6.3. 2022 Air Quality Projects – NO2 & SO2 Monitoring and ULEB testing

Prepared for:	Environmental Science and Policy Comm
Report No.	SPS2310
Activity:	Governance Report
Author:	Sarah Harrison, Scientist - Air Quality
Endorsed by:	Anita Dawe, General Manager Policy and Science
Date:	26 April 2023

PURPOSE

[1] This report presents the results of the two air quality projects undertaken during 2022: Nitrogen Dioxide (NO_2) and Sulphur Dioxide (SO_2) monitoring in Central Dunedin, and in home Ultra-Low Emission Burner (ULEB) testing in Arrowtown.

EXECUTIVE SUMMARY

[2] Nitrogen dioxide and sulphur dioxide were monitored in Central Dunedin for a period of three months, with the resulting concentrations compliant with the NESAQ limits.

[3] Ultra-low emission burner (ULEB) testing was undertaken within seven homes in Arrowtown, in order to accurately record the emissions from real-life use of the burners. This information contributes towards national understanding of the factors that influence emissions and efficiency of wood burners.

RECOMMENDATION

That the Environmental Science and Policy Committee*:*

1) ***Notes** this report.*

BACKGROUND

[4] In addition to required State of the Environment air quality monitoring, ORC air quality scientists periodically undertake specific projects to address key questions or monitor sites or parameters that are outside the regular SOE air quality monitoring programme.

NITROGEN DIOXIDE AND SULPHUR DIOXIDE MONITORING PROJECT

[5] A short-term project was undertaken at the Central Dunedin air quality monitoring site over the winter months of 2022 to monitor nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) using continuous gas analysers. Watercare Laboratory Services provided the sampling equipment and undertook the monitoring.

[6] NO_2 forms during the combustion of fossil fuels, and vehicle emissions are the main sources of NO_2 in urban areas. SO_2 is produced during the combustion of sulphur-containing fossil fuels such as coal. Diesel vehicle and industrial emissions are primary sources of SO_2 in Otago.

[7] Previous monitoring between 1998 and 2005 of NO_2 and carbon monoxide (CO) has been undertaken in Dunedin and Alexandra, and there were no exceedances of New Zealand standards or guidelines. Carbon monoxide (CO) concentrations have been significantly reduced in New Zealand (due to increased vehicle emission requirements), and concentrations are now much lower than the NESAQ (MfE, 2021), so monitoring for CO in the 2022 campaign was not considered necessary. The standards and guidelines for NO_2 and SO_2 are given in Table 1.

Table 1 Standards and guidelines for NO_2 and SO_2

Pollutant	Averaging Time	NESAQ 2004		AAQG 2002		WHO 2021	
		Limit (µg/m³)	Allowable exceedances	Limit (µg/m³)	Allowable exceedances	Limit (µg/m³)	Allowable exceedances
NO_2	1-hour	200	9				
	24-hour			100	NA	25*	3-4
	Annual					10	NA
SO_2	1-hour	350	9				
	1-hour	570	NA				
	24-hours			120	NA	40*	3-4

*99th percentile

[8] The results of the monitoring are shown in the following graphs. NO_2 concentrations were below the NESAQ 1-hour limit of 200 µg/m³, and the AAQG 24-hour limit of 100 µg/m³. On 01/08/2022 the 24-hour average NO_2 concentration was 29 µg/m³, an exceedance of the WHO guideline of 25 µg/m³ (Figure 1), however this guideline allows between 3-4 exceedances per year. SO_2 concentrations did not exceed any standards or guidelines (Figure 2).

Figure 1 NO$_2$ concentrations for July – November 2022

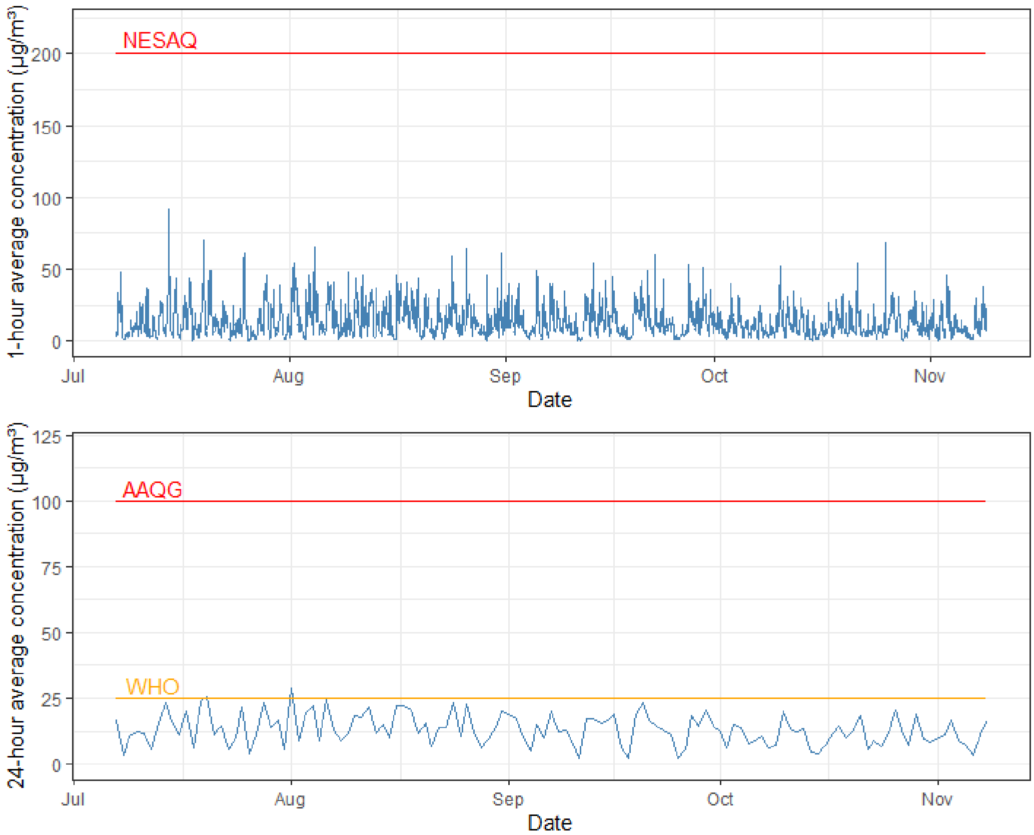
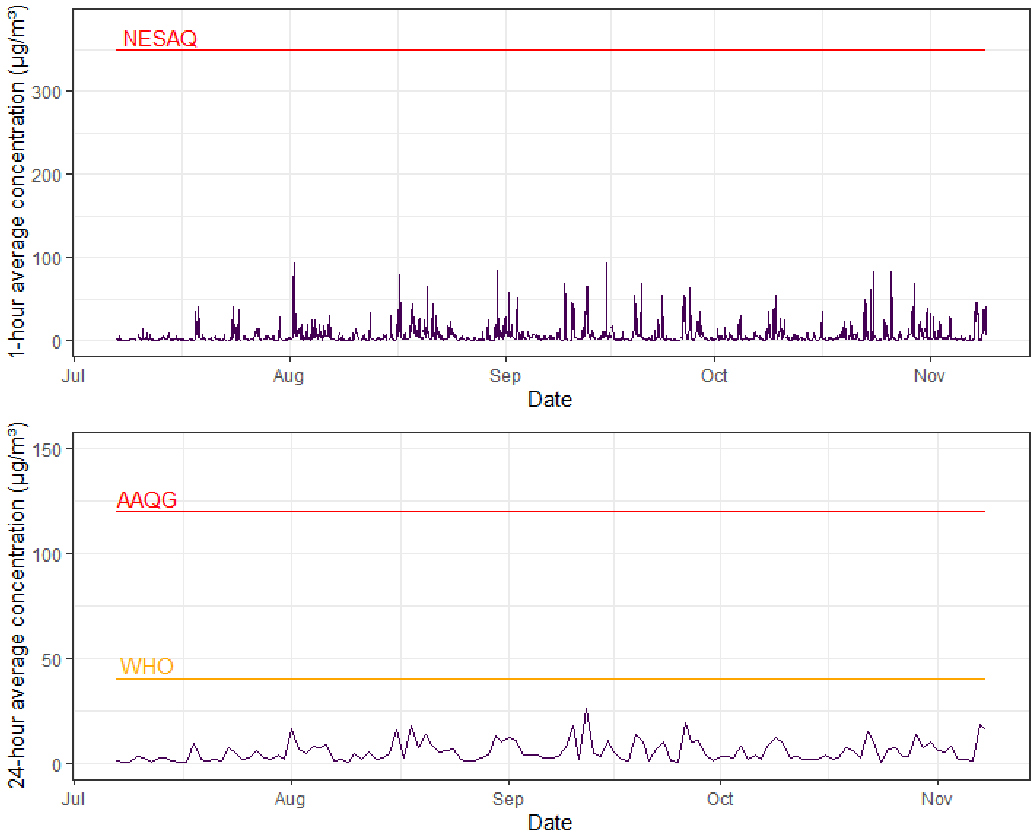
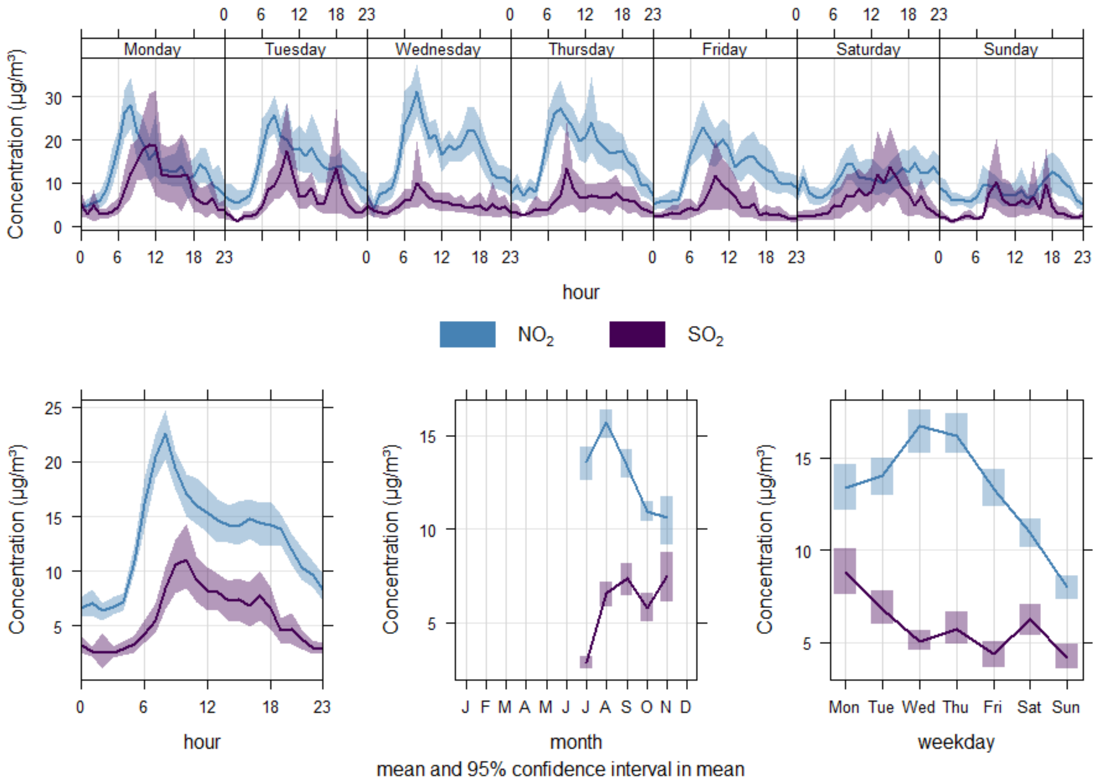


Figure 2 SO_2 concentrations for July – November 2022



[9] The time variation plots in Figure 3 show the concentrations of NO_2 and SO_2 averaged by time of day, month, and weekday. This shows that there are higher concentrations of NO_2 during the weekdays, which suggests traffic and industrial emission sources. Concentrations for both pollutants are elevated in the morning between 6am and noon, and are lowest at night. The month with the highest NO_2 concentrations was August, and the months with the highest SO_2 concentrations were September and November. SO_2 was lowest on Sundays, however there is not a strong pattern for day of the week like there is for NO_2.

Figure 3 **Time variation for NO_2 and SO_2**



REAL-LIFE EMISSIONS TESTING

[10] Ultra-low emission burners (ULEB) have been developed by various manufacturers in response to wood burner pollution in New Zealand and increased regulatory requirements. ULEBs are now effectively the only type of wood burner allowed to be installed in Air Zone 1 (Alexandra, Arrowtown, Clyde and Cromwell) under the Air Plan (Rule 16.3.1.2) that requires an emission rate of less than 0.7 g/kg, and an efficiency of >65%.

[11] However, the performance of ULEB's is known to differ under domestic use ('real life') in comparison to the controlled laboratory testing they undergo to become classified as an ULEB (Canterbury Method 1 test). The real-life emissions from a wood burner may vary by type of wood used (species, dryness, size, and weight of pieces), and the general use such as air flow settings, load size, and frequency of loading wood.

[12] ORC and other regional councils use emission inventories as tools to assess the impact of policies, rules, and interventions on the air quality of an airshed over time (e.g., Wilton, 2019). Emission inventories are calculated based on the number of consented wood burners (and other sources) within an airshed and their predicted emission rate. This testing of real-life emissions enables a more accurate estimate of overall emissions within an airshed; if default wood burner emission rates are used, then the contribution of ULEBs to an airshed's total particulate matter mass may be underestimated.

[13] During winter 2022, ORC contracted Applied Research Services to undertake testing and analysis of real-life emissions from ULEBs in Arrowtown. The report is attached as Appendix 1.

[14] Seven burners were tested within the homes of volunteers for seven days each. Testing involved placing an automated sensor inside the flue, and having participants document the weight, type, and timing of wood added to the fire, and the control settings. The in-flue sensor underwent daily maintenance by a technician.

[15] The tests found that the emissions varied between and within households (Figure 4), but the overall average was consistent with previous studies (Figure 5). The variability between the households strongly indicate that fuel type and operation of the burner have an impact on the emission rates (Applied Research Services, 2023). For example, HH7 used small pieces of wood, resulting in high flue temperatures, low emissions, but with low efficiency[1].

[16] The average emission rates from the national studies are compared in Figure 5. Previous studies include the testing of low-emission burners (LEB), which are burners compliant with MfE standards (emission rate <1.5 g/kg, and efficiency >65%) as well as ULEBs. This study contributes to a growing national body of real-life emission data from domestic wood burners.

Figure 4 **Emission rates by household. Source: Applied Research Services 2023**

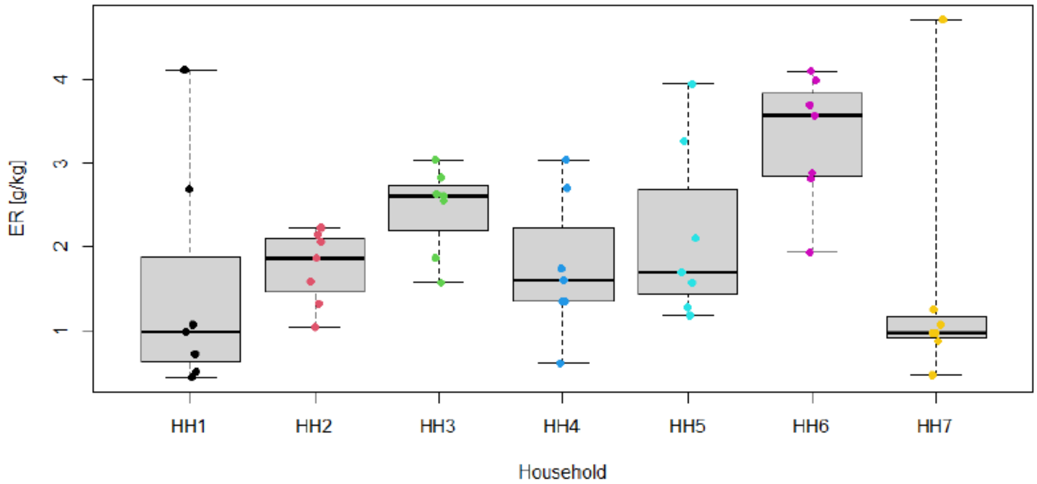
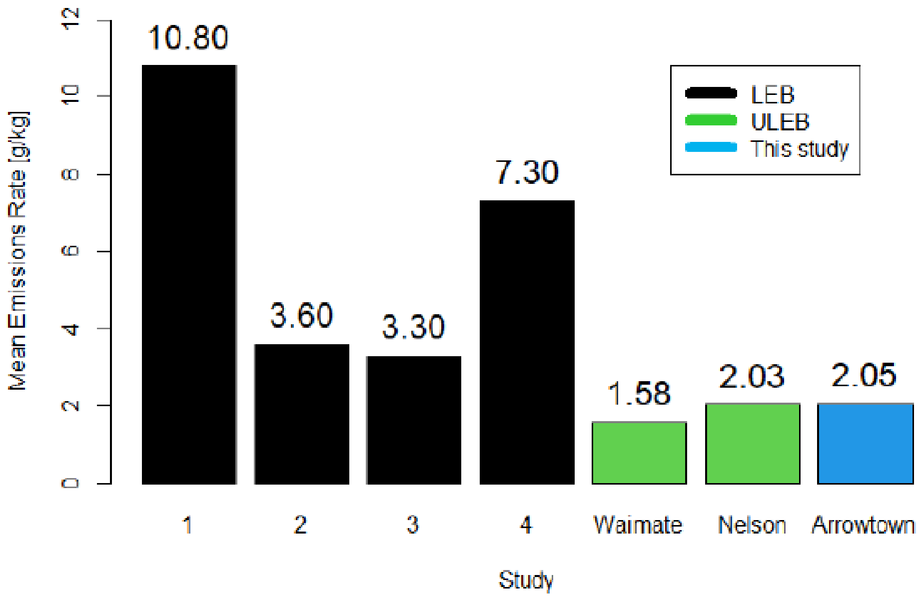


Figure 5 **Emission rates of all New Zealand real-life emission studies. Source: Applied Research Services, 2023**

[1] Emission rate and efficiency are a trade-off, as reducing emissions means that the fire is burning closer to complete combustion, which requires lots of oxygen. The more airflow supplied to the fire means that the more heat is lost up the chimney, thereby reducing thermal efficiency. Conversely, increasing the efficiency also increases particulate matter emissions.



CONSIDERATIONS

Strategic Framework and Policy Considerations

[17] The work outlined in this paper contributes to the following elements of ORC's Strategic Direction

a. Monitoring air quality in the region and investigate pollution sources
b. Provide best available information on Otago's air quality

Financial Considerations

[18] The Air Quality work is a budgeted and planned activity.

Significance and Engagement Considerations

[19] N/A

Legislative and Risk Considerations

[20] N/A

Climate Change Considerations

[21] N/A

Communications Considerations

[22] ORC's Air quality communications ("Burn dry, breathe easy" campaign) will continue for winter 2023.

NEXT STEPS

[23] New proposal for monitoring network upgrades, including monitoring of NO_2 will be included for the next LTP cycle.

[24] The ULEB study data will be shared with other regional councils in New Zealand and will inform future emission inventory studies of Otago airsheds.

ATTACHMENTS

1. Applied Research Ltd 2023 - Arrowtown wood burner testing [**6.3.1** - 31 pages]

REFERENCES

Applied Research Services Ltd, 2023. *Real Life Emissions from Wood Burning Heaters in Arrowtown*. Report 23/3115.

Ministry for the Environment & Stats NZ, 2021. New Zealand's Environmental Reporting Series: Our air 2021

Otago Regional Council, 2021. *Air Quality 2010 – 2019 SoE Report.* State of the Environment Report, September 2021. https://www.orc.govt.nz/media/11935/soe-air-quality-state-and-trends-2010-2019.pdf

Wilton, E. 2019. *Wanaka, Cromwell and Clyde Air Emission Inventory – 2019*. Environet Ltd

World Health Organisation, 2006. *Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005: Summary of risk assessment.* Retrieved from https://www.who.int/airpollution/publications/aqg2005/en/

World Health Organisation, 2021. *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. Retrieved from https://apps.who.int/iris/handle/10665/345329

APPLIED RESEARCH SERVICES LIMITED

P.O. Box 687, Nelson,
New Zealand

Phone (03) 547 7347
Email: info@appliedresearch.co.nz
Web: www.appliedresearch.co.nz

Real Life Emissions from Wood Burning Heaters in Arrowtown

Customer: **Otago Regional Council**
Private Bag 1954
Dunedin 9054

Report 23/3115 **February 2023**

APPLIED RESEARCH SERVICES LIMITED

P.O. Box 687, Nelson,
New Zealand

Phone (03) 547 7347
Email: info@appliedresearch.co.nz
Web: www.appliedresearch.co.nz

Customer: **Otago Regional Council**
Private Bag 1954
Dunedin 9054

P2390/2

Attention: **Sarah Harrison**

Real Life Emissions from Wood Burning Heaters in Arrowtown

Table of Contents

1.0 Overview

In-home measurements of particulate emissions from domestic wood fired heaters were made in Arrowtown, Otago, during the winter of 2022. Tests were carried out by sampling flue gases using automated sampling equipment installed in participant's homes. While sampling was taking place the householders were asked to record information about what was loaded into the heater and how the controls were set.

This report summarises the information obtained during the sampling program.

2.0 Methodology

2.1 Location

Arrowtown is a small town in the Queenstown-Lakes District in Otago, 19 kilometres North-East from the larger resort town of Queenstown. It has high levels of wintertime air pollution from wood burning [1] which is associated with increased risks of diseases such as acute respiratory infection [2].

2.2 Selection of Households

A list of households willing to participate in the sampling program was provided to us by the Otago Regional Council (ORC). All the participants had wood burners as their main source of heating. ORC identified seven households willing to participate in the study. Six of the participants were located within the residential area of Arrowtown and one was located about 3 km south of the town. Table 1 below details the location and heater model for each participant.

Apart from households 1 and 7, all the households also had heat pumps as a secondary source of heating.

Household 2 had underfloor heating on their ground floor, although their wood burner and heat pump were on the first floor.

Table 1 The participants and their heater

Household	Location	Heater	Category
1	Centennial Ave, Arrowtown residential	Blaze King Chinook 30	ULEB
2	Adamson Street, Arrowtown residential	Woodsman Serene	ULEB
3	Norfolk Street, Arrowtown residential	Pyroclassic IV	ULEB
4	Nairn Street, Arrowtown residential	Pyroclassic IV	ULEB
5	Devon Street, Arrowtown residential	Pyroclassic IV Wetback	LEB
6	Thames Street, Arrowtown residential	Metro Wee Rad Ultra	ULEB
7	McDonnell Road, Arrowtown rural	Pyroclassic IV Wetback	LEB

2.3 The Heaters

Four out of five of the models tested in this program were 'Ultra-Low Emissions Burners' (ULEBs), a term coined by Environment Canterbury [3] to describe burners which "meet an emissions and efficiency standard of 38 milligrams per megajoule of useful energy" when tested to Canterbury Method 1 [4].

In two households a Pyroclassic IV had been fitted with a water heating coil (wetback). The heater fitted with wetback has been tested for compliance to the 'Low Emissions Burners' (LEBs) category of burners but not the ULEB category. The LEB term describes a burner which "meets an emission standard of 1 gram of particulate per kilogram of fuel burned or less, and have a thermal efficiency of 65% or greater" when tested to AS/NZS 4012 & 4013 test methods [5],[6].

The official test results obtained for the heaters when tested to these standards are given in Table 2.

All heaters tested in this study have a single combustion chamber (in contrast to the dual chamber heaters tested in Waimate in 2018 during a similar program [7].

2.3.1 Blaze King Chinook 30

Based on information in the operating manual for the Blaze King 30 Series [8] it has the following features: -

- A manually operated catalytic combustor located within the firebox at the top of the unit.
- The appliance has a thermometer that indicates when the catalytic combustor is active or inactive and therefore when the bypass should be engaged or disengaged. The bypass is manually operated using a handle located on the right side of the unit.
- A thermostat control that automatically adjusts the primary air intake and therefore the combustion rate and heat output. The thermostat knob, located at the rear of the appliance, can be set anywhere between a low and a high setting.

The operating manual notes the following requirements for operating the heater: -

- During the initial light-up phase, the bypass should be in the open position and the thermostat knob set to high and that the door must remain ajar until the first intermediate load is fully on fire.
- The bypass should be closed only once the catalytic thermometer needle is in the active zone. The thermostat must remain at a high setting for 20 to 30 minutes.
- The bypass must always be open before opening the loading door.
- The heater must be operated at a high setting for 20 to 30 minutes after every reload of wood.

Figure 1 Location of Controls on the Blaze King Chinook

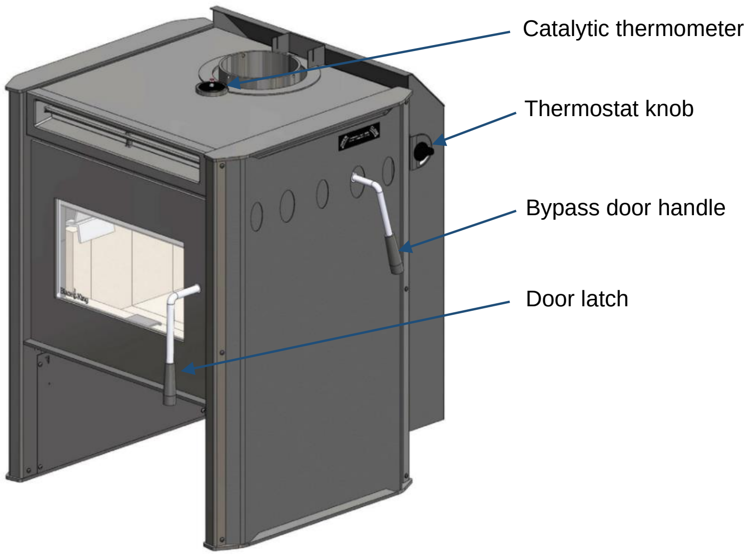


Table 2 Published Test Results for the five tested heaters [3]

Test Method	Canterbury Method 1	AS/NZS 4012/3
Appliance name	**Blaze King Chinook 30**	
Situation	Freestanding	Freestanding
Fuel type	Dry wood	Dry wood
Emission	28 mg/MJ	22 mg/MJ
Emission rate	0.38 g/kg	0.30 g/kg
Efficiency	68%	69%
Water heater	None	None
Approval number	182697	182628
Appliance name	**Woodsman Serene**	
Situation	Freestanding	Freestanding
Fuel type	Dry wood	Dry wood
Emission	26 mg/MJ	not supplied
Emission rate	0.33 g/kg	0.36 g/kg
Efficiency	63%	66%
Water heater	None	None
Approval number	194586	193597
Appliance name	**Pyroclassic IV**	
Situation	Freestanding	Freestanding
Fuel type	Dry wood	Dry wood
Emission	33 mg/MJ	20 mg/MJ
Emission rate	0.44 g/kg	0.30 g/kg
Efficiency	67%	74%
Water heater	None	None
Approval number	194576	121121
Appliance name	**Pyroclassic IV Wetback**	
Situation		Freestanding
Fuel type		Dry wood
Emission		17 mg/MJ
Emission rate		0.30 g/kg
Efficiency		65%
Water heater		Yes
Approval number		121122
Appliance name	**Metro Wee Rad Ultra**	
Situation	Freestanding	Freestanding
Fuel type	Dry wood	Dry wood
Emission	35 mg/MJ	26 mg/MJ
Emission rate	0.46 g/kg	0.35 g/kg
Efficiency	66%	67%
Water heater	None	None
Approval number	191262	191263

2.3.2 Woodsman Serene

The Woodsman Serene is a single chamber burner with a cuboid firebox. It has an air slide to adjust the level of combustion. The location of the control is shown in Figure 2. The Serene instruction manual [9]indicates that the door should be fully closed from the start and that before reloading the air slide should be set to the high setting for 5 minutes.

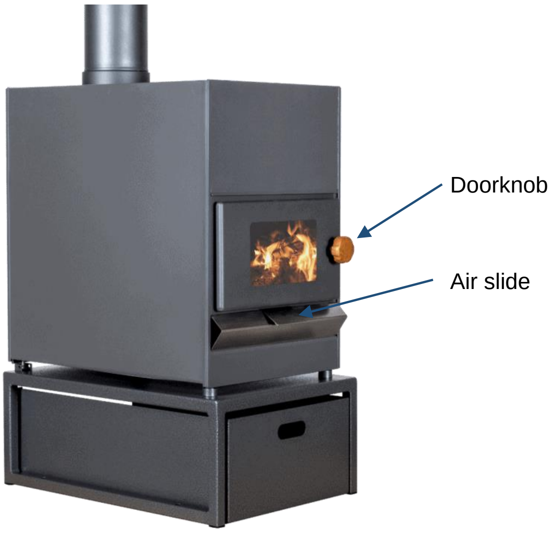
Figure 2 Location of Controls on the Woodsman Serene

2.3.3 Pyroclassic IV and Pyroclassic IV Wetback

The Pyroclassic IV and Pyroclassic IV Wetback have the same tubular ceramic firebox. It has an air slide to boost the air supply when starting up the heater and when reloading.. The location of the controls is shown in Figure 3. The instruction manual [10] indicates that the air slide can be set to low ten minutes after the third intermediate fuel load has been loaded, or approximately 80 to 90 minutes after starting up and that the air slide must be set to high at each refuelling, then can be lowered when the new load of fuel is well lit.

The heater in household 3 was fitted with a 150 mm flue. The heaters in households 4, 5 and 7 were fitted with a 100 mm flue. Households 5 and 7 had a Pyroclassic IV fitted with a wetback.

Figure 3 Location of Controls on the Pyroclassic IV and Pyroclassic IV Wetback



2.3.4 Metro Wee Rad Ultra

The Metro Wee Rad Ultra is a single chamber burner. It has an air slide to adjust the level of combustion. The location of the control is shown in Figure 4.
The instruction manual [11] indicates that the air slide must be set to high before opening the door and that after each refuelling, the air control must be left on high until the fire is re-established.

Figure 4 Location of Controls on the Metro Wee Rad Ultra

2.4 Fuel

Each household was asked to burn whatever they would normally burn, using their own firewood stack. Information on the wood species is based on information supplied by the householders.

Household 1 burned a mix of split gum logs and Douglas fir logs. This household usually doesn't use much kindling as they run their heater non-stop. When they need to carry-out a start-up, they use firelighters and either small pieces from their firewood stack or a bag of kindling from the supermarket. The firewood stack was located near the wood burner inside the living room; so the firewood was always at room temperature and not subjected to weather.

Household 2 burned a mix of split gum and pine logs and used cedar decking offcuts for kindling. Pine-cones, newspaper, then cardboard or dried leaves (when available), were used for start-up. Their firewood stack was outside, well covered with good airflow.

Household 3 burned a mix of split gum and pine logs. They use kindling from their firewood stack and pine-cones for the start-up. Their firewood stack was outside under the deck, mostly covered from the rain and with good airflow.

Household 4 burned split blue gum logs. They use kindling from their firewood stack and firelighters for the start-up. Their firewood stack was outside, well covered with good airflow. Their heater had a large, raised hearth with a wood storage drawer underneath it. The householders were storing their firewood for the day in this drawer to keep it at room temperature and potentially dry it.

Household 5 burned split larch logs. They use kindling from their firewood stack and reusable firelighters which are soaked with methylated spirits before use [12]. Their firewood stack was outside, well covered with good airflow.

Household 6 burned a mix of split pine, Oregon pine (Douglas fir) and gum logs. They use newspaper, small logs from their firewood stack and pine-cones for the start-up. Their firewood stack was outside, well covered with good airflow.

Household 7 burned cut up pallet wood. They used newspaper and small pieces cut from the pallets as kindling for the start-up. Their pallet stack was outside, loosely covered with a tarpaulin. The householder was cutting up a couple of pallets every couple of days, then putting the pieces in cardboard boxes in the lounge by the wood burner. This allowed the firewood to be at room temperature and to dry.

The moisture content of a representative portion of the fuel was measured on-site with an electronic moisture meter (Carrel Electrade C901 with hammer probe). For household 2, the cedar pieces were too small and too hard to allow the moisture content to be measured on site. Its moisture content was determined in our laboratory by oven drying.

All seven households burned dry wood (fuel moisture < 20% on a wet weight basis (wwb)).

In addition, wood samples from each household were returned to the laboratory for determination of density. The resin content of a composite sample from each household was determined using a method based on ASTM-D1108-96. The composite was prepared based on the proportion of each fuel burned by the household during the test period. The resin content and density results relate only to the samples analysed in the laboratory and may not be representative of all the fuel burned.

Information on the fuel is given in Appendix 2.

2.5 Data Recorded by Householders

Participants were asked to complete a worksheet during each run on which they recorded details of the operation of the heater and the weight and description of what was burned. An example of this worksheet is shown in Appendix 3. A set of electronic kitchen scales was provided for this purpose. Households varied in the level of information they provided on these worksheets.

2.6 Emissions Sampling

A portable emissions sampler was installed in each household for the duration of the tests. Details of this sampler are given in our Technical Bulletin 72 (Appendix 1). Results from the sampler can be used to calculate an emission rate in g/kg (dry wood basis) independently of any information recorded by the householder. The samplers operate when the flue gases are above 90 ^{o}C.

The sampling equipment is designed to be set up and monitored by trained technicians. A staff member from our Nelson laboratory (Gus Roux) stayed in Arrowtown during the test program to maintain the samplers and carry out daily changes of filters and desiccant.

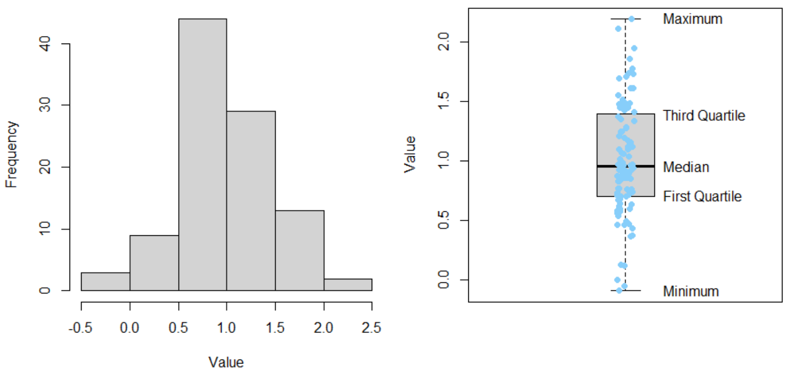
There were two samplers operating during the test program and seven days of testing were completed at all seven participating households. Test dates for each household are given in Appendix 4.

2.7 Statistical Analysis

Statistical analysis was carried out using R [13], p-values are given at the 95% confidence level. Where data has been fitted to a log-normal distribution both geometric and arithmetic mean (average) results are given as each is appropriate for particular uses. Confidence intervals for the arithmetic mean of log-normally distributed data were calculated using Land’s method [14] as implemented in the EnvStats package for R [15].

In some cases, the distribution of data is shown using box and whisker plots such as that on the right of Figure 5. This is a convenient way of visualising the distribution of large numbers of data points, where the individual points (shown in blue) may be omitted. A quartile is the range of values that contain 25% of the data points. The same data is shown on the left of Figure 5 in a histogram which gives the number of observations that fall in a particular range.

Figure 5 Examples of Histogram and Box and Whisker Plots



3.0 Results and Analysis

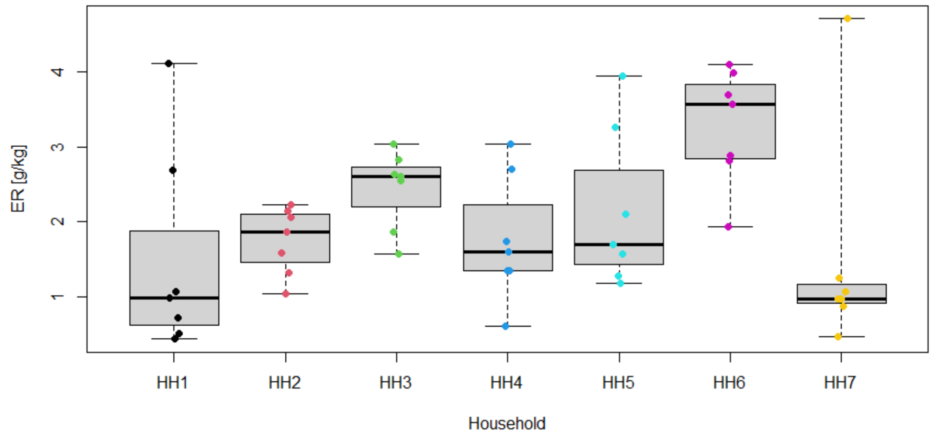
3.1 Emissions Data

Emission rates expressed as grams of emissions per kilogram of fuel on a dry weight basis are given in Table 3 and shown graphically, by household, in Figure 6.

Table 3 Emission Rates

Emission Rates [g/kg]		Household						
		1	2	3	4	5	6	7
Run	a	1.0	1.3	2.5	1.3	3.3	3.7	4.7
	b	0.4	1.9	3.0	1.3	1.2	1.9	1.0
	c	2.7	1.0	2.6	1.7	1.3	4.1	1.2
	d	0.5	2.1	1.9	2.7	2.1	3.6	1.0
	e	0.7	2.1	1.6	3.0	1.7	2.8	1.1
	f	4.1	2.2	2.6	0.6	1.6	4.0	0.5
	g	1.1	1.6	2.8	1.6	3.9	2.9	0.9
Mean		1.5	1.7	2.4	1.8	2.1	3.3	1.5

Figure 6 Emission Rates by Household



Overall, the emission rates range from 0.4 to 4.7 g/kg with an overall arithmetic mean of 2.05 g/kg. The arithmetical means of the individual households are presented in Table 3

The distribution of emission rates is approximately log-normal (p = 0.15 for the Shapiro-Wilke test) with an approximately linear diagnostic plot (see Figure 7). On this basis the overall emission rate data has a geometric mean of 1.74 g/kg. Assuming a log-normal distribution for the emission rates, the 95% confidence interval for the arithmetic mean emission rate is estimated to be 1.76 and 2.58.

Four of the households (households 3,4,5, and 7) had a Pyroclassic IV heater, two of which (Households 5 and 7) were fitted with a wetback. There is considerable variability in the median emission rates for these four households which indicates that installation, fuel and operating procedures have a significant effect on the overall results.

<u>Figure 7</u> <u>Diagnostic Plot showing near normality of log(ER) data</u>

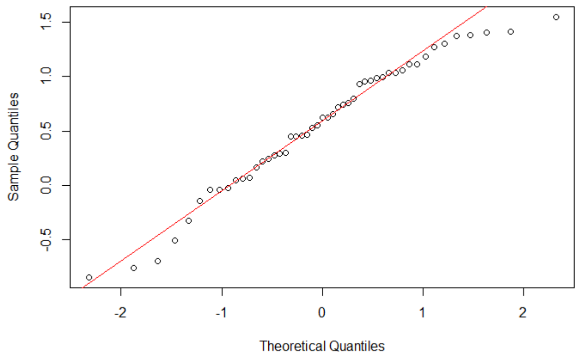
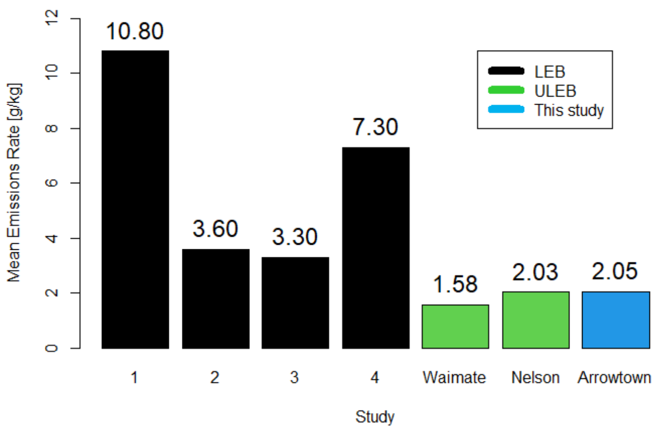


Figure 8 gives a comparison of the results of this study with those from earlier studies. The average emission rate for the seven heaters in this study is lower than the average emission rates obtained from 4 similar studies on single chamber LEB wood burners which achieved emission rates below 1.5 g/kg when tested to AS/NZS 4012/3. These studies are represented by bars 1, 2, 3 and 4 in Figure 8.

The 'Waimate' bar in Figure 8 gives the result of a previous in-home study carried out in 2018 in Waimate on downdraft ULEBs [7]. Downdraft burners have two combustion chambers. The gases flow from the burning fuel in the upper chamber down into a lower chamber for additional combustion time.

The 'Nelson' bar in Figure 8 gives the results of a study carried out in 2021 in Nelson on single combustion chamber ULEBs [16].

<u>Figure 8</u> <u>Comparison with Earlier Studies</u>



3.2 Other Data

Although the primary focus of the test program was to measure emission rates, additional information was obtained during this test program which is relevant to understanding the performance of the appliances and the impact of wood burning on the air shed in general.

3.2.1 Flue Temperatures

Flue gas temperature is an important variable in combustion analysis. It varies with time and depends on parameters such as the type of fuel, the design of the heater, the control settings on the heaters or how the fuel is loaded in the fire box. Flue temperatures were recorded at 30 second intervals while the samplers were running. The samplers run when the flue temperature is above 90 ^oC. This avoids blockage of the sampling probe by condensation. The flue gas velocities are much lower below this temperature because the flue draft depends on flue temperature and so the quantity of emissions at lower flue temperatures is expected to be small.

Table 4 gives the average flue temperature for each household and the distribution of flue temperature for each household is summarised in Figures 9 and 10.

Table 4 Average Flue Temperature by Household

Average Flue Temperature [Degree C]	Household						
	1	2	3	4	5	6	7
	154.9	188.7	165.5	219.6	180.0	175.5	239.4

Household 7 (burning pallet wood) had the highest mean and maximum flue temperatures and lowest overall emissions with one outlier. However when all the appliances in the study were considered there was no significant correlation between the daily emission rates and the mean efficiency (p=0.06) or flue temperature (p=0.06). Other factors such as the appliance type, installation and fuel quality also have a significant effect on emission rates.

On average, Household 1 had the lowest flue temperatures of the households tested and this is associated with low air control settings (see section 3.2.3). This resulted in a higher operating efficiency (see section 3.2.2) but created issues with deposition of creosote in the flue (see section 3.2.7). The lower flue temperatures were probably the result of both the thermostat setting (see section 3.2.3) and the large fuel loads burned in this appliance (see section 3.2.5)

Figure 9 Flue Temperatures by Household

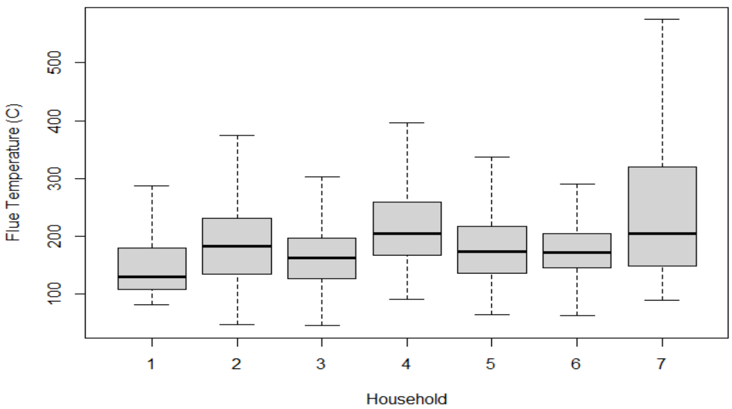
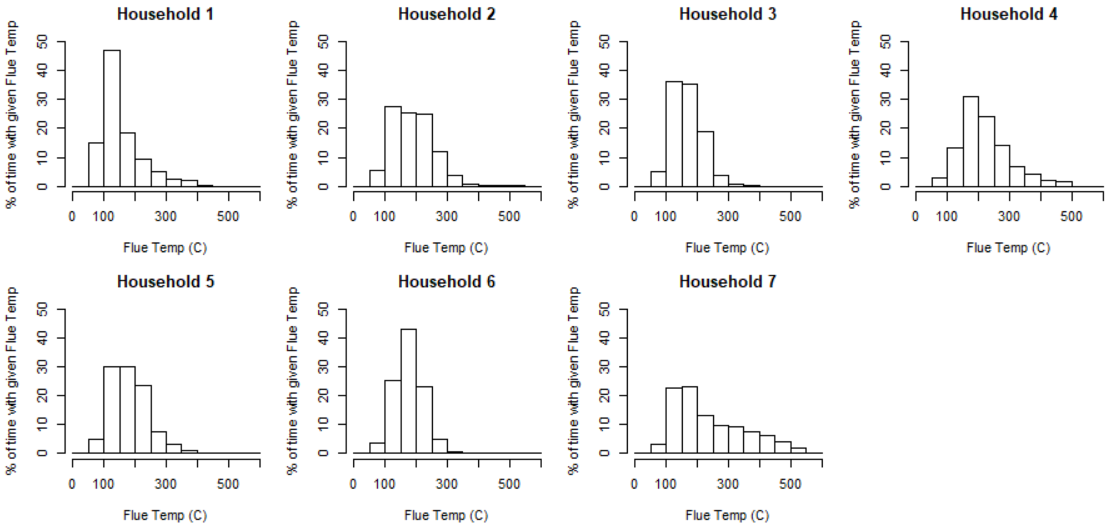


Figure 10 Flue Temperature by Household



3.2.2 Efficiency

The efficiency of each appliance was estimated at 30 second intervals from an analysis of the flue gas composition and flue temperature using the stack loss method (Ref. 9). Figure 11 shows the distribution of efficiencies obtained for all these 30 second intervals. The estimated efficiency by household is given in Table 5 and shown graphically in Figure 12. The average efficiency was 64%. Apart from the Blaze King in Household 1, the average efficiencies estimated for each heater are lower than those obtained during testing to CM-1 or AS/NZS 4012/3.

There is a significant ($p = 1.7 \times 10^{-5}$) negative correlation between efficiency and flue temperature, but flue temperature explains only some of the variation in efficiency (R^2 = 33%). The degree of correlation can be seen in Figure 13.

The Blaze King was operated in a way that gave low flue temperatures which contributed to the high efficiency but caused creosote build-up in the flue (see section 3.2.7). Conversely the Pyroclassic with wetback in Household 7 was operated in a way that gave high flue temperatures and largely low emissions but at the cost of efficiency.

Overall, there was no significant correlation between the daily emission rates and the mean efficiency (p=0.06).

Figure 11 Estimated Efficiency of the Heaters during the Program

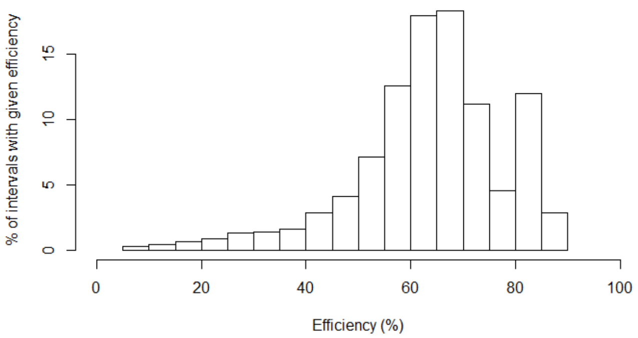


Table 5 Estimated Efficiency by Household

	Household						
Estimated Efficiency (%)	1	2	3	4	5	6	7
	79	58	61	58	63	59	53

Figure 12 Estimated Efficiency by Household

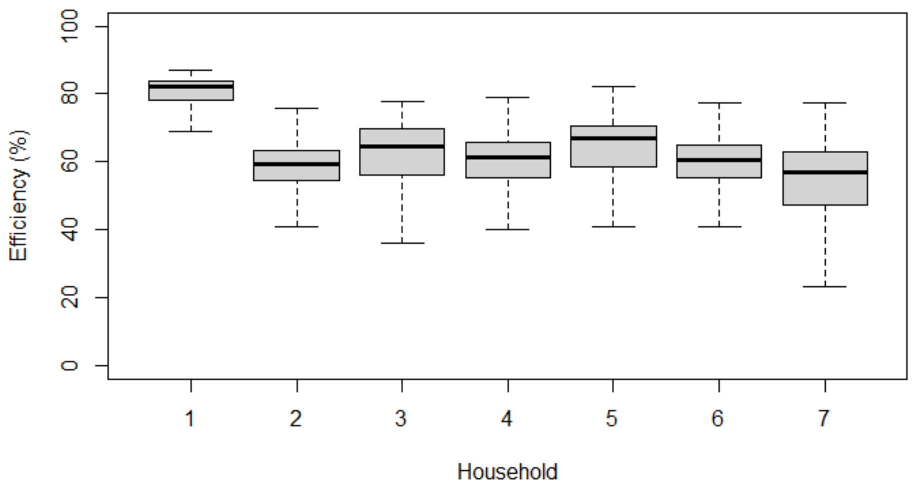
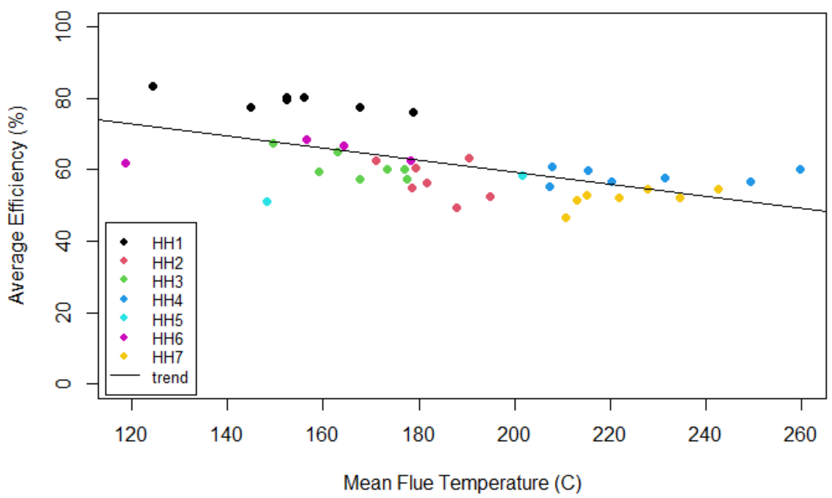


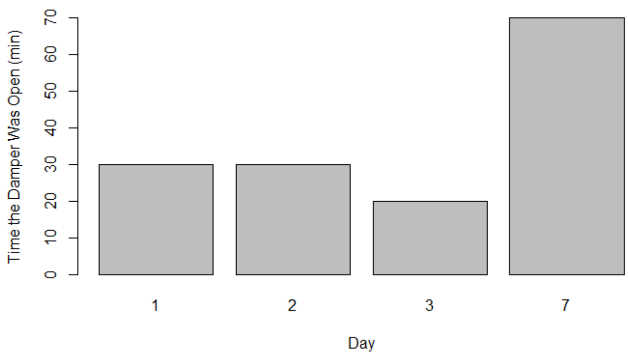
Figure 13 Correlation between Efficiency and Flue Temperature



3.2.2 Bypass Position

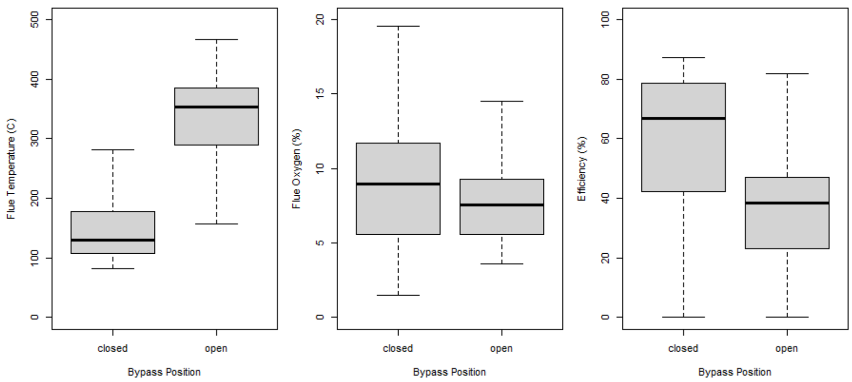
The Blaze King Chinook 30 heater in household 1 has a catalytic combustor. The combustor is enabled when the bypass is closed. The householder was asked to record the bypass position on their daily worksheets. They used the heater with the bypass open 4 times when they had to relight their fire. Short periods when the bypass door was opened for refuelling have not been included in the analysis. The bypass was open for 2.1% of the time the heater was operating. The length of time the damper was open (on each occasion it was opened) is summarised in Figure 14. The householder indicated that the damper was not opened on days 4, 5, and 6.

Figure 14 Length of time the Damper was Open



When the bypass was open, flue temperatures were significantly ($p< 10^{-16}$) higher (by 185 °C on average), flue oxygen levels were slightly lower and the efficiency was significantly ($p< 10^{-16}$) lower (by 23 %) (Figure 15). Because the damper is only open for a short time the overall efficiency of the heater is not significantly affected.

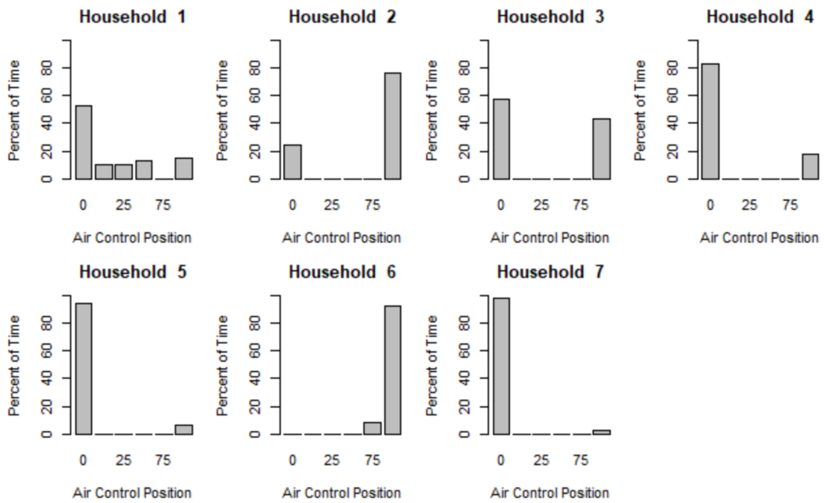
Figure 15 Effect of Bypass Position (Blaze King, Household 1)



3.2.3 Air Control

All appliances had a combustion air control, but it differed in its mode of operation depending on the appliance. The Blaze King (Household 1) had a thermostat which uses a bimetallic element to regulate the air flow. The Serene (Household 2) and Wee Rad Ultra (Household 6) have a slide which regulates the primary air supply in order to control the output. The Pyroclassic heaters (households 3, 4, 5 and 7) have a turbo control which is intended to boost the primary air on startup and reloading but otherwise remain closed. The householders were asked to record the air control position on their daily worksheets and the results are summarised in Figure 16. Households 4,5 and 7 used their Pyroclassic heater with air slide mostly closed as expected. Household 3 did not follow the same method for recoding control settings as the other household and we think they may have omitted to note some of the times when the air slide was closed.

Figure 16 Length of time the Air control was Open/Closed



The Blaze King in Household 1 was operated predominantly with its thermostat on the low setting which was associated with low flue temperatures and the associated issues (see section 3.2.7).

3.2.4 Wood Moisture

All seven households burned well-seasoned wood with a moisture content below 20% on a wet weight basis (see Appendix 1). The small number of households and limited range of wood moisture preclude any reliable analysis of the effect of wood moisture on emissions for this data set.

3.2.5 Fuel Loading

All households recorded information on the weight of wood that was burned during the sampling program. The quality of this information varied but appears to be reasonably accurate for all households.

The overall distribution of weights is shown in Figure 17, while Figure 18 shows the individual load weights for each household along with the corresponding box plot. The mean wood load over all tests was 2134 g. All the households used a range of load sizes but those used by household 1 were noticeably larger.

No correlation (p=0.3322) was found between the mean load weight and the mean emission rate for each household.

Figure 17 Weight of Fuel per Load for All Loads

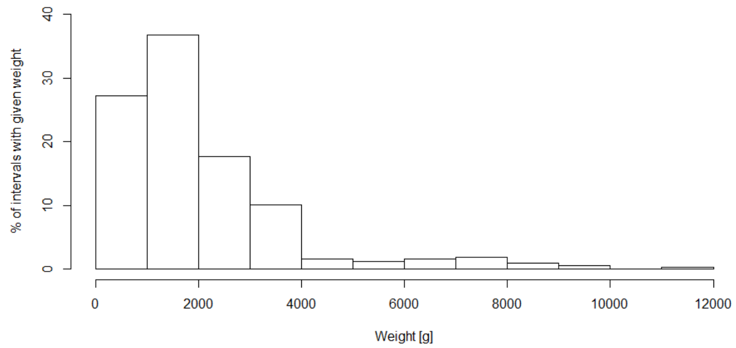
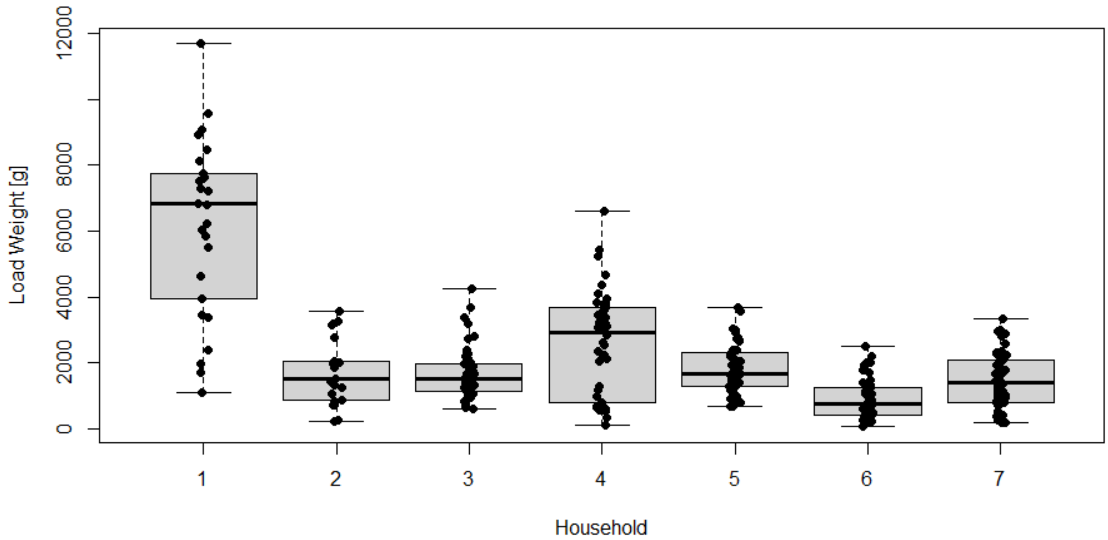


Figure 18 Weight of Fuel per Load by Household



3.2.6 Time of Day of Heater Operation

Table 6 shows the proportion of time the portable samplers were operating (flue temperature > 90 ºC), on average, over each hour of the day. This gives a good indication of when the heaters were being used. For example, the value of 94.5% at 19 indicates that during the test program the heaters were in-use with flue gases above 90 degree C, on average, 94.5% of the time between 19:00 and 20:00.

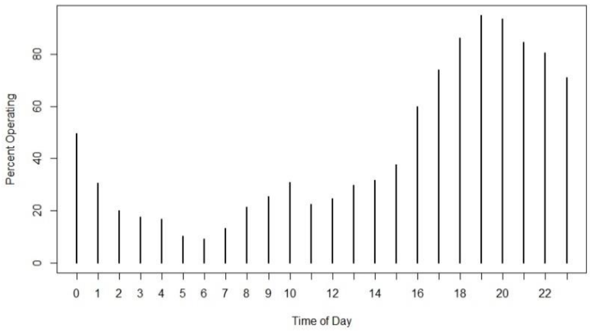
Overall, the samplers were operating and recording data 43% of the time they were installed at the participants' households. The rest of the time the samplers were on idle.

This information is shown graphically in Figure 19. The data is based on runs from all seven households.

Table 6 Relative Frequency of All Heaters Operation as a Function of Time of Day.

Time	0	1	2	3	4	5	6	7	8	9	10	11
% Operating	49.5	30.6	19.9	17.5	16.7	10.1	9.2	13.1	21.5	25.4	31.0	22.3
Time	12	13	14	15	16	17	18	19	20	21	22	23
% Operating	24.7	29.8	31.6	37.7	60.0	74.1	86.2	94.9	93.7	84.7	80.5	71.1

Figure 19 Time of Day Profiles for All Heaters Use



The same information is broken down, by household, in Figure 20

The heater in household 1 was operated throughout the day and night (the householders work from home). Overall, their heater was operating for about 66% of the time.

The householders in household 2 were back home after work in the afternoon during most the weekdays. They were mostly using their wood burner in the afternoon and evening. Overall, their heater was operating about 19% of the time.

The householders in household 3 were mostly home all day as they were working from home and with a young child, therefore they were using their wood burner all day. Overall, their heater was operating about 53% of the time.

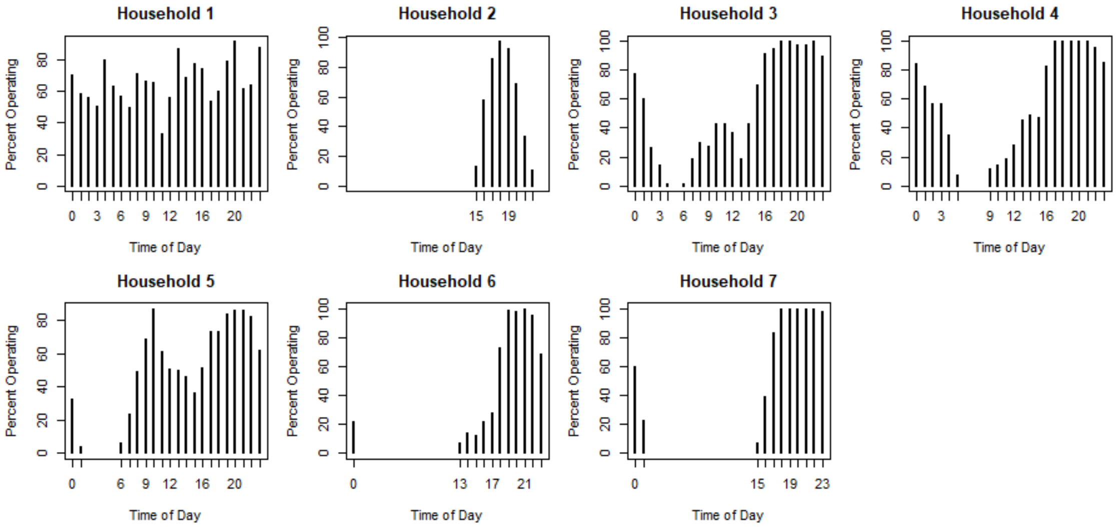
The householders in household 4 were back home after work in the afternoon most of the weekdays. They used their wood burner some mornings, and most afternoons and evenings. Overall, their heater was operating about 54% of the time.

The householders in household 5 were mostly home as they were working from home, with sick children. Overall, their heater was operating about 49% of the time.

The householders in household 6 were mostly home all day as they were working from home, however they were only using their wood burner in the evening. Overall, their heater was operating about 27% of the time.

The householders in household 7 were mostly home all day as they were working from home, however they were only using their wood burner in the afternoons. Overall, their heater was operating about 34% of the time.

Figure 20 Time of Day Profiles for Individual Households



3.2.7 Other Comments

The householders in Household 1 could smell smoke inside their house when their fire was on the low setting. This was solved by closing a skylight that had been left partially open.

Additionally, in Household 1, we noticed creosote was being dislodged from the inside of the flue when the holes were being drilled to fit the sampler probes to the flue. A build-up of residue was also evident on the outside of the flue at some locations where two flue sections joined as well as around some rivets - see photos in Figure 21. During the daily visit we also noticed water dripping down the inside of the flue when the heater was on its low setting. These issues suggest that the low flue temperatures are causing condensation in the flue.

In Household 2 and 5 we noted a small amount of water coming into the room from the flue ceiling plate and dropping onto the heater's top plate – this may indicate that the flashing on the roof is not water-tight.

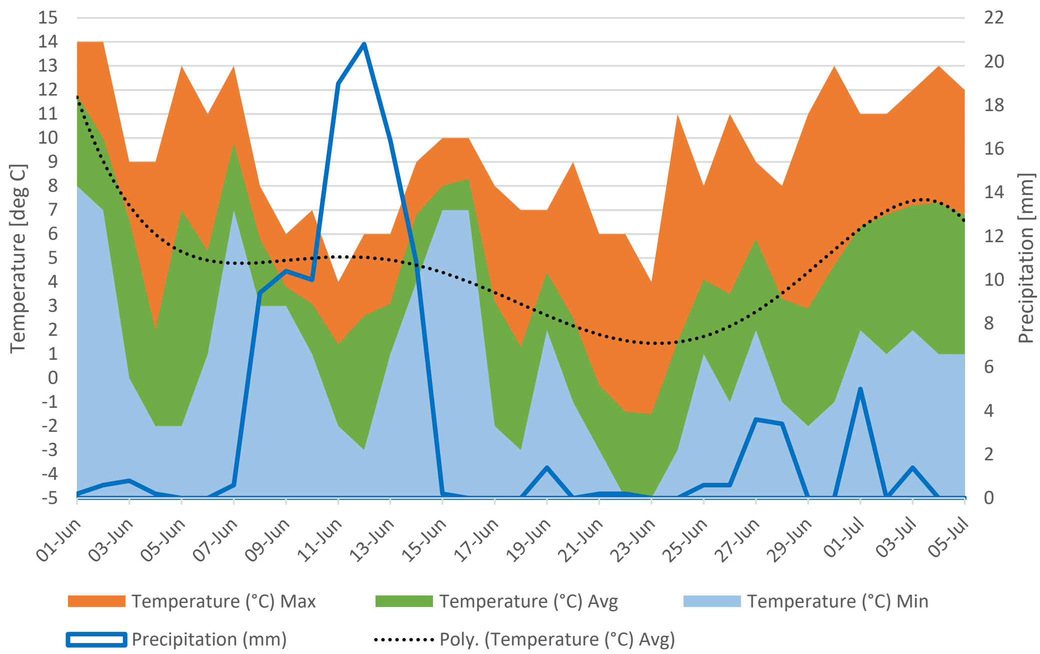
Figure 21 Household 1 Flue Showing Build-up of Creosote

3.3 Weather

The sampling program started on the 1st of June 2022 and finished on the 5th of July 2022. Arrowtown is located in the foothills of the Southern Alps. The temperatures in Arrowtown for June typically ranges between 7 ºC and 0 ºC. The typical probability of precipitation in June is 36 - 40%, and this consists of a small amount of rain mixed with snow [17].

During our sampling program, Queenstown Airport weather station recorded a maximum of 12 ºC, a minimum of -2 ºC and a total of 116 mm of rain [18]. Figure 22 shows the weather during this time. There was a period of high precipitation, rain and snow, from the 7th to the 15th of June. The coldest days were the 22nd and 23rd of June. We assume the weather in Arrowtown and 14 kilometres away at Queenstown Airport, was similar.

Figure 22 Weather Data during the Sampling Program



4.0 References

[1] I. Longley, "Investigating indoor air quality in arrowtown using hau-haus," NIWA, Tech. Rep., 2020. [Online]. Available: https://niwa.co.nz/sites/niwa.co.nz/files/CONA Arrowtown 2019 report 2_Indoor Air Quality.pdf

[2] A.-D. S. Hammond V, "Acute respiratory infection risk associated with exposure to outdoor pm10 emissions from domestic heating," N Z Med J, Tech. Rep. 135(1556):53-61., 2022.

[3] E. Canterbury, "Authorised burners," Tech. Rep., 2023. [Online]. Available: https://-www.ecan.govt.nz/data/authorised-burners/

[4] "Canterbury method 1 for testing of ultra-low emission wood burners revision 1.6,," Environment Canterbury, Tech. Rep., 2015. [Online]. Available: file:///C:/Users/wayne/Downloads/-Appendix1CanterburyMethodRevisionv1.6January2017.PDF

[5] "As/nzs 4012:2014 domestic solid fuel burning appliances - method for determination of power output and efficiency," Tech. Rep., 2014. [Online]. Available: https://www.standards.govt.nz/shop/-asnzs-40122014/

[6] "As/nzs 4013:2014 domestic solid fuel burning appliances - method for determination of flue gas emission," Tech. Rep., 2014.

[7] "Real life emissions from downdraft wood burning heaters in waimate." Applied Research Services Ltd for Environment Canterbury, Tech. Rep. 18/2939, 2018.

[8] "Quick reference guide: Operating instructions," Blaze King, Tech. Rep., 2021.

[9] "Specifications, installation and operating instructions for the:woodsman serene series ultra low emission burners," Harris Home Fires, Tech. Rep. V2.3. [Online]. Available: https://-www.woodsman.co.nz/_files/ugd/dcf459_5c9b9d07c11040efb135342abcb3b1f0.pdf

[10] "Operating instructions model: PyroclassicÂ® iv wood burner," Pyroclassic Fires, Tech. Rep., 2020. [Online]. Available: https://pyrofires.co.nz/wp-content/uploads/2021/02/Pyroclassic-Fires-Operating-Instructions-June20.pdf

[11] “Wood fire installation and owners operation manual. wee rad ultra.” Pioneer Manufacturing Ltd, Tech. Rep., 2018. [Online]. Available: https://www.metrofires.co.nz/wp-content/uploads/2019/03/Metro-Wee-Rad-Ultra-Manual-09-18W.pdf
[12] R. Chalmers, “Pyro fires reusable firelighters. how to light your pyroclassic iv wood fire,” Pyro Fires, Tech. Rep., 2016. [Online]. Available: https://www.youtube.com/watch?v=alt8nTwJyho
[13] R. D. C. Team, “R: A language and environment for statistical computing.” R Foundation for Statistical Computing, Vienna, Austria, Tech. Rep., 2008. [Online]. Available: http://www.R-project.org.
[14] C. Land, “Confidence intervals for linear functions of the normal mean and variance.” *The Annals of Mathematical Statistics*, vol. 42, no. 4, pp. 1187–1205., 1971.
[15] S. Millard, “Envstats: An r package for environmental statistics.” Springer, New York., Tech. Rep., 2013.
[16] “Real life emissions from masport waimakariri and woodsman serene heaters in nelson 2021,” Applied Research Services Ltd for Environment Canterbury., Tech. Rep. 22/3094, 2021.
[17] “June weather in arrowtown new zealand,” Weather Spark, Tech. Rep., 2022. [Online]. Available: https://weatherspark.com/m/144793/6/Average-Weather-in-June-in-Arrowtown-New-Zealand
[18] “Queenstown, otago, new zealand weather history - queenstown airport station,” Weather Underground, Tech. Rep., 2022. [Online]. Available: https://www.wunderground.com/history/monthly/-nz/queenstown/NZQN/date/2022-6

<u>This Report:</u>

Report: 23/3115

Prepared by: G Roux and W.S. Webley

Approved by: W.S. Webley

Release Date: 28 February 2023

This report must not be reproduced except in full. Results are based on materials and information supplied by the client. Applied Research Services Ltd shall not be liable in respect of any loss or damage (including consequential loss or damage) resulting from use of reports prepared by them.

Appendix 1 Details of the Sampling System

APPLIED RESEARCH SERVICES LIMITED

Technical Bulletin 72

Portable Emissions Sampler

1.0 Overview

The portable emissions sampler captures particulate emissions using a method based on Oregon Method 41 (OM41), also known as the Condar Method. Barnett, S. (1985).

2.0 Principle of Operation

The sampler contains two separate analysers: a particulate sampler and a flue gas analyser. The sampler is controlled by a computer which activates the sampling pump whenever the flue temperature exceeds 100 °C and logs data whenever the pump is running.

Schematic diagrams of the two analysers are given in Figure 1 and the analysers are described below. A photograph of the sampler in use is given in Figure 3.

Figure 1 Schematic of Apparatus

Figure 1a Gas Analyser

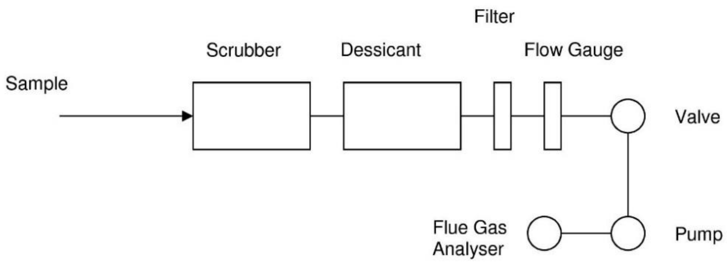
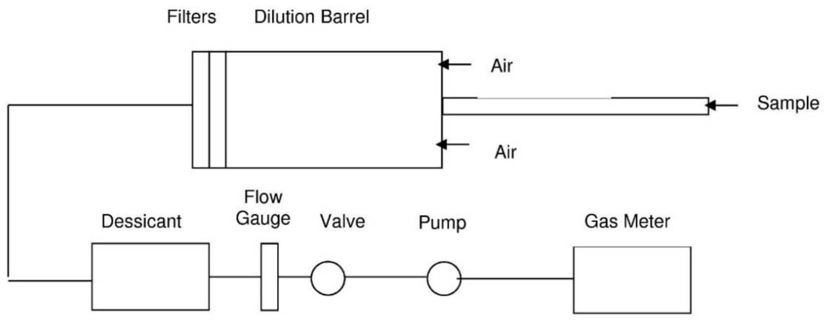


Figure 1b Particulate Sampler



Applied Research Services Ltd, P.O. Box 687, Nelson, New Zealand
Technical Bulletin Number 72, Revision 3 12 September 2017 Page 1/6

2.1 The Particulate Sampler

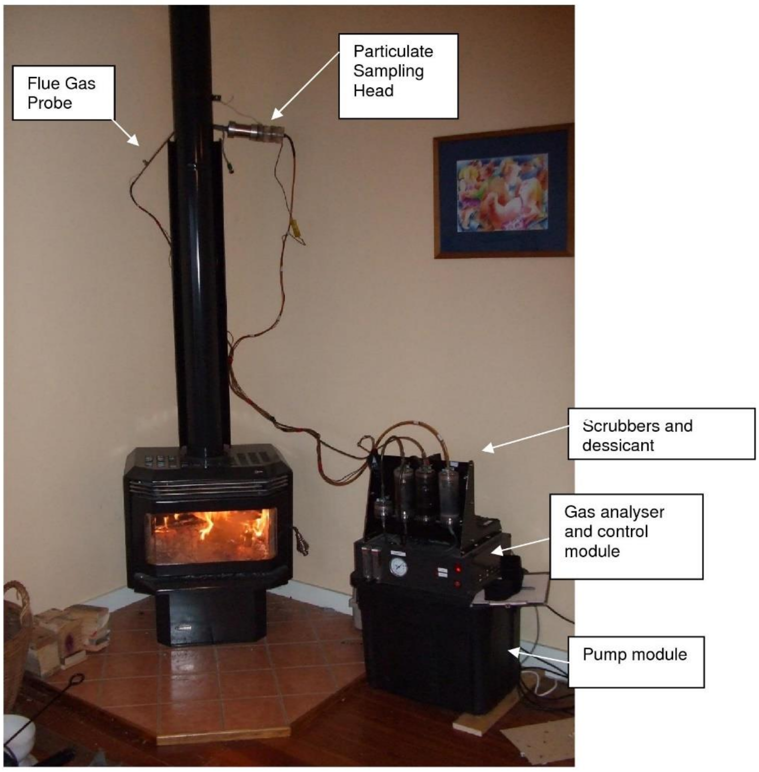
The sampling head includes a dilution system to dilute and cool the flue gas. This simulates the dilution and cooling that occurs when flue gases mix with ambient air and results in condensation of oily compounds such as poly-aromatic hydrocarbons which can then be captured on the filters.

The sampling head consists of a stainless steel dilution manifold (length 100 mm, internal diameter 49 mm) fitted with two end caps. One end cap is fitted with a short probe which is inserted into the flue so that the inlet is near the flue center. Dilution air is admitted to the manifold via 12 x 1 mm diameter holes in the face of the end cap. As with AS/NZS 4012/3 the sample is collected on two 47 mm glass fibre filters (Gelman Type A/E Cat No 61631) mounted on two filter holders fitted to the other end cap of the manifold.

2.2 The Gas Analyser

The flue gas composition is also measured and is used to calculate the total volume of gas which has passed up the flue per kg of fuel burnt. Flue gases are scrubbed and filtered before being passed to the analyser.

Figure 3 Photograph of The Sampler Installed in Home



3.0 Sample Calculations

Calculations follow the method set out in OM41. SI units have been used for clarity and calculations have been set out in what we believe to be a more readily understood form. Calculations are based on the values of flue temperature and flue oxygen level averaged over the run.

Particulate matter is collected on filters which are weighed before and after the run. Filters are held in a dessicator and weighed every 24 hours until constant weights are obtained. The deposit on the filter is calculated from the difference in filter weights.

Weight before: 0.2236 g
Weight after: 0.2357 g
Filter deposit: 0.0121 g

The volume of diluted sample drawn through the filters is determined from the difference in dry gas meter reading taken before and after the run

Gas meter before run: 128392 litres
Gas meter after run: 130024 litres
Volume of diluted gas: 1632 litres

The dilution ratio is the ratio of volumes of the diluted gas stream to the undiluted gas stream. For the runs carried out as part of the program to which this revision refers the dilution ratio was verified by comparing the results of 5 calibration runs carried out with the samplers installed in a test rig complying to the requirements of AS/NZS 4012/3.

Dilution ratio: 13.0

The flow of flue gases into the sample probe is dependent on their viscosity. The viscosity varies with their temperature in a known way – the viscosity varies as the square root of the absolute temperature. OM41 corrects for this variation using the stack correction factor (STF). Values of the STF at various temperatures are set out in the standard.

Flue Temperature: 258.57 C
STF per OM41: 0.7438
Actual Dilution Ratio for run: 17.48

The volume of the undiluted sample drawn into the manifold via the sample probe is obtained by dividing the volume of the diluted sample by the dilution ratio.

Volume of undiluted sample: 93.38 litres

The concentration of particulates in the flue gas is obtained by dividing the weight of particulates collected on the filter by the volume of the undiluted sample.

Particulate concentration: 0.0001296 g/litre

If enough air is supplied to exactly consume the wood then the volume of flue gases generated per kilogram of wood is burned is fixed by the stoichiometry of the combustion reaction. Wood is composed primarily of cellulose and its composition is relatively species independent.

Stoichiometric volume of dry flue gases per kg of wood: 5164 litre/ kg

In real life, more air is supplied for combustion than is actually required. This leads to the excess air passing into the flue gases. As a result, the volume of the flue gases is greater than it would be if only the stoichiometric amount of air was supplied. The proportion of excess air can be determined by measuring the flue oxygen concentration and the actual volume of flue gases van then be calculated. In OM41 this is done using the SDM tabulated for a given flue oxygen level.

Flue oxygen level: 15.7
SDM per OM41: 3.68
Actual volume of dry flue gases per kg of wood: 18985 litres/ kg

The emissions rate is obtained by multiplying the particulate concentration by the volume of flue gases per kg of wood.

Emissions Rate: 2.46 g/kg

4.0 Uncertainty Analysis

Table 1 gives estimated uncertainties for the sample calculations set out in Section 3.

Table 1 Estimated Uncertainties

	Values	Unit	Estimated Uncertainty	
			absolute	%
Weight of filter after run	0.2357	g	0.0001	
Weight of filter before run	0.2236	g	0.0001	
Weight deposited on filter	0.0121	g	0.0002	1.7
Gas meter after run	130024	l	0.5	
Gas meter before run	128392	l	0.5	
Volume of diluted sample	1632	l	1	0.1
Dilution Ratio	13.0			5.0
Flue Temperature	259	C	1	
STF	0.744	OM41	0.006	0.8
Temp corrected dilution ratio	17.48			5.8
Volume of undiluted sample	93.38	l		5.9
emissions concentration	0.0001296	g/l		7.5
Stoichiometric volume of dry flue gases	5164	l/kg		5.0
Flue Oxygen	15.71		0.25	
SDM	3.68	OM41	-0.30442	8.3
Actual volume of flue gases	18985	l/kg		13.3
emissions rate	2.46	g/kg		20.8

5.0 Differences from OM41

The methodology used here follows that in OM41 except that the dimensions of the sampling head are different. The portable emissions sampler used in this study uses a sampling head incorporating the same filter system as used in tests to AS/NZS 4012/3.

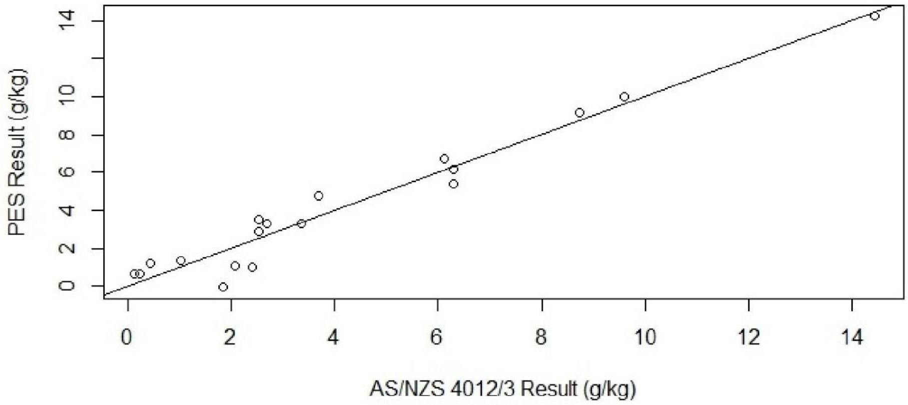
6.0 Comparison of Results Obtained with AS/NZS 4012/3

Laboratory tests of wood burners for compliance to particulate emissions standards in New Zealand are currently carried out according to methods set out in the joint Australian/ New Zealand standard AS/NZS 4012/3. The test involves capture of the entire gas stream exiting the flue which is then passed to a dilution tunnel where it is mixed with room air which provides dilution and cooling. The particulate sample is drawn from the end of the dilution tunnel. Because the velocity of gas in the dilution tunnel is more easily measured than that in the flue the amount of particulate generated is relatively easily calculated.

During the comparative tests the portable emissions sampler was set up in the test room and run at the same time as the laboratory test rig.

The graph below (Figure 2) shows the results of eighteen runs carried out on a Tropicair Duo down-draft heater under a range of 'real life' scenarios. There is a good agreement ($R^2 = 0.87$) between the emissions rates obtained with the portable emissions samplers (PES) and the AS/NZS 4012/3 test rig.

Figure 2 Comparison of Results Obtained with Portable Emissions Sampler and AS/NZS 4012/3



7.0 Assumptions Inherent in OM41

- The filter system collects the all the particulates in the sample. Deposition in the probe and material passing the filters is insignificant.
- The STF and SDM factors correctly represent actual behaviour.
- Calculations are based on STF and SDM factors calculated for average values of flue oxygen and flue temperature. It is assumed that these will correctly represent the actual behaviour.
- It is assumed that the volume of dry flue gases per kg of wood consumed does not vary significantly with fuel type.

The good correlation between results obtained with the portable emissions samplers and those measured using AS/NZS 4012/3 suggests that these assumptions are valid.

7.0 References

Barnett, S. (1985). Handbook for Measuring Woodstove Emissions and Efficiency Using the Condar (Oregon Method 41) Sampling System", Condar Co.

Appendix 2 Information on Wood Burned

		Proportion	Density	Moisture	Resin Content
		% by weight	kg/m3	% wwb	%
Household 1	Gum	96.4	0.63	16.3	0.29
	Douglas fir	3.6	0.51	13.9	
Household 2	Kindling (cedar)	16.6	0.81	10.5	0.58
	Gum	49.9	0.63	13.7	
	Pine	33.5	0.49	13.6	
Household 3	Gum	35.4	0.47	19.6	0.21
	Pine	64.6	0.41	17.2	
Household 4	Gum	100.0	0.50	16.9	0.26
Household 5	Larch	100.0	0.47	19.0	0.12
Household 6	Gum	15.1	0.62	18.1	0.26
	Pine	53.0	0.47	17.1	
	Oregon	32.0	0.70	17.3	
Household 7	Pallet	100.0	0.41	16.9	0.80

The wood species was based on information supplied by each household.
The proportion is based on information recorded by the householder for each fuel load. Cardboard and firelighters have been excluded.
Moisture values are based on readings taken of a selection of pieces of each fuel type in the householder’s wood pile and are expressed on a wet weight basis.
Density and resin content values are based on samples of each species taken at random from the wood pile and returned to the lab for analysis.

Appendix 3 Example of Worksheet Completed by Householders

Name

Address

Date

Time	What went on the fire	Weight	Air Control Setting (Front Lever) High, Medium or Low	Damper Control Setting – If applicable (Side Lever) – Open or Closed	Observations

Appendix 4 Run Data

Household	Run	Start Date	Sampler	Emissions Rate g/kg
1	a	1/06/2022	1	1.0
1	b	2/06/2022	1	0.4
1	c	3/06/2022	1	2.7
1	d	4/06/2022	1	0.5
1	e	5/06/2022	1	0.7
1	f	7/06/2022	1	4.1
1	g	8/06/2022	1	1.1
2	a	1/06/2022	2	1.3
2	b	3/06/2022	2	1.9
2	c	4/06/2022	2	1.0
2	d	5/06/2022	2	2.1
2	e	6/06/2022	2	2.1
2	f	7/06/2022	2	2.2
2	g	8/06/2022	2	1.6
3	a	9/06/2022	1	2.5
3	b	10/06/2022	1	3.0
3	c	11/06/2022	1	2.6
3	d	12/06/2022	1	1.9
3	e	13/06/2022	1	1.6
3	f	14/06/2022	1	2.6
3	g	15/06/2022	1	2.8
4	a	10/06/2022	2	1.3
4	b	11/06/2022	2	1.3
4	c	13/06/2022	2	1.7
4	d	14/06/2022	2	2.7
4	e	15/06/2022	2	3.0
4	f	16/06/2022	2	0.6
4	g	17/06/2022	2	1.6
5	a	16/06/2022	1	3.3
5	b	20/06/2022	1	1.2
5	c	22/06/2022	1	1.3
5	d	23/06/2022	1	2.1
5	e	24/06/2022	1	1.7
5	f	25/06/2022	1	1.6
5	g	26/06/2022	1	3.9
6	a	27/06/2022	1	3.7
6	b	28/06/2022	1	1.9
6	c	29/06/2022	1	4.1
6	d	30/06/2022	1	3.6
6	e	1/07/2022	1	2.8
6	f	2/07/2022	1	4.0
6	g	3/07/2022	1	2.9
7	a	29/06/2022	2	4.7
7	b	30/06/2022	2	1.0
7	c	1/07/2022	2	1.2
7	d	2/07/2022	2	1.0
7	e	3/07/2022	2	1.1
7	f	4/07/2022	2	0.5
7	g	5/07/2022	2	0.9