



**StoveCAT Woodstove Retrofit  
Efficacy Testing OMNI Report**

**# 0323WS001N**

**Prepared for:**

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## 1. Introduction

OMNI-Test Laboratories, Inc. (OMNI) was contracted by Puget Sound Clean Air Agency (PSCAA) to evaluate whether provided woodstove retrofit devices were able to effectively reduce particulate matter (PM) and polycyclic aromatic hydrocarbon (PAH) emissions from residential wood burning stoves that predate EPA emissions certification.

Testing was performed on two different uncertified stoves without any retrofit device over a range of specified operating conditions in order to establish a baseline set of results. The stoves were then equipped with the provided retrofit devices to compare test results against the baseline data. This evaluation contracted is for emission evaluations only. The retrofit devices connected to the systems were not evaluated against any safety or installation requirements.

The two uncertified stoves used for testing were already in OMNI's possession for the purpose of performing studies similar in nature to this project. The stoves and their relative condition are discussed in Section 2 of this report.

A total of four retrofit devices were evaluated for this project. Each device for testing was selected by PSCAA. A representative sample of each retrofit device was submitted to OMNI from the manufacturer of each product at the beginning of the testing phase. Further descriptions of each retrofit device are discussed in Section 2 of this report.

Testing was conducted at OMNI's facilities in Portland, Oregon by Sebastian Button between June 24 and October 16, 2015.

Emissions of total particles (PM) and PAHs were measured. Additionally, carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), temperatures (chimney, room, meter boxes, particulate filters and dilution tunnel), fuel mass, and air and sample flow were measured to support emission and efficiency calculations. Standard methods were used to the extent feasible for all testing.

A detailed description of the testing program is provided as Section 2. The results of the testing are summarized in Section 3. Complete individual test data records, calculations, laboratory notes, PAH lab analyses, calibration records, and photographic documentation can be found in appendices attached to this report.

## 2. Methodology

### 2.1 Measurement Methods

Standard sampling methods were used to collect and monitor all parameters. Table 1 lists the methods used and the pollutants measured. PM samples were collected from a dilution tunnel. PAH samples and supporting measurements were taken from the heater chimney (stack). The pollutants measured included:

- PM measured from the dilution tunnel
- PAHs measured from the stack
- Carbon monoxide (CO) measured from the stack
- Carbon dioxide (CO<sub>2</sub>) measured from the stack

**Table 1 - Compounds, Parameters, Sampling and Monitoring Methods, Collection and Monitoring Devices, Analytical Laboratories, and Analytical Methods**

Group	Analytical Compounds	Sampling Method	Collection Device	Analytical Laboratory	Analytical Method
Particles	Total PM	EPA Method 5G-3	47 mm Glass Fiber A/E Filter	OMNI	Gravimetric
Gases	Carbon Monoxide (CO)	EPA Method 10	Non-dispersive infrared analyzer (NDIR)	N/A	N/A
	Carbon Dioxide(CO <sub>2</sub> )	EPA Method 3A	Non-dispersive infrared analyzer (NDIR)	N/A	N/A
	Polycyclic Aromatic Hydrocarbons (PAH)	EPA Compendium Method 0010	102 mm Glass Fiber A/E Filter & XAD-2 Sorbent Resin	RJ Lee Group	EPA Compendium Method TO-13 Modified*
Efficiency	Flue Gas CO, CO <sub>2</sub>	CSA B415.1-10	Non-dispersive infrared analyzer (NDIR)	N/A	N/A

\*See appropriate laboratory reports in the appendices for modifications to analytical method

In addition to the above sampling methods, the stoves were operated in accordance with EPA Method 28.

### **2.1.1 Method Modifications**

The test methods listed in Section 2.1 were strictly adhered to with a couple of notable exceptions detailed below.

#### **EPA Method 5G-3:**

1. Section 8.5.1 specifies a dilution tunnel flow rate of  $140 \pm 14$  dscf/min. Due to the nature of the stoves used in this project, which have poor heat transfer efficiency, stack gas temperatures were much higher than those typically encountered during 5G-3 testing. As a result of these high stack temperatures, the dilution tunnel flow rate needed to be increased in order to keep tunnel temperatures and filter temperatures manageable.
2. Equation 5G-4, emissions adjustment factor was not used. All emissions rates reported are the raw unadjusted values. The adjustment factor changes emission values in a non-linear manner, which would have the effect of distorting the results of any emission reduction evaluations.

#### **EPA Method 28:**

1. Fuel moisture requirements specified in section 7.1.2 were ignored as required by the test plan to perform tests with higher moisture fuel.
2. Test fuel loading densities were not strictly adhered to as specified in section 8.8.4. All fuel loads were identical with respect to the number and mix of 2x4s and 4x4s, as well as test fuel length. These parameters were established using test loads in the moisture range specified in section 7.1.2. The majority of the higher moisture tests loads were well over the specified loading density, as they contained as much as an extra 3 lbs of water when compared to a fuel load in the proper moisture range.

#### **EPA Compendium Method 0010**

1. Sampling was not done isokinetically in accordance with 6.6.1. This test method is written for tests done on stacks that have flow rates which are more or less constant for the duration of the test. For a batch load process such as a wood stove, flow rates are too variable from test to test and minute to minute to maintain isokinetic flow. Instead of using a hooked nozzle, the sample was withdrawn from the stack from a probe at 90 degrees the flow of stack gases, to negate any effects of stagnation, and the sample rate was kept constant throughout the test run.
2. Upon completion of each test run the filter and XAD-2 cartridge from the PAH sampling system were sealed and stored in a refrigerator until a batch of samples were ready for shipment to the analytical laboratory, RJ Lee Group. All sample recovery and analysis were performed as described in the lab reports in Appendix 3.

## 2.2 Test Appliances and Retrofit Devices

### Schrader Woodstove (Unknown Model)

The Schrader stove is a freestanding woodstove with a medium (1.64 ft<sup>3</sup>) sized firebox and a 6 inch flue collar located on the top of the unit. The unit is constructed primarily of steel and the firebox is lined with firebrick.



Figure 1 - Schrader Woodstove

Combustion air is controlled by dual spin draft knobs on each of the two doors. This stove does not contain any sort of baffling or secondary air combustion. Although the stove body is in good overall condition, the doors do not close tightly, causing an air leak into the stove. This air leak lead to relatively high “low burn” tests, as summarized in Section 3.

**Blaze King Princess (Pre-NSPS Non-catalytic model)**

The princess stove is a freestanding woodstove with a slightly larger (2.14 ft<sup>3</sup>) sized firebox and a 6 inch flue collar located on the top of the unit. This unit is also constructed primarily of steel and the firebox is lined with firebrick.



**Figure 2 - Princess Woodstove**

Combustion air enters the firebox through an opening located at the bottom rear of the heater and is controlled by a flapper door connected to a bimetallic thermostat coil, which reduces airflow with increasing temperature in order to maintain a constant combustion rate. Similar to the Schrader stove, this appliance does not have any secondary air system or internal flame baffling.



## StoveCAT

The StoveCAT retrofit device is a passive system that utilizes a three stage reticulated ceramic catalyst structure and a secondary air intake system to ensure adequate combustion air is present.



Figure 5 – Grace-Fire Device



## 2.3 Test Plan and Summary of Test Runs

The experimental design for this project was developed by PSCAA. For each of the two uncertified woodstoves that were used for testing, a set of baseline emissions results were established by performing a pair of tests with the stove operating within three different operational parameters pairs, as described in Table 2. This resulted in six baseline emissions tests for each woodstove.

**Table 2 - Test Parameters**

<b>Parameter Pair ID</b>	<b>Burn Rate</b>	<b>Wood Moisture</b>
B	Low	Higher (30-40% Dry Basis)
C	High	Higher (30-40% Dry Basis)
D	Low	Lower (19-25% Dry Basis)

For the tests performed on these particular woodstoves, the term “Low Burn Rate” does not strictly adhere to the Method 28 definition of a low burn ( $<0.80$  kg/hr), but is rather in reference to the air control setting, which was adjusted the lowest possible level for each given stove during these tests. As the data summary in Section 3 shows, the low burn rates were higher than 0.80 kg/hr. Similarly, in an effort to maintain consistent results, the target burn rate for “High Burn Rate” tests was 3.0 – 4.0 kg/hr, rather than burning the appliances at the maximum air setting.

Upon completion of the baseline tests on the Schrader stove, each of the four retrofit devices was installed in accordance with instructions received from each manufacturer, and tested once at each of the three parameter pairs. The top three performing retrofit devices, as determined by PSCAA, were then subjected to further tests on the Princess stove.

Table 3 presents a summary of all tests performed, including which test parameter was used. For all tests the air controls were set at the beginning of the test, and not changed until testing was completed; see laboratory run notes in Appendix 4 for exact test settings.



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### Table 3 - Summary of Test Runs Performed

[illegible]

### **3. Testing Results**

#### **3.1 Particulate Sampling Results**

Particulate emissions results for all test runs performed are summarized in Table 4. Complete minute by minute particulate sampling data for each run is presented in Appendix 1. Each test run presented passed all quality checks for precision and proportionality, including pre and post-test leak checks. Table 5 summarizes the calculated efficiencies and CO emissions using CSA B415.1.

As indicated in the laboratory notes in Appendix 4, during several test runs, the front filter of the sampling trains were changed out during testing. The changes were necessary due to particle and moisture loading on the filters, which caused the sample rates to drop to the point that sampling pumps could not maintain sufficient flow. This is a relatively common issue with high emissions appliances, and is one of reasons dual sampling trains are used, to validate results when one of the trains experiences a temporary loss in flow. As mentioned above, even with the filter change outs, sampling proportionality and dual train comparisons were within acceptable limits for each test run.

#### **3.2 PAH Sampling Results**

PAH emissions results are summarized in Table 6. As the lab reports in Appendix 3 explain, for the first set of samples received (Run 2), the filter and the XAD-2 extractions were analyzed separately, but for all subsequent analyses the extractions were combined into a single sample for cost effectiveness.

One issue of note regarding the Run 2 samples; there was the large concentration of phenolic compounds in the extracts, which proved disruptive to the chromatography equipment. After consultations with the analytical laboratory director, it was determined that all subsequent analyses would include a “clean-up” process on the extractions to eliminate the extraneous materials. This process was done primarily to protect the laboratory equipment from potential unwarranted damage, and also allowed for a “cleaner,” targeted analysis of EPA 7-PAHs, which are classified as probable human carcinogens.

### Table 4 – Particulate Matter Emission Results

[illegible]

### Table 5 - Efficiency and CO Emissions Results

Parameter	HHV efficiency	LHV efficiency	CO emission
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## Test Results - EPA Method 28 & 5G

Manufacturer: Schrader  
 Retrofit Device StoveCAT  
 Project No.: 0323WS001N  
 Test Parameter ID: D  
 Run: 18  
 Test Date: 08/24/15

Burn Rate (Composite)	<b>2.14 kg/hr dry</b>
Average Tunnel Temperature	132 degrees Fahrenheit
Average Gas Velocity in Dilution Tunnel - vs	18.45 feet/second
Average Gas Flow Rate in Dilution Tunnel - Qsd	11422.3 dscf/hour
Average Gas Flow Rate in Chimney Flue - Qsf	1163.7 dscf/hour
Average Delta p	0.071 inches H2O
Average Delta H	1.14 inches H2O
Total Time of Test	127 minutes

	PAH SAMPLE TRAIN	PM SAMPLE TRAIN 1	PM SAMPLE TRAIN 2
Total Sample Volume - Vm	8.970 cubic feet	14.460 cubic feet	16.363 cubic feet
Average Orifice Temperature	84 degrees Fahrenheit	93 degrees Fahrenheit	88 degrees Fahrenheit
Total Sample Volume (Standard Conditions) - Vmstd	8.758 dscf	14.187 dscf	16.024 dscf
Total Particulates - m <sub>t</sub>		9.6 mg	9.9 mg
Particulate Concentration (dry-standard) - C <sub>p</sub> /C <sub>s</sub>		0.00068 grams/dscf	0.00062 grams/dscf
Total Particulate Emissions - E <sub>T</sub>	See PAH Analysis	16.36 grams	14.94 grams
Particulate Emission Rate		7.73 grams/hour	7.06 grams/hour
Emissions Factor		3.62 g/kg	3.30 g/kg
Difference from Average Total Particulate Emissions		0.71 grams	0.71 grams
<b>Dual Train Comparison Results Are Acceptable</b>			

### FINAL AVERAGE RESULTS

Total Particulate Emissions - E <sub>T</sub>	15.65 grams
Particulate Emission Rate	<b>7.39 grams/hour</b>
Emissions Factor	3.46 grams/kg

# OMNI-Test Laboratories, Inc.

**Manufacturer:** Schrader  
**Model:** StoveCAT  
**Date:** 08/24/15  
**Run:** 18  
**Control #:** N/A  
**Test Duration:** 127  
**Output Category:** Low

**Technicians:** S. Button

## Test Results in Accordance with CSA B415.1-09

	HHV Basis	LHV Basis
Overall Efficiency	69.2%	74.8%
Combustion Efficiency	97.5%	97.5%
Heat Transfer Efficiency	71%	76.8%

Output Rate (kJ/h)	29,305	27,799	(Btu/h)
Burn Rate (kg/h)	2.14	4.71	(lb/h)
Input (kJ/h)	42,331	40,155	(Btu/h)

Test Load Weight (dry kg)	4.52	9.97	dry lb
MC wet (%)	18.29		
MC dry (%)	22.38		
Particulate (g )	0		
CO (g)	183		
Test Duration (h)	2.12		

Emissions	Particulate	CO
g/MJ Output	0.00	2.95
g/kg Dry Fuel	0.00	40.40
g/h	0.00	86.34
lb/MM Btu Output	0.00	6.85

Air/Fuel Ratio (A/F)	14.03
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## Test Results - EPA Method 28 & 5G

Manufacturer: Schrader  
 Retrofit Device StoveCAT  
 Project No.: 0323WS001N  
 Test Parameter ID: B  
 Run: 19  
 Test Date: 08/25/15

Burn Rate (Composite)	<b>2.38 kg/hr dry</b>
Average Tunnel Temperature	134 degrees Fahrenheit
Average Gas Velocity in Dilution Tunnel - vs	17.16 feet/second
Average Gas Flow Rate in Dilution Tunnel - Qsd	10599.7 dscf/hour
Average Gas Flow Rate in Chimney Flue - Qsf	1177.1 dscf/hour
Average Delta p	0.063 inches H2O
Average Delta H	1.14 inches H2O
Total Time of Test	127 minutes

	PAH SAMPLE TRAIN	PM SAMPLE TRAIN 1	PM SAMPLE TRAIN 2
Total Sample Volume - Vm	8.970 cubic feet	14.423 cubic feet	17.022 cubic feet
Average Orifice Temperature	82 degrees Fahrenheit	90 degrees Fahrenheit	86 degrees Fahrenheit
Total Sample Volume (Standard Conditions) - Vmstd	8.793 dscf	14.226 dscf	16.769 dscf
Total Particulates - m <sub>t</sub>		11.6 mg	13.8 mg
Particulate Concentration (dry-standard) - C <sub>p</sub> /C <sub>s</sub>		0.00082 grams/dscf	0.00082 grams/dscf
Total Particulate Emissions - E <sub>T</sub>	See PAH Analysis	18.29 grams	18.46 grams
Particulate Emission Rate		8.64 grams/hour	8.72 grams/hour
Emissions Factor		3.63 g/kg	3.67 g/kg
Difference from Average Total Particulate Emissions		0.08 grams	0.08 grams
<b>Dual Train Comparison Results Are Acceptable</b>			

### FINAL AVERAGE RESULTS

Total Particulate Emissions - E <sub>T</sub>	18.38 grams
Particulate Emission Rate	<b>8.68 grams/hour</b>
Emissions Factor	3.65 grams/kg

# OMNI-Test Laboratories, Inc.

**Manufacturer:** Schrader  
**Model:** StoveCAT  
**Date:** 08/25/15  
**Run:** 19  
**Control #:** N/A  
**Test Duration:** 127  
**Output Category:** Low

**Technicians:** S. Button  
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## Test Results in Accordance with CSA B415.1-09

	HHV Basis	LHV Basis
Overall Efficiency	67.7%	73.2%
Combustion Efficiency	97.9%	97.9%
Heat Transfer Efficiency	69%	74.7%

Output Rate (kJ/h)	31,908	30,268	(Btu/h)
Burn Rate (kg/h)	2.38	5.24	(lb/h)
Input (kJ/h)	47,141	44,719	(Btu/h)

Test Load Weight (dry kg)	5.04	11.10	dry lb
MC wet (%)	25.99		
MC dry (%)	35.12		
Particulate (g )	0		
CO (g)	175		
Test Duration (h)	2.12		

Emissions	Particulate	CO
g/MJ Output	0.00	2.58
g/kg Dry Fuel	0.00	34.65
g/h	0.00	82.45
lb/MM Btu Output	0.00	6.01

Air/Fuel Ratio (A/F)	13.70
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## Test Results - EPA Method 28 & 5G

Manufacturer: Schrader  
 Retrofit Device StoveCAT  
 Project No.: 0323WS001N  
 Test Parameter ID: C  
 Run: 20  
 Test Date: 08/26/15

Burn Rate (Composite)	<b>3.74 kg/hr dry</b>
Average Tunnel Temperature	177 degrees Fahrenheit
Average Gas Velocity in Dilution Tunnel - vs	19.44 feet/second
Average Gas Flow Rate in Dilution Tunnel - Qsd	11174.6 dscf/hour
Average Gas Flow Rate in Chimney Flue - Qsf	1529.2 dscf/hour
Average Delta p	0.076 inches H2O
Average Delta H	1.16 inches H2O
Total Time of Test	79 minutes

	PAH SAMPLE TRAIN	PM SAMPLE TRAIN 1	PM SAMPLE TRAIN 2
Total Sample Volume - Vm	5.580 cubic feet	9.105 cubic feet	9.944 cubic feet
Average Orifice Temperature	83 degrees Fahrenheit	93 degrees Fahrenheit	87 degrees Fahrenheit
Total Sample Volume (Standard Conditions) - Vmstd	5.446 dscf	8.927 dscf	9.752 dscf
Total Particulates - m <sub>t</sub>		5.3 mg	5.4 mg
Particulate Concentration (dry-standard) - C <sub>p</sub> /C <sub>s</sub>		0.00059 grams/dscf	0.00055 grams/dscf
Total Particulate Emissions - E <sub>T</sub>	See PAH Analysis	8.74 grams	8.15 grams
Particulate Emission Rate		6.63 grams/hour	6.19 grams/hour
Emissions Factor		1.77 g/kg	1.65 g/kg
Difference from Average Total Particulate Emissions		0.29 grams	0.29 grams
<b>Dual Train Comparison Results Are Acceptable</b>			

### FINAL AVERAGE RESULTS

Total Particulate Emissions - E <sub>T</sub>	8.44 grams
Particulate Emission Rate	<b>6.41 grams/hour</b>
Emissions Factor	1.71 grams/kg

# OMNI-Test Laboratories, Inc.

**Manufacturer:** Schrader  
**Model:** StoveCAT  
**Date:** 08/26/15  
**Run:** 20  
**Control #:** N/A  
**Test Duration:** 79  
**Output Category:** High

**Technicians:** S. Button  
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## Test Results in Accordance with CSA B415.1-09

	HHV Basis	LHV Basis
Overall Efficiency	64.4%	69.6%
Combustion Efficiency	96.5%	96.5%
Heat Transfer Efficiency	67%	72.2%

Output Rate (kJ/h)	47,776	45,320	(Btu/h)
Burn Rate (kg/h)	3.74	8.25	(lb/h)
Input (kJ/h)	74,148	70,337	(Btu/h)

Test Load Weight (dry kg)	4.93	10.86	dry lb
MC wet (%)	26.11		
MC dry (%)	35.34		
Particulate (g )	0		
CO (g)	254		
Test Duration (h)	1.32		

Emissions	Particulate	CO
g/MJ Output	0.00	4.04
g/kg Dry Fuel	0.00	51.51
g/h	0.00	192.79
lb/MM Btu Output	0.00	9.38

Air/Fuel Ratio (A/F)	11.87
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## Test Results - EPA Method 28 & 5G

Manufacturer: Princess  
 Retrofit Device StoveCAT  
 Project No.: 0323WS001N  
 Test Parameter ID: C  
 Run: 31  
 Test Date: 09/28/15

Burn Rate (Composite)	<b>2.47 kg/hr dry</b>
Average Tunnel Temperature	131 degrees Fahrenheit
Average Gas Velocity in Dilution Tunnel - vs	16.70 feet/second
Average Gas Flow Rate in Dilution Tunnel - Qsd	10305.8 dscf/hour
Average Gas Flow Rate in Chimney Flue - Qsf	1562.2 dscf/hour
Average Delta p	0.067 inches H2O
Average Delta H	1.11 inches H2O
Total Time of Test	139 minutes

	PAH SAMPLE TRAIN	PM SAMPLE TRAIN 1	PM SAMPLE TRAIN 2
Total Sample Volume - Vm	9.817 cubic feet	15.628 cubic feet	17.123 cubic feet
Average Orifice Temperature	79 degrees Fahrenheit	88 degrees Fahrenheit	84 degrees Fahrenheit
Total Sample Volume (Standard Conditions) - Vmstd	9.625 dscf	15.274 dscf	16.726 dscf
Total Particulates - m <sub>t</sub>		15.7 mg	17.6 mg
Particulate Concentration (dry-standard) - C <sub>i</sub> /C <sub>s</sub>		0.00103 grams/dscf	0.00105 grams/dscf
Total Particulate Emissions - E <sub>T</sub>	See PAH Analysis	24.54 grams	25.12 grams
Particulate Emission Rate		10.59 grams/hour	10.84 grams/hour
Emissions Factor		4.29 g/kg	4.39 g/kg
Difference from Average Total Particulate Emissions		0.29 grams	0.29 grams
<b>Dual Train Comparison Results Are Acceptable</b>			

### FINAL AVERAGE RESULTS

Total Particulate Emissions - E <sub>T</sub>	24.83 grams
Particulate Emission Rate	<b>10.72 grams/hour</b>
Emissions Factor	4.34 grams/kg

# OMNI-Test Laboratories, Inc.

**Manufacturer:** Princess  
**Model:** StoveCAT  
**Date:** 09/28/15  
**Run:** 31  
**Control #:** N/A  
**Test Duration:** 139  
**Output Category:** High

**Technicians:** S. Button  
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## Test Results in Accordance with CSA B415.1-09

	HHV Basis	LHV Basis
Overall Efficiency	56.4%	61.0%
Combustion Efficiency	96.4%	96.4%
Heat Transfer Efficiency	59%	63.3%

Output Rate (kJ/h)	27,604	26,186	(Btu/h)
Burn Rate (kg/h)	2.47	5.44	(lb/h)
Input (kJ/h)	48,925	46,410	(Btu/h)

Test Load Weight (dry kg)	5.72	12.61	dry lb
MC wet (%)	24.94		
MC dry (%)	33.23		
Particulate (g )	0		
CO (g)	347		
Test Duration (h)	2.32		

Emissions	Particulate	CO
g/MJ Output	0.00	5.42
g/kg Dry Fuel	0.00	60.63
g/h	0.00	149.73
lb/MM Btu Output	0.00	12.61

Air/Fuel Ratio (A/F)	20.35
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## Test Results - EPA Method 28 & 5G

Manufacturer: Princess  
 Retrofit Device StoveCAT  
 Project No.: 0323WS001N  
 Test Parameter ID: B  
 Run: 32  
 Test Date: 09/29/15

Burn Rate (Composite)	<b>1.43 kg/hr dry</b>
Average Tunnel Temperature	112 degrees Fahrenheit
Average Gas Velocity in Dilution Tunnel - vs	17.44 feet/second
Average Gas Flow Rate in Dilution Tunnel - Qsd	11130.6 dscf/hour
Average Gas Flow Rate in Chimney Flue - Qsf	965.1 dscf/hour
Average Delta p	0.070 inches H2O
Average Delta H	1.08 inches H2O
Total Time of Test	227 minutes

	PAH SAMPLE TRAIN	PM SAMPLE TRAIN 1	PM SAMPLE TRAIN 2
Total Sample Volume - Vm	16.033 cubic feet	25.173 cubic feet	26.954 cubic feet
Average Orifice Temperature	80 degrees Fahrenheit	89 degrees Fahrenheit	86 degrees Fahrenheit
Total Sample Volume (Standard Conditions) - Vmstd	15.696 dscf	24.574 dscf	26.243 dscf
Total Particulates - m <sub>t</sub>		27.1 mg	29.1 mg
Particulate Concentration (dry-standard) - C <sub>p</sub> /C <sub>s</sub>		0.00110 grams/dscf	0.00111 grams/dscf
Total Particulate Emissions - E <sub>T</sub>	See PAH Analysis	46.44 grams	46.69 grams
Particulate Emission Rate		12.27 grams/hour	12.34 grams/hour
Emissions Factor		8.57 g/kg	8.61 g/kg
Difference from Average Total Particulate Emissions		0.13 grams	0.13 grams
<b>Dual Train Comparison Results Are Acceptable</b>			

### FINAL AVERAGE RESULTS

Total Particulate Emissions - E <sub>T</sub>	46.57 grams
Particulate Emission Rate	<b>12.31 grams/hour</b>
Emissions Factor	8.59 grams/kg

# OMNI-Test Laboratories, Inc.

**Manufacturer:** Princess  
**Model:** StoveCAT  
**Date:** 09/29/15  
**Run:** 32  
**Control #:** N/A  
**Test Duration:** 227  
**Output Category:** Low

**Technicians:** S. Button

## Test Results in Accordance with CSA B415.1-09

	HHV Basis	LHV Basis
Overall Efficiency	56.3%	60.8%
Combustion Efficiency	93.0%	93.0%
Heat Transfer Efficiency	61%	65.4%

Output Rate (kJ/h)	15,980	15,159	(Btu/h)
Burn Rate (kg/h)	1.43	3.16	(lb/h)
Input (kJ/h)	28,389	26,930	(Btu/h)

Test Load Weight (dry kg)	5.42	11.95	dry lb
MC wet (%)	24.37		
MC dry (%)	32.22		
Particulate (g )	0		
CO (g)	590		
Test Duration (h)	3.78		

Emissions	Particulate	CO
g/MJ Output	0.00	9.75
g/kg Dry Fuel	0.00	108.74
g/h	0.00	155.84
lb/MM Btu Output	0.00	22.66

Air/Fuel Ratio (A/F)	23.32
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## Test Results - EPA Method 28 & 5G

Manufacturer: Princess  
 Retrofit Device StoveCAT  
 Project No.: 0323WS001N  
 Test Parameter ID: D  
 Run: 33  
 Test Date: 09/30/15

Burn Rate (Composite)	<b>1.18 kg/hr dry</b>
Average Tunnel Temperature	106 degrees Fahrenheit
Average Gas Velocity in Dilution Tunnel - vs	16.10 feet/second
Average Gas Flow Rate in Dilution Tunnel - Qsd	10410.0 dscf/hour
Average Gas Flow Rate in Chimney Flue - Qsf	908.5 dscf/hour
Average Delta p	0.065 inches H2O
Average Delta H	1.12 inches H2O
Total Time of Test	318 minutes

	PAH SAMPLE TRAIN	PM SAMPLE TRAIN 1	PM SAMPLE TRAIN 2
Total Sample Volume - Vm	22.460 cubic feet	35.795 cubic feet	39.579 cubic feet
Average Orifice Temperature	78 degrees Fahrenheit	88 degrees Fahrenheit	85 degrees Fahrenheit
Total Sample Volume (Standard Conditions) - Vmstd	22.113 dscf	35.117 dscf	38.750 dscf
Total Particulates - m <sub>t</sub>		22 mg	23.6 mg
Particulate Concentration (dry-standard) - C <sub>p</sub> /C <sub>s</sub>		0.00063 grams/dscf	0.00061 grams/dscf
Total Particulate Emissions - E <sub>T</sub>	See PAH Analysis	34.56 grams	33.60 grams
Particulate Emission Rate		6.52 grams/hour	6.34 grams/hour
Emissions Factor		5.53 g/kg	5.38 g/kg
Difference from Average Total Particulate Emissions		0.48 grams	0.48 grams
<b>Dual Train Comparison Results Are Acceptable</b>			

### FINAL AVERAGE RESULTS

Total Particulate Emissions - E <sub>T</sub>	34.08 grams
Particulate Emission Rate	<b>6.43 grams/hour</b>
Emissions Factor	5.46 grams/kg

# OMNI-Test Laboratories, Inc.

**Manufacturer:** Princess  
**Model:** StoveCAT  
**Date:** 09/30/15  
**Run:** 33  
**Control #:** N/A  
**Test Duration:** 318  
**Output Category:** Low

**Technicians:** S. Button  
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 \_\_\_\_\_  
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## Test Results in Accordance with CSA B415.1-09

	HHV Basis	LHV Basis
Overall Efficiency	55.8%	60.3%
Combustion Efficiency	94.1%	94.1%
Heat Transfer Efficiency	59%	64.1%

Output Rate (kJ/h)	13,030	12,360	(Btu/h)
Burn Rate (kg/h)	1.18	2.60	(lb/h)
Input (kJ/h)	23,349	22,149	(Btu/h)

Test Load Weight (dry kg)	6.25	13.77	dry lb
MC wet (%)	17.06		
MC dry (%)	20.57		
Particulate (g )	0		
CO (g)	592		
Test Duration (h)	5.30		

Emissions	Particulate	CO
g/MJ Output	0.00	8.57
g/kg Dry Fuel	0.00	94.71
g/h	0.00	111.63
lb/MM Btu Output	0.00	19.91

Air/Fuel Ratio (A/F)	24.55
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VERSION:

2.3

3/23/2010

## Test Results - EPA Method 28 & 5G

Manufacturer: Princess  
 Retrofit Device StoveCAT  
 Project No.: 0323WS001N  
 Test Parameter ID: B  
 Run: 34  
 Test Date: 10/01/15

Burn Rate (Composite)	<b>1.42 kg/hr dry</b>
Average Tunnel Temperature	105 degrees Fahrenheit
Average Gas Velocity in Dilution Tunnel - vs	16.75 feet/second
Average Gas Flow Rate in Dilution Tunnel - Qsd	10867.8 dscf/hour
Average Gas Flow Rate in Chimney Flue - Qsf	1193.6 dscf/hour
Average Delta p	0.067 inches H2O
Average Delta H	1.09 inches H2O
Total Time of Test	259 minutes

	PAH SAMPLE TRAIN	PM SAMPLE TRAIN 1	PM SAMPLE TRAIN 2
Total Sample Volume - Vm	18.293 cubic feet	28.614 cubic feet	31.385 cubic feet
Average Orifice Temperature	75 degrees Fahrenheit	84 degrees Fahrenheit	81 degrees Fahrenheit
Total Sample Volume (Standard Conditions) - Vmstd	18.136 dscf	28.294 dscf	30.961 dscf
Total Particulates - m <sub>t</sub>		41.1 mg	41.1 mg
Particulate Concentration (dry-standard) - C <sub>p</sub> /C <sub>s</sub>		0.00145 grams/dscf	0.00133 grams/dscf
Total Particulate Emissions - E <sub>T</sub>	See PAH Analysis	68.15 grams	62.28 grams
Particulate Emission Rate		15.79 grams/hour	14.43 grams/hour
Emissions Factor		11.10 g/kg	10.15 g/kg
Difference from Average Total Particulate Emissions		2.93 grams	2.93 grams
<b>Dual Train Comparison Results Are Acceptable</b>			

### FINAL AVERAGE RESULTS

Total Particulate Emissions - E <sub>T</sub>	65.21 grams
Particulate Emission Rate	<b>15.11 grams/hour</b>
Emissions Factor	10.63 grams/kg

# OMNI-Test Laboratories, Inc.

**Manufacturer:** Princess  
**Model:** StoveCAT  
**Date:** 10/01/15  
**Run:** 34  
**Control #:** N/A  
**Test Duration:** 257  
**Output Category:** Low

**Technicians:** S. Button

## Test Results in Accordance with CSA B415.1-09

	HHV Basis	LHV Basis
Overall Efficiency	55.0%	59.5%
Combustion Efficiency	93.2%	93.2%
Heat Transfer Efficiency	59%	63.8%

Output Rate (kJ/h)	15,619	14,816	(Btu/h)
Burn Rate (kg/h)	1.43	3.16	(lb/h)
Input (kJ/h)	28,391	26,932	(Btu/h)

Test Load Weight (dry kg)	6.14	13.53	dry lb
MC wet (%)	23.99		
MC dry (%)	31.56		
Particulate (g )	0		
CO (g)	682		
Test Duration (h)	4.28		

Emissions	Particulate	CO
g/MJ Output	0.00	10.20
g/kg Dry Fuel	0.00	111.15
g/h	0.00	159.30
lb/MM Btu Output	0.00	23.70

Air/Fuel Ratio (A/F)	25.24
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VERSION:

2.3

3/23/2010



#### 4. Testing Results

##### Emissions Reduction

### **Puget Sound Clean Air Agency Mean Reduction in Emissions for StoveCAT Wood Heater Retro-Fit Compared to Baseline on Two Uncertified Wood Stoves**

