freed up resources to do limited speciated PAH sampling during week one.

2.2 Measurement Methods

PM emissions were measured from the OWB during two weeks in October 2007, one week in March 2008 and one week in April 2008. The first two weeks of testing used a TSI/Matter Engineering Rotating Disk Dilutor (RDD), providing a 785:1 dilution ratio. SO2 was used to verify proper operation of the RDD by introducing a known amount of SO2 upstream from the RDD inlet and measuring the SO2 concentration out of the RDD. OWB stack flows were measured by introducing a known amount of SO2 into the stack and measuring the stack SO2 downstream; the background SO2 was subtracted from these measurements. During week two, a prototype catalytic converter was used on the OWB; SO2 could not be used for stack flow measurements during these tests since the catalyst converts SO2 to SO3. In addition, the OWB damper blower was used for the catalyst tests, since proper draft could not be obtained without it.

The TSI RDD was unavailable for rental for the third and fourth weeks of testing. Therefore, tests for the last two weeks were done using an EPA-method dilution tunnel with a 110:1 dilution ratio that was built specifically for these tests. Tunnel flow and CO2 stack/tunnel concentration ratios were used to determine stack emissions; this work was done by the company running the dilution tunnel. Each test week consisted of three days of sampling, except for week two. During that week, the OWB was tested with the add-on, catalytic oxidizer for only two days. A day of testing was typically 7 to 8 hours burn duration. During tests with loads of 300 pounds or less, the load was fully charred and mostly burned at the end of the burn.

Other measurements include OWB stack temperature, OWB water jacket temperature (a rough indicator of heat output), wood moisture content using a Delmhorst (Towaco NJ) model J-2000 meter, real-time PM measurements (TEOM) from the dilution system, speciated PAH (week-one only, five samples), and for the first test using the rotating disk dilutor, a verification of dilution ratio. During the first test, stack SO2 was also measured. A Thermo/MIE (Franklin, MA) DR-4 nephelometer was also used during the last two weeks of testing; size correction was set to "off" and data were collected at 1-minute intervals. The DR-4 data were not used, since it was clear from casual comparisons to the TEOM that the DR-4 was not able to measure the fresh smoke aerosol with any degree of consistency.

PAH samples were collected using a filter/XAD-2 trap sampler and analyzed using CARB Method 429. The PAH data are the sum of both gas and particulate phase. The collection duration was four hours. Naphthalene dominates all other PAHs by a very large degree. Calculated PAH emissions in grams per hour for measured species are presented in table 3-1.

A model 1400AB TEOM was used for PM measurements without any size-cut inlet. Flow was reduced to 1.0 standard liters per minute, and time constants were reduced from 300/300 to 30/30 seconds. Data were recorded at 1-minute intervals. Slope and offset factors were set to 1.0 and 0 respectively. The system temperatures were set to between 20 and 30C depending on ambient dew point. This difference in filter temperature might affect results, with higher TEOM filter temperatures resulting in lower PM measurements.

As a check on TEOM performance, 47-mm Teflon filter gravimetric samples were collected from the same sample location as the TEOM using Savillex filter holders. These filter samples were low flow (1 to 2 lpm) and short duration (1-2 hours). These are conditions that minimize loss of semi-volatile PM from the filter. Samples were refrigerated immediately after collection and analyzed by CT DEP. Filters from weeks three and four were weighed both immediately after removal from refrigeration and then again after 24-hours equilibration; there was a very consistent mass loss of 13 percent (R2 = 0.998). It is unclear if it is water or semi-volatile PM, but since the sample RH was not high and the sample composition being mostly organic carbon (not prone to absorbing water), it can be assumed it is loss of volatile components of wood smoke aerosol. Another rationale that the loss is not water is that the filters were collected over a wide range of RH, and that would cause a substantial range of water uptake if that were occurring. Thus, the very high correlation noted above indicates that it is unlikely that water loss that is driving the 13 percent mass loss during filter equilibration.

3. SUMMARY OF PM EMISSION RESULTS FOR ALL TESTS

3.1 Introduction

PM emissions for these tests were characterized as grams per hour at 25C and 1013 mb (STP) and were not corrected for water vapor. Emissions varied greatly depending on the damper mode (open or closed); damper open mode is when the bulk of emissions occur. Damper closed emissions are much lower and don't really contribute to the overall emissions because of much lower stack flows and much lower stack PM concentrations. Taken together, these factors reduce damper closed PM emissions to a very low level, causing damper open emissions to drive the overall PM emission rates.

Because of this, a mean emission rate (grams per hour) is sensitive to the ratio of damper open/closed time, which wasn't always the same across all tests. One of the lessons learned is that having some idea of the overall OWB load with respect to the percent of time the firing air damper is open is essential in estimating average emissions for any in-use OWB. Results reported here focus on damper open PM emission rates.

It was also noted that emissions are much higher during the first half of the burn cycle. Emissions were especially high during the first hour or so after a fresh load of wood. Once the wood is mostly burned to charcoal, PM emissions drop substantially. For days when a 600 pound load was burned for two successive test days, PM emissions for the second test day were always substantially lower. Time-series plots for each run are presented below.

3.2 Results

The emissions data presented here are constrained to damper open mode, and are the mean pm in grams per hour. The range of percent wood moisture content readings is also reported.

3.2.1 Fall tests with RDD; TEOM at 30C

Oct. 2: 71 g/h 611 lb of wood on lot, seasoned hardwood for all three days in October.
Moisture: 14 to 29 percent

Oct. 3: 55 g/h 614 lb fresh load of wood on lot (moisture same as Oct. 2)

Oct. 4: 24 g/h (continued burn of load from Oct. 3 - mostly charcoal)

3.2.2 Tests with catalyst

The second week of fall testing was with the prototype catalyst - these results can not be compared to other test burns. Data are constrained to times when the catalyst was working. Catalyst performance was erratic, resulting in very different results for the two days. Moisture same as Oct. 2 (same OWB owner's wood pile):

Oct. 10: 12 g/h 600 lb fresh load of wood on lot (moisture same as Oct. 2)

Oct. 11: 1.5 g/h (continued burn of Oct. 10 wood load)

3.2.3 Dilution tunnel tests, winter/spring 2008

Week of March 11: TEOM at 20C.

Mar 11: 221 g/h 300 lb wet hemlock slab; moisture range: 21-35 percent

Mar 12: 265 g/h 300 lb "kiln-dry" white pine; moisture range: 11- 28 percent

Mar 13: 147 g/h 300 lb "wet" mixed hardwood; moisture range: 26 - 36 percent

Week of April 8: TEOM at 25C.

Apr 8: 81 g/h 300 lb EPA Method 28 seasoned oak crib; moisture range: 14 - 29 percent

Apr 9: 96 g/h 300 lb seasoned mixed hardwood; moisture range: 13 - 39 percent

Apr 10: 81 g/h 150 lb seasoned mixed hardwood, burned to end of load; moisture range: 15 - 37 percent

3.2.4 PAH results

Table 3-1. PAH Emissions

PAH	PAH Emissions in Grams per Hour @ STP, Wet				
Date	10/2/2007	10/3/2007	10/3/2007	10/4/2007	10/4/2007
naphthalene	0.83283	0.51363	3.60259	5.17109	4.94183
2-methylnaphthalene	0.02023	0.05119	0.08455	0.18409	0.07079
acenaphthylene	0.00060	0.00164	0.00169	0.00236	0.00320
acenaphthene	0.00093	0.00187	0.00180	0.00234	0.00212
fluorene	0.00116			0.00311	
phenanthrene	0.00151	0.00381	0.00323	0.00405	0.00185
anthracene		0.00023		0.00023	
fluoranthene	0.00128	0.00504	0.00216	0.00121	0.00169
pyrene	0.00192	0.00650	0.00308	0.00268	
benzo(a)anthracene	0.00283	0.00596	0.00143	0.00063	0.00078
chrysene	0.00353	0.00736	0.00168	0.00061	0.07594
benzo(b)fluroanthene	0.00315			0.00047	
benzo(k)fluroanthene		0.00687	0.00184		0.00035
benzo(e)pyrene	0.00094		0.00087	0.00029	0.00008
benzo(a)pyrene	0.00127	0.00149	0.00102	0.00026	0.00008
perylene	0.00018		0.00021	0.00027	0.00002
indeno(1,2,3-c,d)pyrene	0.00043	0.00083	0.00034	0.00013	0.00012
dibenzo(a,h)anthracene	0.00011	0.00024	0.00011	0.00003	
benzo(g,h,i)perlene	0.00055	0.00104	0.00047	0.00014	0.00013
PM g/h @ STP, Wet	30.7	42.9	14.5	17.1	14.5
Percent damper open:	34.7	48.3	41.3	54.7	51.3

Notes: Oct. 2 and 3 runs are with new full wood load; Oct. 4 is with Oct. 3's load.
Empty cells indicate non-detects. Values are the sum of gas and vapor phase PAH.
PM emissions match PAH sample collection time.

Virtually all the PAH by mass is naphthalene for all the samples. For the last three samples, it makes up 25 to 30 percent of the total PM emissions. While this does not mean PAHs make up that amount of the PM (since gas phase PAH is included here), it does indicate that OWBs can be very large sources of naphthalene. Additional detail on the PAH sampling method is included in the appendix to this report.

3.2.5 Summary of Results

One would expect that average damper open PM emissions for October 2 and 3 would be somewhat similar to April 8-10, and that is what we observed. Softwood (hemlock, pine) is very dirty, as expected. Wet hardwood (maple, birch, oak) is dirtier than seasoned hardwood, again as expected. The PM emissions for seasoned hardwood (October 2-3 and April 8-10) are reasonably similar, giving confidence that the two different dilution methods are reasonably comparable. The EPA Method 28 crib burn was somewhat cleaner than a similar load of mixed hard cordwood, again as expected because of optimal air circulation with the crib load's construction. The smaller load of April 10 seasoned mixed hardwood was somewhat cleaner than the same but larger 300 pound load of April 9, again as expected. Time series plots for each burn day are included in the appendix to this report.

There is a caveat for emission data across weeks in addition to the two different dilution methods used: the TEOM was run at different temperatures each week for various reasons. The most important need was that filter temperature had to be well above ambient dew point. Higher TEOM temperatures could result in lower PM measurements - how much is hard to estimate. A five degree C increase should not be the driver behind the March and April results. The gravimetric filter measurements let us control for different TEOM responses across the study; those differences varied from +30 percent to -20 percent depending on the test week, and are not applied to the data presented here. Regressions of the TEOM PM vs. matching gravimetric filter data for each burn week (except the catalyst test week) are included in the appendix.

Stack concentrations of SO_2 were 20 to 30 ppm during the first week of tests. A sample of the wood being burned was sent to EPA for analysis. 100 ppm Sulfur was found in that sample. Presumably wet sulfur deposition is the source of the sulfur found in the wood, and the cause of SO_2 emissions in the stack. The full elemental analysis of that wood is presented in section 4.

4. Discussion and Conclusions

4.1 Effect on emissions due to fuel use

The range in emissions of 24 to 265 grams per hour obtained from the testing program suggests that fuel type and characteristics will greatly affect "real-world" OWB emissions. Testing from this project indicates that fuel parameters, such as moisture content and wood species, play a vital role in determining air emission outcomes. Test results showed that burning seasoned hardwood resulted in the lowest emission outcomes. Table 4-1 displays the emissions from the hardwood loads. These data suggest that emissions from various seasoned hardwood loads occur within a small range from 55 grams per hour to 96 grams per hour. However, when the moisture content of the fuel charge increases by 10 percent, emissions increase by 65 percent to 167 percent over those obtained with seasoned hardwood.

Table 4-1. Emissions from Hardwood loads

Date of Test	PM Emissions, grams/hour STP	Wood Load Description	Wood Moisture Content Range (%)
10/3/07	55	614 lb user's hardwood, split	14-29
10/2/07	71	611 lb user's hardwood, split	14-29
4/10/08	81	150 lb seasoned hardwood, split	15-37 (same woodpile as 4/9)
4/8/08	81	300 lb EPA crib red oak dimensional lumber	14-29
4/9/08	96	300 lb seasoned hardwood, split	13-39
3/13/08	147	300 lb "wet" mixed hardwood, split	26-36

Emission tests conducted during this project (see Table 4-2) using softwood similar to that used for indoor woodstove testing indicated that emissions from this fuel type could be 200 to 500 percent higher than those obtained from burning hardwood. In addition, the testing found that emissions were highest (265 g/hr) when using a fuel type similar to that used with EPA Method 28 for indoor woodstoves. This compares with an emission rate of 81 grams per hour when using the fuel type indicated with EPA Method 28 for OWBs. This indicates that the test for indoor woodstoves may be more rigorous than the test required for OWBs.

Table 4-2. Emissions from Softwood Loads

Date of Test	PM Emissions, grams/hour STP	Wood Load Description	Wood Moisture Content Range (%)
3/11/08	221	300 lb wet hemlock slab, 48" lengths	21-35
3/12/08	265	300 lb "kiln dry" white pine split	11-28

Testing indicates that emissions at the end of the fuel charge, as well as those during damper down times, may significantly underestimate short term impacts. Emissions from the continued loads represent the lowest emissions. Emissions from these loads were 50 percent to 90 percent cleaner than those from the first 8 hours of the fuel charge (see Table 4-3). In order to determine accurate short term impacts, changes in testing would be required to either set testing at a pre-determined time length or to use real-time monitoring techniques to capture changes in emissions over time.

Table 4-3. Emissions from end of fuel charge

Date of Test	PM Emissions, grams/hour STP	Wood Load Description	Wood Moisture Content Range (%)
10/4/07	24	continued burn of 10/3 load	n/a
10/11/07 (Catalyst)	1.5	continued burn of 10/10 load	n/a

4.2 Issues Related to Fueling Protocols

Work could be done with EPA to revise EPA Method 28 OWHH to more closely approximate worst case scenario. Use of this option would harmonize emission results from indoor woodstoves and OWBs and provide a better method for comparing emissions across residential wood burning devices. There may be some opposition from industry to this approach.

One regulatory strategy would be to develop and enforce fuel requirements for users. This option would be difficult and resource intensive to enforce. In addition, many states are precluded from taking enforcement actions in residential situations. Emissions other than PM should be investigated further.

This work suggests that the species of wood and moisture content play critical roles in determining the extent of emissions from wood burning. It is possible that these parameters will play a critical role in emission outcomes in all wood burning devices. States should consider developing fuel protocols for all wood burning sources, including wood pellets and wood chips, to ensure the lowest possible emission outcomes.

4.3 Use of Control Technologies

This project tested the impact of an add-on control device to reduce emissions. This control device was external to the OWB, and was an oxidation catalyst with a propane pre-heater. Table 4 highlights the emission measured from using the prototype control device. Based on the testing, an 80 percent reduction in emissions could be obtained during high load times and a 94 percent reduction during low load times.

Table 4-4. Emissions from add on control devices

Date of Test	PM Emissions, grams/hour STP	Wood Load Description	Wood Moisture Content Range (%)
10/10/07 (Catalyst)	12	610 lb user’s hardwood, split	14-29
10/11/07 (Catalyst)	1.5	continued burn of 10/10 load	n/a

4.3.1 Recommendations

To date, regulatory actions have focused on placing emission limits on new units. Within one year’s time, the regulatory actions have resulted in a reduction of emissions over previous units by as much as 95 percent. Little to no action, however, has been focused on add-on technology to address existing units, a significant portion of the air quality problem. Based on the data obtained in this project, reducing emissions from existing units is technically feasible. It is likely that emissions from existing OWBs could be reduced significantly if programs were put in place that require the use of add-on control technologies or require emission limits on the existing fleets of OWBs. However, there are no commercially available retrofit technologies available at this time.

4.4 Other Pollutants of Concern

The primary pollutant of concern from wood burning has traditionally been particulate matter, PAHs, and POMs. Under this work, NESCAUM also completed elemental analysis of a limited sample of the fuel used for testing. This analysis revealed elemental sulfur levels fifty times higher than anticipated based on EPA studies. While the data set completed under this project is too limited to make conclusive findings, it does raise concerns regarding the potential emissions of other pollutants, especially in areas prone to acid deposition and other pollutants often related to the burning of coal. Specific pollutants of concern include sulfur dioxide and mercury. To this day, there has been no study of the elemental constituents of wood in the Northeast. Based upon these preliminary findings, NESCAUM recommends that emission tests on all wood burning in the Northeast should include characterization of sulfur dioxide and mercury emissions. Additionally, research regarding the effects of soil constituents and air pollution on the elemental composition of wood would provide further insights.

Table 4-5. Elemental analysis of OWB owner's wood

PANalytical

Sample WOOD

IQ+ concentrations of sample WOOD

	Compound Name	Conc. (%)	Absolute Error (%)
1	C6H10O5	(99.77)	
2	Mg	0.008653	0.001
3	Al	0.04703	0.001
4	Si	0.01665	0.001
5	P	0.001100	0.001
6	S	0.01134	0.001
7	K	0.07914	0.001
8	Ca	0.05234	0.001
9	Mn	0.008213	0.001
10	Fe	0.009439	0.001

Normalised to: 100. %

Appendices

1. Eleven time series plots of grams per hour PM emissions and stack mode/temperature
2. TEOM vs. filter scatter-plots for weeks 1, 3, and 4
3. Scatter-plot of mass loss over 24 hour filter equilibration for weeks 3-4
4. PAH Laboratory report excerpt and documentation of sample run times and volumes.