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Effects of Fuel and Operation on Particulate Emissions from Woodburners

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Executive Summary

Particulate pollution from woodburners for home heating in winter is a significant air quality issue in most New Zealand urban areas, including Auckland. There is a lack of reliable information on the quantities of particulate discharged from the woodburners used by residents in New Zealand, and a complete lack of data using fuel commercially available in Auckland in a "real life" burning protocol. This is the first study to address this issue. A woodburner testing programme was carried out in an Auckland laboratory between December 2007 and March 2009 to investigate the effects of important variables on emissions and measure emission factors reflecting real life operation of woodburners in the region. Each test burning cycle consisted of start up, high burn and low burn. Altogether, 31 combinations have been tested. Three woodburners (two new and one old) were tested by using pine, blue gum and macrocarpa from wood merchants in the region. The other fuel parameters tested included moisture content (15%, 25% or 35% wet weight, representative of dry, damp or wet wood, respectively), cut (split or unsplit wood) and size (small or large log). Five tests were carried out for each combination to give an indication of variations for each test combination. A combination refers to a specific set of the variables (i.e., burner, wood species, moisture content, cut and size). In total, the whole dataset contains 155 test cycles.

In this report, the emission factor is calculated as grams of particulates for each kilogram of wood burnt (g/kg, dry weight) or each megajoule of heat released (g/MJ). The measured emission factors provide a critical input into the Domestic Fire Emissions Prediction Model which supplies data for the Auckland Emissions Inventory. The emission rate (grams of particulates for each hour of operation, g/hr) and the burner rate (kilogram of wood burnt for each hour of operation, kg/hr) are also calculated.

Our results can be used for assessing options to effectively reduce pollution from domestic fires. This report includes information that is also useful for:

- Providing appropriate emission factors, emission rates and burn rates to calculate woodburner emissions for emissions inventories and airshed modelling, and
- Investigating options for efficient domestic heating by woodburners and effective emissions reductions from woodburners.

We identify the significant variables and estimate the magnitude of emission changes relating to the variables. The characteristics of the best and the worst performance are analysed to provide information about emission reductions that can be achieved by encouraging good and targeting poor practice. Our results are also compared with those of other real life testing studies.

Key results

- Variables significantly affecting emissions include the burner, burner operation, wood moisture content, cut and species.
    - Burning wet or damp wood emits much more particulate than dry wood. Compared to dry wood, wet or damp wood increases the emission factors (per kg or MJ) by more than a factor of two, and the emission rates by more than 70%.
    - The emission factors from the high burn cycle are the lowest. Compared to high burn, start up and low burn increase the emission factors (per kg or MJ) by more than 50% and the emission rates (g/hr) by more than 30%.
    - The emission factors (per kg or MJ) for unsplit wood are 60% higher, compared to split wood. However, the emission rates of split and unsplit wood are not significantly different.
    - The effects of wood species on emissions were not conclusive. The per kg emission factors of pine are more than 20% higher than those of blue gum, and the emission rates are more than 40% higher, but the per MJ emission factors are not significantly different. There was no significant difference in emissions between macrocarpa and pine or blue gum.
    - The old burner generally had higher emissions than the two new ones.
    - Log size was not found to be a significant variable affecting emissions in these tests.
- Low emissions closely link to dry wood while high emissions link to wet or damp wood.
- The average emission factors are 5.2 ± 1.0 g/kg or 0.76 ± 0.22 g/MJ for the two new burners, and 6.5 ± 1.3 g/kg or 1.03 ± 0.22 g/MJ for the old burner.
- The average emission rates are 12.5 ± 1.8 g/hr for the two new burners, and 13.8 ± 2.8 g/hr for the old burner.
- The average burn rates are 2.8 ± 0.1 kg/hr (dry wood) or 3.6 ± 0.1 kg/hr (wet wood) for the two new burners, and 2.3 ± 0.1 kg/hr (dry wood) or 3.1 ± 0.1 kg/hr (wet wood) for the old burner.

Previous real life testing in New Zealand suggests an emissions factor of 4.6 g/kg for new burners and 14.0 g/kg for old ones. Of the three burners tested, the emissions from the two new burners (5.2 ± 1.0 g/kg) are comparable, but the emissions from the old burner (6.5 ± 1.3 g/kg) are lower than expected.

1 Introduction

1.1 Background

Particulate pollution from woodburners used for home heating in winter is a significant air quality issue in most New Zealand urban areas, including Auckland. There is a lack of reliable information on the quantities of particulates discharged from the woodburners used by residents, particularly in Auckland. As emissions from woodburners are calculated by multiplying the quantities of wood burnt by emission factors, the emission factors are critical in estimating air pollution from domestic sources.

The National Environmental Standard for Air Quality (NES) requires that woodburners installed after 1 September 2005 on a property of 2 hectares or less meet a thermal efficiency of at least 65% and an emission standard of less than 1.5 g/kg. Under the NES definition, a woodburner means a domestic heating appliance that burns wood, but does not include an open fire, a multifuel heater, a pellet heater, a coal burning heater, or a wood-burning cooking stove (MfE, 2005). These standards are measured in accordance with the method in the Australian and New Zealand standards AS/NZS 4012/3. The standard test methods are designed to provide consistency for comparing different woodburners. However, they are not designed to represent the actual emissions since real life operations and fuel characteristics vary significantly. There is insufficient information on real life emissions that is suitable for emissions inventories and evaluation of emission reduction options in Australia (Todd, 2007) and in New Zealand.

Several tests have been carried out under real life conditions in New Zealand. In 2003 and 2004, seven woodburners, including four low emission woodburners, were tested in three stages: Stage I (in a laboratory using a prescribed operating procedure and merchant supplied wood), Stage II (in-home using the same operating procedure as Stage I and merchant supplied wood) and Stage III (in-home, operated by the householders using their own wood supply, i.e., real life emissions) (Scott, 2005). The results demonstrated a wide range of emission factors. During winter 2005 in situ emissions were investigated for 12 old solid fuel burners (installed prior to 1994) in Tokoroa (Wilton, et al., 2006). A year later, testing was carried out for nine NES compliant burners, including six which replaced the pre-1994 old burners in the previous testing (Kelly, et al., 2007). The Tokoroa studies suggest that NES compliant burners emit significantly lower particulates than older burners. Recently 18 NES compliant woodburners were tested in Nelson, Rotorua and Taumarunui with an aim to provide a representative emission factor (Smith, et al., 2008). In Australia, research has been carried out to measure in situ particulate emission rates of wood burners for 18 households in Launceston, Tasmania (Meyer, et al., 2008). A recent U.S. study demonstrated that emissions from woodburners are highly variable depending on several factors including appliance type, wood species and moisture content (Kinsey et al., 2009). These studies provided important information on the magnitude of real life emissions. However, it is not appropriate to directly apply these emission factors to Auckland without also considering the home heating behaviours in Auckland. For example, Auckland residents usually light their fires only in the evening, but many residents in the South Island keep their burners running for the whole day. Different emission factors should be used for different operating regimes. In addition, although some previous studies (Scott, 2005; Wilton et al., 2006; Kinsey et al., 2009) have considered the effects of important variables on emissions, e.g., wood moisture content and burner operating condition, they have not quantified these effects on emissions. In the in-situ testing, the released heat is not measured, therefore, the emission factors (per MJ) are not usually available. The purpose of this study is to resolve some of these issues.

1.2 Objectives of the study

The woodburner testing was carried out in a laboratory between December 2007 and March 2009 to measure emission factors reflecting home heating conditions in Auckland. The programme was also designed to investigate the effects of important variables on emissions. The purpose of this study is to:

- Estimate emission factors, emission rates and burn rates used to calculate woodburner emissions for the emission inventory and airshed modelling in Auckland, and
- Investigate significant variables affecting woodburners emissions.

Care should be taken when comparing the results of this study to those of other studies due to differences in test design and procedures.

2 Methodology

2.1 Testing programme

The Auckland tests were carried out at Spectrum Laboratories Limited. The burners were operated in the laboratory, using the calorimeter room and sampling train prescribed in AS/NZS 4012/3. Fuel was sourced from wood merchants in the region. To simulate real life operations in Auckland, each test burning cycle consisted of three operating conditions from start up to high burn and low burn, on a daily basis, based on an adapted methodology by Mallett and Spectrum Laboratories Limited (see Appendix A). Briefly, for high burn or low burn, the heat output control was set to achieve maximum or minimum burning rate. The start up phase lasted for approximately 50 minutes, and high burn or low burn for approximately 120 minutes each, with an overall test duration of approximately five hours. Particulate mass emissions, flow volume and temperature were measured for each operating condition and the average of the three conditions is used to represent the mean for the cycle. Particulates were collected on two filters from the front and the back of the sampling train, respectively. Figure 2.1 shows the calorimeter room for the testing.

Figure 2.1

The calorimeter room for the woodburner testing at Spectrum Laboratories Limited.

Three woodburners were tested. Masport LE3000 (series number s/n 3 045088, internal firebox size: 520 mm wide × 330 mm high × 400 mm deep) and Metro Eco Wee Rad (s/n 078821, 375 mm × 332 mm × 374 mm) were new NES compliant burners. Masport Belvedere (s/n 802471, 480 mm × 320 mm × 330 mm) was a second hand burner about 15 years old. Three wood species, pine, blue gum and macrocarpa, were used. In terms of size, small logs include those with a diameter less than 120 mm and large equal to or greater than 120 mm, all about 260 mm in length. Another fuel parameter was cut (split or unsplit wood). Figure 2.2 shows a batch of wood used in the testing.

Figure 2.2
A batch of wood used in the woodburner testing.

The testing was designed to test three levels of moisture content 15%, 25% and 35% (wet weight) as representative of dry, damp and wet wood, respectively. If required, firewood was pre-processed for the required moisture levels. If it was too dry, it would be hydrated in an insulated container for a period of time. If it was too wet, it would be dried in a heated container (at ~50 ^{o}C) or by an electric fan, for a period of time. The pre-processing lasted one day or longer depending on how much moisture had to be adjusted and the time needed for the moisture content to stabilise. The wood moisture content was measured using an electrical resistance moisture meter (Carrel and Carrel). Additional checks were undertaken of the accuracy of the moisture meter by comparing results from moisture tests using a kiln drying method. Wood moisture content can be expressed as dry or wet weight. **In this report it is reported on a wet weight basis**.

A combination consists of a specific set of the variables (i.e., burner, wood species, moisture content, cut and size). For example, one combination is large, split, dry, macrocarpa for Masport LE3000. Altogether, 31 combinations have been tested, with five tests for each combination to give an indication of variability. The project was carefully designed to cover each variable with a reasonable number of tests. In total, the dataset contains 155 test cycles (see Table 2.1 and Tables B1.1 - B1.3 of Appendix B). Figure B1.3 (Appendix B) shows a record of a test result.

Table 2.1
Combinations of emissions tests and five tests for each combination.

Burner	Wood	Size	Cut	Dry*	Damp*	Wet*
Masport LE3000	**Pine**	Small	Split	x	x	x
			Unsplit			
		Large	Split	x	x	x
			Unsplit			
	Macrocarpa	Small	Split	x		
			Unsplit	x		
		Large	Split	x		
			Unsplit			
	Blue gum	Small / large	Split / unsplit			
Metro Eco Wee Rad	**Pine**	Small	Split / unsplit			
		Large	Split		x	
			Unsplit			
	Macrocarpa	Small	Split / unsplit			
		Large	Split	x	x	x
			Unsplit			
	Blue gum	Small	Split / unsplit			
		Large	Split	x	x	x
			Unsplit	x	x	x
Masport Belvedere	**Pine**	Small	Split			
			Unsplit	x	x	x
		Large	Split		x	
			Unsplit	x	x	x
	Macrocarpa	Small / large	Split / unsplit			
	Blue gum	Small	Split			x
			Unsplit	x	x	x
		Large	Split			
			Unsplit			x

* Referring to moisture content 15% (dry), 25% (damp) and 35% (wet) (wet weight), respectively.

2.2 Data analysis

The emissions are presented as emission factors and emission rates. The emission factor usually refers to particulate discharges from a specific amount of fuel used, expressed as grams of particulates for each kilogram of wood burnt (g/kg, dry weight unless otherwise indicated; denoted as the per kg emission factor in this report). It can also refer to particulate discharges for a specific amount of heat generated, expressed as grams of particulates for each megajoule of heat released (g/MJ; denoted as the per MJ emission factor in this report). The per kg emission rate is useful in estimating air pollution caused by home heating and the per MJ emission rate incorporates efficiency by calculating emissions per unit of useful heat released. The per MJ emission rate is also useful for comparing fuels with different heat calorific values per kilogram. Note that this heat output measured in AS/NZS4013 is not the in-situ heat output from the burner which is usually less. The emission rate is calculated as particulate discharges for a specific time period, and is expressed as grams of particulates for each hour of operation (g/hr). The emission rate is useful as input for dispersion modelling. In addition, particulate concentrations on any given evening are directly related to rate of emissions from all the woodburners (and open fires) being used. Of the three indicators, the per kg emission factor is often simply referred to as the emission factor and is the most commonly used term. The burner rate, expressed as kilogram of wood burnt for each hour of operation (kg/hr), is also calculated.

The measured emissions show a skewed distribution caused by some relatively high values (see Figures C1.1 – C1.3, Appendix C). Although median is better than mean to represent the tendency of the data in this kind of distribution, for the purpose of calculating emissions across a whole airshed, mean values should be used (Wilton, et al., 2006). For estimating the uncertainty of the measurements, emission factors are expressed as mean ± 95% confidence interval of t-distribution in this report, considered to be more appropriate than the normal distribution (Kelly, et al., 2007).

Statistical approaches are useful for determining whether or not the emissions differ significantly for the variables tested, and whether or not the effects of the variables on the emissions are significant. In this study, the Wilcoxon Signed Ranks test and the Friedman test are used to test the effects of burner operation, because the variables (i.e. start up, high burn and low burn) are related in each test run. The Mann-Whitney test and the Kruskal-Wallis test are used to test the effects of the burner, wood species, moisture content, wood surface and size because the variables are assumed to be independent of each other (i.e. each test run is independent). The p-value is used to estimate the significance level (statistically significant if $p < 0.05$ and strongly significant if $p < 0.01$). See Appendix C for a brief discussion about these statistical procedures, which were carried out by using the SPSS Statistics package (version 17).

3 Variables affecting emissions

3.1 Introduction

In this chapter, we investigate the effects of six important variables on emissions: burner operation (start up, high burn or low burn), burner model, wood species, moisture content, wood surface and size. First, emissions for start up, high burn and low burn are compared. Secondly, for each of the five remaining variables, there are two datasets for analysis. One is the subset of data where the other four variables are the same, which provides a good indication of the effects of the variable under consideration. Due to a limited number of the tests in each subset of data (ranging from 35 to 120 tests depending on variable), there is a high degree of uncertainty for those results. Another group of data is the dataset including all the 31 combinations (155 tests), which provides a larger sample size, but includes the confounding effects of other variables. As illustrated in Figures C1.1-C1.3 (Appendix C), the whole dataset shows a skewed distribution with some relatively high values. Evidence from both datasets is discussed when drawing conclusions. The influences of the variables on emissions are also compared. Finally, we identify the significant variables and estimate the magnitude of emission changes for each variable.

3.2 Burner operation

Real life daily operations of woodburners in Auckland are simulated as a burning cycle from start up to high burn and then to low burn. For high burn or low burn, the heat output control is set to achieve maximum or minimum burning rate. It is expected that emissions from start up, high burn or low burn will be significantly different. The box plot (Figure 3.1) shows that there is a wide range of scatter in the emissions with a few high values. The per kg emissions measured for start up, high burn and low burn are 6.2 ± 1.1, 4.0 ± 0.9 and 8.4 ± 1.4 g/kg, respectively. They are significantly different ($p<0.01$, the Friedman test for the group and the Wilcoxon Signed Ranks test for the pair-wise). On average, per kg emissions of start up and low burn are 55% and 110% higher than those of high burner, respectively.

Start up involves a transfer of energy from the burning fuel to heat the mass of the burner and to heat the calorimeter room; thus the measured heat output (MJ) during this phase is different to the high burn and low burn phases. The heat released to the room is 2.6 ± 0.1, 9.3 ± 0.4 and 12.2 ± 0.6 MJ per kilogram dry wood for start up, high burn and low burn, respectively. Therefore, the per MJ emission factor is the highest for start up, 2.50 ± 0.43 g/MJ, compared to 0.52 ± 0.15 g/MJ and 0.87 ± 0.17 g/MJ for high burn and low burn, respectively. They are significantly different ($p<0.01$, the Friedman test for the group and the Wilcoxon Signed Ranks test for the pair-wise). On average, the per MJ emission factors of start up and low burn are 383% and 68% higher than those of high burn, respectively.

More wood was used to light up and establish fires. The burn rates (kilograms of wood burnt per hour of operation, dry weight) are 5.4 ± 1.1, 2.6 ± 1.1 and 1.5 ± 1.1 kg/hr for start up, high burn and low burn, respectively. The emission rate is the highest for start up, 30.6 ± 5.5 g/hr, compared to 8.1 ± 1.3 g/hr and 10.7 ± 1.6 g/hr for high burn and low burn, respectively. They are significantly different ($p<0.01$, the Friedman test for the group and the Wilcoxon Signed Ranks test for the pair-wise). On average, emission rates of start up and low burn are 277% and 32% higher than those of high burn, respectively.

Figure 3.1

Emissions for different burner operations: start up, high burn and low burn[1].

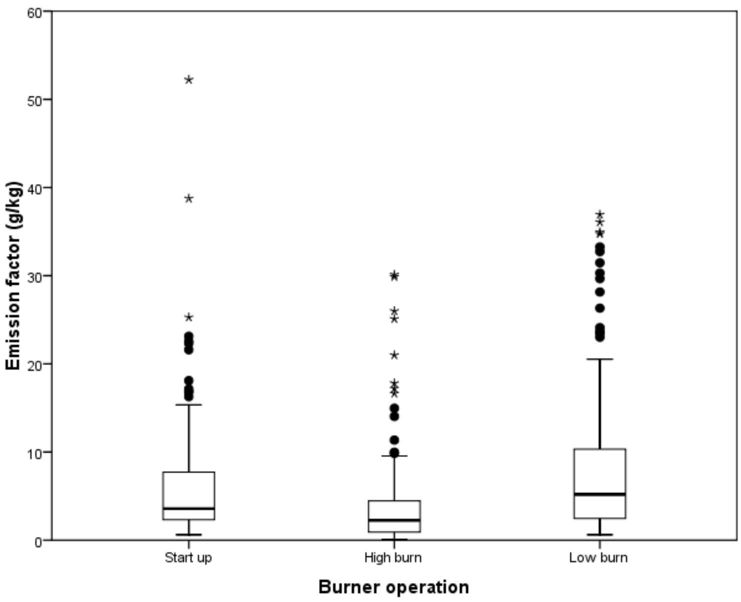


Table 3.1 summarises the mean emissions for start up, high burn and low burn. Overall, the emissions per kg of fuel of high burn are the lowest. Compared to high burn, start up and low burn have higher emission factors by more than 50% and the emission rates by more than 30%. Meyer et al. (2008) demonstrated that air supply is a major determinant of particulate emissions from wood heaters. In high burn, air supply is sufficient for complete combustion and therefore less pollution occurs. In low burn, the air supply is insufficient, resulting in incomplete combustion and more pollution. In start up, air controls were set to high output and air supply should therefore be sufficient. This may explain why per kg emission factors of start up are lower than those of low burn, but higher than those of high burn.

[1] Boxes represent upper and lower quartiles, whiskers extend to 1.5 times the height of the boxes or to the minimum or maximum values if no case in that range, the lines in the boxes are the median, and dots and stars are outliers.

Table 3.1

Emissions for different burner operations*.

Burner operation	Emission factor per kg	Emission factor per MJ	Emission rate	Number of tests
Start up	**6.2 ± 1.1 g/kg**	**2.50 ± 0.43 g/MJ**	**30.6 ± 5.5 g/hr**	**154**
High burn	**4.0 ± 0.9 g/kg**	**0.52 ± 0.15 g/MJ**	**8.1 ± 1.3 g/hr**	**155**
Low burn	**8.4 ± 1.4 g/kg**	**0.87 ± 0.17 g/MJ**	**10.7 ± 1.6 g/hr**	**155**

* The mean emissions for start up, high burn and low burn are significantly different ($p<0.01$, the Friedman test for the group and the Wilcoxon Signed Ranks test for the pair-wise).

3.3 Burner type

Subset of data with the same fuel

To evaluate the performance of the tested burners, mean emissions from different burners are compared when using the same fuel. The daily test results are shown in Figures D1.1-D1.3 (Appendix D). They cover all three burners, all three wood types, large size, split and unsplit cut, and dry, damp and wet wood. Comparison of emissions from paired burners is listed in Table 3.2. The results suggest that there is a difference between individual burners. However, this dataset contains only six combinations. The whole dataset of 31 combinations provides further information about the performance of individual burners.

Table 3.2

Comparison of mean emissions from different burners when using the same fuel.

Burner	Fuel	Emission factor and emission rate	
Masport LE3000 vs Metro Eco **(10 tests)**	**Large split dry macrocarpa or large split damp pine**	**2.3 ± 0.8** **5.3 ± 1.9**	**vs** **g/kg***
		0.28 ± 0.12 **0.55 ± 0.18**	**vs** **g/MJ***
		7.3 ± 2.6 **14.9 ± 5.0**	**vs** **g/hr***
Masport LE3000 vs Masport Belvedere **(5 tests)**	**Large split damp pine**	**3.1 ± 1.2** **7.6 ± 4.3**	**vs** **g/kg***
		0.38 ± 0.20 **1.03 ± 0.73**	**vs** **g/MJ***
		10.1 ± 3.1 **20.0 ± 11.0**	**vs** **g/hr***
Metro Eco vs Masport Belvedere **(10 tests)**	**Large split damp pine or large unsplit wet blue gum**	**13.7 ± 5.7** **6.0 ± 2.1**	**vs** **g/kg***
		2.68 ± 1.70 **1.08 ± 0.34**	**vs** **g/MJ****
		26.4 ± 8.9 **13.6 ± 6.4**	**vs** **g/hr***
Masport LE3000 and Metro Eco vs Masport Belvedere **(5 tests)**	**Large split damp pine**	**4.9 ± 1.9** **7.6 ± 4.3**	**vs** **g/kg****
		0.52 ± 0.18 **1.03 ± 0.73**	**vs** **g/MJ***
		13.5 ± 4.4 **20.0 ± 11.0**	**vs** **g/hr****

* These emissions of the paired burners are significantly different ($p<0.05$, the Mann-Whitney test).

** These emissions of the paired burners are not significantly different ($p>0.05$, the Mann-Whitney test).

The whole dataset

The emissions from different burners and their comparisons are listed in Table 3.3. The emission factors (per kg) are 4.0 ± 0.9 g/kg for Masport LE3000, 6.2 ± 1.7 g/kg for Metro Eco and 6.5 ± 1.3 g/kg for Masport Belvedere. There is a difference among the three burners ($p<0.05$, the Kruskal-Wallis test). Masport Belvedere produces significantly higher emissions than Masport LE3000 or the two new burners together (Masport LE3000 and Metro Eco, 5.2 ± 1.0 g/kg) ($p<0.05$, the Mann-Whitney test). The differences between Metro Eco and Masport LE3000 or between Metro Eco and Masport Belvedere are not statistically significant ($p>0.05$, the Mann-Whitney test).

The emission factors (per MJ) are 0.54 ± 0.16 g/MJ for Masport LE3000, 0.97 ± 0.39 g/MJ for Metro Eco and 1.03 ± 0.22 g/MJ for Masport Belvedere. There is a difference among the three burners ($p<0.01$, the Kruskal-Wallis test). Masport Belvedere produces significantly higher emissions than Masport LE3000, Metro Eco or the two new burners together (Masport LE3000 and Metro Eco, 0.76 ± 0.22 g/MJ) ($p<0.05$, the

Mann-Whitney test). The difference between Masport LE3000 and Metro Eco is not significant (p>0.05, the Mann-Whitney test).

The emission rates are 11.2 ± 2.0 g/hr for Masport LE3000, 13.6 ± 3.0 g/hr for Metro Eco, and 13.8 ± 2.8 g/hr for Masport Belvedere. The difference among the three burners is not significant (p>0.05, the Kruskal-Wallis test). The emission rates from Masport Belvedere are not significantly different from the two new burners together (Masport LE3000 and Metro Eco, 12.5 ± 1.8 g/hr) (p>0.05, the Mann-Whitney test).

Table 3.3

Comparison of mean emissions from different burners for the whole dataset.

Burner	Emission factor and emission rate
Masport LE3000 vs Metro Eco (45 tests vs 50 tests)	**4.0 ± 0.9 vs 6.2 ± 1.7 g/kg** 0.54 ± 0.16 vs 0.97 ± 0.39 g/MJ** 11.2 ± 2.0 vs 13.6 ± 3.0 g/hr****
Masport LE3000 vs Masport Belvedere (45 tests vs 60 tests)	**4.0 ± 0.9 vs 6.5 ± 1.3 g/kg* 0.54 ± 0.16 vs 1.03 ± 0.22 g/MJ* 11.2 ± 2.0 vs 13.8 ± 2.8 g/hr****
Metro Eco vs Masport Belvedere (50 tests vs 60 tests)	**6.2 ± 1.7 vs 6.5 ± 1.3 g/kg** 0.97 ± 0.39 vs 1.03 ± 0.22 g/MJ* 13.6 ± 3.0 vs 13.8 ± 2.8 g/hr****
Masport LE3000 and Metro Eco vs Masport Belvedere (95 tests vs 60 tests)	**5.2 ± 1.0 vs 6.5 ± 1.3 g/kg* 0.76 ± 0.22 vs 1.03 ± 0.22 g/MJ* 12.5 ± 1.8 vs 13.8 ± 2.8 g/hr****

* These emissions of the paired burners are significantly different (p<0.05, the Mann-Whitney test).

** These emissions of the paired burners are not significantly different (p>0.05, the Mann-Whitney test).

Discussion

Emissions are highly dependent on burners being used and new burners are not always cleaner than the old ones. The subset of data with the same fuel suggests that there is a difference between individual burners. However, this dataset contains only six combinations (30 tests). The whole dataset provides further information about the performance of individual burners. However, different fuel parameters were tested on each burner in the whole dataset, as compared to the same fuel parameters in the subset of data. The difference in fuel parameters may contribute to the difference in emissions of the burners in the whole dataset. A study is on-going to adjust the effect of fuel parameters on emissions. Nevertheless, the whole dataset is considered to contain better information about the performance of individual burners, but extreme care must be taking when comparing emissions of the burners based on all 31 combinations.

The average emissions of the two NES-compliant burners, Masport LE3000 and Metro Eco, are also calculated and compared to the non-compliant burner Masport Belvedere. This comparison aims to provide some possible indication of the emissions from the NES-compliant burners tested, as compared to the non-compliant burner. It should not be considered as a definitive difference between emissions of "generic NES-compliant burners" and those of "generic non-compliant burners". In fact, emissions from Masport LE3000 and Metro Eco vary significantly.

The results of the whole dataset suggest that the old burner (Masport Belvedere) produces 25% (for per kg emission factors) or 34% (for per MJ emission factors) more emissions than the new burners (Masport LE3000 and Metro Eco together). However, the emission rates from the tests for the three burners are not significantly different. It is not clear at this stage if the size of the burner and/or the selected tests used for each burner is leading to the similarity of the emissions measurements.

The Tokoroa studies (Wilton et al., 2006; Kelly et al., 2007) suggest that NES-compliant burners emit significantly lower particulates than older ones. Recent tests in Nelson, Rotorua and Taumarunui (Smith et al., 2008) support the lower emissions of NES burners. In this study, the old burner emits slightly more than the two new ones on average. However, in reality, old burners are likely to produce much more pollution than our tests of this single older burner suggest. This will be discussed further in Section 5.2.

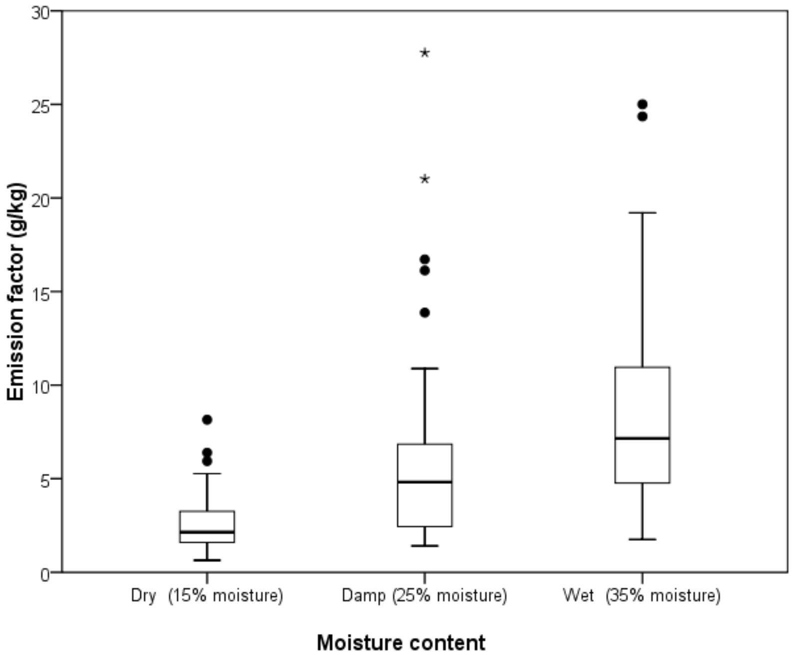
3.4 Fuel moisture content

Subset of data with the same other parameters

To assess the effect of fuel moisture content on emissions, we compare test results of different moisture content levels for the same burner and the same other fuel characteristics (i.e., size, cut, and wood type). The daily emissions are shown in Figures E1.1-E1.8 (Appendix E). There are 24 combinations which cover all three burners, all three wood types, small and large size, and split and unsplit cut. The overall results are presented in Figure 3.2 and Table 3.4. Generally, emissions from dry wood are the lowest and wet wood the highest. Per kg emissions from dry, damp and wet wood are 2.7 ± 0.5, 6.4 ± 1.8 and 8.9 ± 1.9 g/kg, respectively. The emission factors are significantly different ($p<0.01$, the Kruskal-Wallis test for the group and the Mann-Whitney test for the pair-wise).

Figure 3.2

Emissions from dry, damp and wet wood for the same burner and other fuel characteristics (i.e., size, cut, and wood type) (24 test combinations).



The emission factors (per MJ) from dry, damp and wet wood are 0.34 ± 0.07, 0.91 ± 0.30 and 1.45 ± 0.46 g/MJ, respectively. They are significantly different ($p<0.01$, the Kruskal-Wallis test for the group and the Mann-Whitney test for the pair-wise). The emission rates from dry, damp and wet wood are 8.3 ± 1.7, 14.6 ± 3.7 and 17.1 ± 3.2 g/hr, respectively. There is a difference among the three categories of moisture content ($p<0.01$, the Kruskal-Wallis test). Emission rates from dry wood are significantly lower than from damp or wet wood ($p<0.01$, the Mann-Whitney test). The difference between damp and wet wood is not significant ($p>0.05$, the Mann-Whitney test).

The whole dataset

The mean per kg emission factors are 2.9 ± 0.7, 6.5 ± 1.5 and 7.9 ± 1.6 g/kg from dry, damp and wet wood, respectively. There is a difference among the three categories of moisture content ($p<0.05$, the Kruskal-Wallis test). Emissions from dry wood are significantly lower than from damp or wet wood ($p<0.01$, the Mann-Whitney test). The difference between damp and wet wood is not significant ($p>0.05$, the Mann-Whitney test).

The per MJ emission factors from dry, damp and wet wood are 0.41 ± 0.13, 0.90 ± 0.25 and 1.34 ± 0.37 g/MJ, respectively. They are significantly different ($p<0.01$, the Kruskal-Wallis test for the group and the Mann-Whitney test for the pair-wise). The emission rates from dry, damp and wet wood are 8.8 ± 1.8, 15.4 ± 3.1 and 15.2 ± 2.8 g/hr, respectively. There is a difference among the three categories of moisture content ($p<0.01$, the Kruskal-Wallis test). The emission rates from dry wood are significantly lower than from damp or wet wood ($p<0.01$, the Mann-Whitney test). The difference between damp and wet wood is not significant ($p>0.05$, the Mann-Whitney test).

Discussion

Wood moisture content is a very important variable affecting emissions. Damp or wet wood contains more moisture and needs more energy to evaporate the water in the fuel. This causes the fire box temperature to drop and reduces combustion efficiency. As a result, more particulates are emitted (Meyer, et al., 2008). Table 3.4 summarises the emissions for different moisture content levels for the subset of data (with the same other parameters) and whole datasets. Both datasets demonstrate that emissions from damp or wet wood are significantly higher than from dry wood. Overall, compared to dry wood, wet or damp wood increases the emission factors by more than a factor of two, and the emission rates by more than 70%.

Table 3.4

Emissions for different moisture content levels for the subset of data (with the same other parameters) and the whole dataset.

Moisture content	Emission factor and emission rate	
	Subset of data *	**Whole dataset***
Dry (15%)	**2.7 ± 0.5 g/kg 0.34 ± 0.07 g/MJ 8.3 ± 1.7 g/hr (40 tests)**	**2.9 ± 0.7 g/kg 0.41 ± 0.13 g/MJ 8.8 ± 1.8 g/hr (55 tests)**
Damp (25%)	**6.4 ± 1.8 g/kg 0.91 ± 0.30 g/MJ 14.6 ± 3.7 g/hr (40 tests)**	**6.5 ± 1.5 g/kg 0.90 ± 0.25 g/MJ 15.4 ± 3.1 g/hr (50 tests)**
Wet (35%)	**8.9 ± 1.9 g/kg 1.45 ± 0.46 g/MJ 17.1 ± 3.2 g/hr (40 tests)**	**7.9 ± 1.6 g/kg 1.34 ± 0.37 g/MJ 15.2 ± 2.8 g/hr (50 tests)**

* There is a significant difference among the three categories of moisture content ($p<0.05$, the Kruskal-Wallis test). See text for comparison of emissions for paired categories of moisture content.

3.5 Wood species

Subset of data with the same other parameters

To assess the effect of wood types on emissions, test results from different wood types are compared for the same burner and other fuel parameters. The daily emissions are shown in Figures F1.1-F1.8 (Appendix F). There are 17 combinations. Emissions for the paired wood types are presented in Figure F1.9 (Appendix F) and Table 3.5. The results suggest that there is a difference between wood species. The emissions from pine are significantly higher than from blue gum ($p<0.01$, the Mann-Whitney test).

Table 3.5

Comparison of emissions from different wood species with the same burner and the same other fuel parameters.

Wood	Burner and other fuel parameters	Emission factor and emission rate
Pine vs Blue gum (20 tests)	**Masport Belvedere small unsplit dry, damp or wet wood; or Metro Eco large split damp wood**	**8.3 ± 1.9 vs 4.1 ± 1.0 g/kg* 1.17 ± 0.34 vs 0.61 ± 0.19 g/MJ* 18.5 ± 3.3 vs 9.4 ± 2.1 g/hr***
Pine vs Macrocarpa (15 tests)	**Masport LE3000 small or large split dry wood, or Metro Eco large split damp wood**	**3.9 ± 1.4 vs 2.8 ± 1.3 g/kg** 0.41 ± 0.14 vs 0.39 ± 0.22 g/MJ** 12.1 ± 3.4 vs 8.4 ± 3.7 g/hr***
Blue gum vs Macrocarpa (15 tests)	**Metro Eco large split dry, damp or wet wood**	**3.6 ± 1.5 vs 6.1 ± 2.4 g/kg** 0.49 ± 0.22 vs 0.73 ± 0.27 g/MJ** 8.9 ± 3.3 vs 14.9 ± 4.4 g/hr***

* These emissions of the paired wood types are significantly different (p<0.05, the Mann-Whitney test).

** These emissions of the paired wood types are not significantly different (p>0.05, the Mann-Whitney test).

The whole dataset

The emissions from different wood species are listed in Table 3.6. For the whole dataset, the per kg emission factors are 6.4 ± 1.2, 5.1 ± 1.5 and 4.8 ± 1.6 g/kg for pine, blue gum and macrocarpa, respectively. There is a difference among the three wood species (p<0.05, the Kruskal-Wallis test). The emissions from pine are higher than from blue gum (p<0.05, the Mann-Whitney test). The difference between macrocarpa and pine or blue gum is not significant (p>0.05, the Mann-Whitney test). The per MJ emission factors are 0.89 ± 0.19, 0.94 ± 0.36 and 0.66 ± 0.25 g/MJ for pine, blue gum and macrocarpa, respectively. The difference among the three burners is not significant (p>0.05, the Kruskal-Wallis test). The emission rates are 15.0 ± 2.4 g/hr, 10.6 ± 2.5 g/hr and 12.6 ± 3.3 g/hr for pine, blue gum and macrocarpa, respectively. There is a difference among the three wood species (p<0.01, the Kruskal-Wallis test). The emission rates from pine are higher than from blue gum (based on p<0.01 for the Mann-Whitney test). The difference between macrocarpa and pine or blue gum is not significant (p>0.05, the Mann-Whitney test).

Table 3.6

Emissions from different wood species for the whole dataset.

Wood	Emission factor and emission rate*
Pine **(70 tests)**	**6.4 ± 1.2 g/kg** **0.89 ± 0.19 g/MJ** **15.0 ± 2.4 g/hr**
Blue gum **(55 tests)**	**5.1 ± 1.5 g/kg** **0.94 ± 0.36 g/MJ** **10.6 ± 2.5 g/hr**
Macrocarpa **(30 tests)**	**4.8 ± 1.6 g/kg** **0.66 ± 0.25 g/MJ** **12.6 ± 3.3 g/hr**

* See text for comparison of emissions from different wood species.

Discussion

The emissions are related to specific wood species. Both the subset of data and the whole dataset show a difference of emissions from some paired wood species. The subset of data contains only 17 combinations. The whole dataset provides more information for comparing emissions and is used to estimate the difference of the emissions from three wood species. From the whole dataset, the per kg emission factors of pine are 25% higher than those of blue gum, and the emission rates are 42% higher, but the per MJ emission factors are not significantly different. The whole dataset also suggests that the difference between macrocarpa and pine or blue gum is not significant. The effect of wood species on emissions may relate to calorific value, wood density, or the amount of bark, knots or resin on the wood surface.

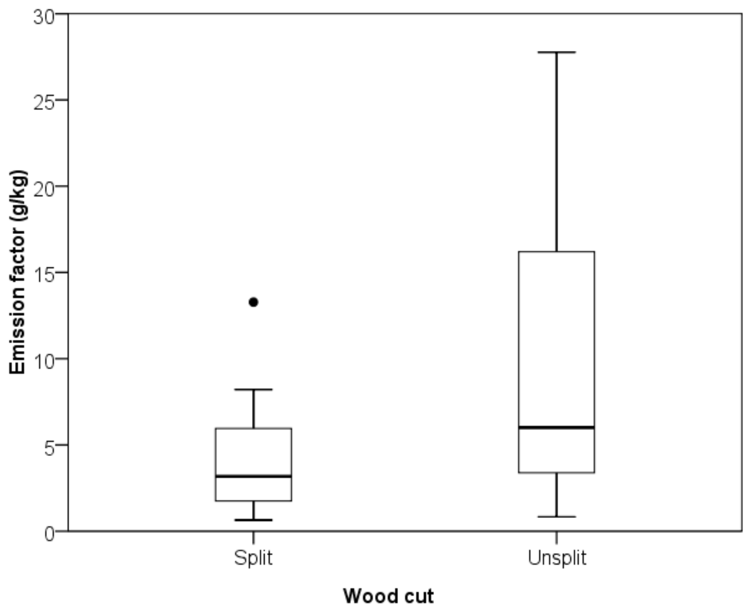
Testing of large split South Island wood (pine, douglas fir and willow) and lower North Island pine, all of damp wood, was also carried out for the Metro Eco burner. The results are shown in Figure F1.10 and Tables F1.1-F1.4 (Appendix F). It appears that emissions are different among South Island pine, lower North Island pine and Auckland-sourced pine. However, when including all the wood used in the tests, the difference between the South Island wood and the Auckland-sourced wood is not statistically significant (see Appendix F). This provides further evidence that emissions are related to specific species but that the variations of emissions from different wood species are relatively small, compared to other significant fuel variables, e.g., moisture content.

3.6 Split and unsplit logs

Subset of data with the same other parameters

To assess whether splitting logs has an effect on emissions, test results from split and unsplit logs are compared for the same burner and the same other fuel parameters. The daily emissions are shown in Figures G1.1-G1.6 (Appendix G). There are 12 combinations. The results are presented in Figure 3.3 and Table 3.7. Overall, per kg emissions from split logs (4.0 ± 1.1 g/kg) are significantly lower than from unsplit logs (9.5 ± 3.0 g/kg) ($p<0.01$, the Mann-Whitney test). The per MJ emission factors for split and unsplit wood are 0.57 ± 0.16 and 1.74 ± 0.67 g/MJ, respectively. They are significantly different ($p<0.01$, the Mann-Whitney test). The emission rates for split and unsplit wood are 10.2 ± 2.6 and 19.1 ± 5.7 g/hr, respectively. The Mann-Whitney test demonstrates that the difference is statistically significant ($p<0.05$).

Figure 3.3
Emissions of spilt and unsplit logs for the same burner and the same other fuel characteristics (i.e., wood types, size and moisture content).



The whole dataset

For the whole dataset, the mean per kg emissions for split and unsplit wood are 4.5 ± 0.7 and 7.1 ± 1.5 g/kg, respectively. The Mann-Whitney test demonstrates that the difference is statistically significant ($p<0.05$). The per MJ emission factors for split and unsplit wood are 0.56 ± 0.09 and 1.24 ± 0.32 g/MJ, respectively. They are significantly different ($p<0.01$, the Mann-Whitney test). The emission rates for split and unsplit wood are 11.6 ± 1.5 and 14.7 ± 2.9 g/hr, respectively. The difference is not significant ($p>0.05$, the Mann-Whitney test).

Discussion

Table 3.7 summarises the emissions from split and unsplit logs for the subset of data (with the same other parameters) and the whole dataset. Overall, unsplit wood generates higher emissions than split wood. Compared to split wood, the emission factors of unsplit wood increase by more than 60%. Higher emissions from unsplit wood may be due to a higher proportion of bark, knots or resin on the wood surface which would have different burning properties than the wood inside. Further investigation is needed to understand this big difference in emissions. The emission rates of split and unsplit wood are not significantly different.

Table 3.7

Emissions from split and unsplit logs for the subset of data (with the same other parameters) and the whole dataset.

Wood surface	**Emission factor and emission rate**	
	Subset of data*	**Whole dataset***
Split	**4.0 ± 1.1 g/kg** **0.57 ± 0.16 g/MJ** **10.2 ± 2.6 g/hr** **(30 tests)**	**4.5 ± 0.7 g/kg** **0.56 ± 0.09 g/MJ** **11.6 ± 1.5 g/hr** **(85 tests)**
Unsplit	**9.5 ± 3.0 g/kg** **1.74 ± 0.67 g/MJ** **19.1 ± 5.7 g/hr** **(30 tests)**	**7.1 ± 1.5 g/kg** **1.24 ± 0.32 g/MJ** **14.7 ± 2.9 g/hr** **(70 tests)**

* See text for comparison of emissions from split and unsplit logs.

3.7 Small and large logs

Subset of data with the same other parameters

To assess the effect of log sizes on emissions, test results from small and large log sizes are compared for the same burner and the same other fuel parameters. There are 16 combinations. The emission factors from small (5.9 ± 1.3 g/kg or 0.86 ± 0.22 g/MJ) and large (5.3 ± 1.8 g/kg or 0.82 ± 0.29 g/MJ) logs are not significantly different ($p>0.05$, the Mann-Whitney test). The emission rates are 13.8 ± 2.3 and 11.7 ± 3.6 g/hr for small and large logs, respectively. The Mann-Whitney test demonstrates that the difference is statistically significant ($p<0.05$).

The whole dataset

The emission factors are 5.3 ± 1.0 g/kg (or 0.80 ± 0.17 g/MJ) and 5.9 ± 1.2 g/kg (or 0.91 ± 0.24 g/MJ) for small and large logs, respectively. The Mann-Whitney test demonstrates that the difference is not statistically significant ($p>0.05$). The emission rates are 12.7 ± 1.9 and 13.2 ± 2.2 g/hr for small and large logs, respectively. The difference is not statistically significant ($p>0.05$, the Mann-Whitney test).

Discussion

Table 3.8 summarises the emissions from small and large logs for the subset of data (with the same other parameters) and the whole dataset. The emission factors for small and large logs are not significantly different. The emission rates for small and large logs are statistically different for the small dataset, but not for the whole dataset. Note that the smaller dataset was from tests only on the two burners with larger fireboxes, whereas the whole dataset includes larger wood (only) in the smaller Metro-Eco and this may have affected the results. However, the differences in both datasets are small and overall, in our tests log size was not a significant factor affecting emissions. Some studies have shown that large logs produce more pollution than small ones. For example, Scott (2005) reported increased emissions from large logs (1.5 to 3 kg in weight). This inconsistency may arise due to different criteria for small and large logs, different test procedures or different sample size.

Table 3.8

Comparison of emissions from small and large logs for the subset of data (with the same other parameters) and the whole dataset.

Log size	**Emission factor and emission rate**	
	Subset of data* (40 tests)	**Whole dataset* (155 tests)**
Small	**5.9 ± 1.3 g/kg** **0.86 ± 0.22 g/MJ** **13.8 ± 2.3 g/hr**	**5.3 ± 1.0 g/kg** **0.80 ± 0.17 g/MJ** **12.7 ± 1.9 g/hr**
Large	**5.3 ± 1.8 g/kg** **0.82 ± 0.29 g/MJ** **11.7 ± 3.6 g/hr**	**5.9 ± 1.2 g/kg** **0.91 ± 0.24 g/MJ** **13.2 ± 2.2 g/hr**

* See text for comparison of emissions from small and large logs.

3.8 Comparison of variables

In previous sections, the effect of burner model, wood species, moisture content, wood surface and size on emissions is investigated by using each of two datasets: a subset of data including only the tests with the same other four variables and the whole dataset of all the tests. Evidence from both datasets is considered but with more emphasis on the whole dataset where appropriate because of its larger sample size, particularly for quantitatively estimating emission changes. In fact, the results from two datasets are broadly consistent. In this section, we identify the significant variables and estimate the magnitude of emission changes for each variable.

Table 3.9 summarises the variables and parameters which do not have significant effects on emissions from our tests. Table 3.10 lists the variables and parameters which affect on emissions (i.e. statistically significant differences). The magnitude of the emission changes is derived from the whole dataset. They provide an indication how much emissions may increase for the different variables. For example, compared to dry wood, wet wood could increase the per kg emission factors by 172% (i.e. emissions are almost three times higher), the per MJ emission factors by 229% and the emission rates by 72%. The tests from the overall dataset suggest that per kg emission factors from the old burner are only 25% higher than from the two new ones. However, in reality, old burners could produce much more pollution than new ones and study results may be an artefact of the tests that were run on the different burners. This will be discussed further in Section 5.2.

Table 3.9

Variables where the differences in emissions are not significant.

Variable	Parameter
Log size	**Small logs versus large logs**
Wood species	**Macrocarpa versus pine** **Macrocarpa versus blue gum**

Table 3.10

Variables and parameters that affect emissions.

Variable	Parameter	Percentage increase in emissions		
		Emission factor (g/kg)	**Emission factor (g/MJ)**	**Emission rate (g/hr)**
Moisture content	Wet wood versus dry wood Damp wood versus dry wood	172% 124%	229% 122%	72% 74%
Burner operation	Low burn versus high burn Start up versus high burn	113% 56%	68% 383%	32% 277%
Wood surface	Unsplit wood versus split wood	60%	121%	*
Wood species	Pine versus blue gum	25%	*	42%
Burner	Masport Belvedere versus Masport LE3000 and Metro Eco	25%	34%	*

* The difference is not significant ($p>0.05$, the Mann-Whitney test).

As discussed in previous sections, most of the results are broadly consistent with other studies (e.g., higher emissions from damp or wet wood than from dry wood), but some are not (e.g., insignificant difference for small and large logs). The inconsistency in the effects of log size may be due to different criteria for small and large logs, different test procedures or different sample size.

For a change for each of the significant variables and parameters, our study estimates the magnitude of the corresponding emission change. Our dataset can also be used to explore the influence of several variables and parameters combined. For example, Table 3.11 lists the effects of two variables: moisture content and wood surface. Compared to split dry wood, the emissions factor for unsplit wet wood is about four times higher per kg of wood burnt and six times higher for the energy released (per MJ) and the emission rate is about double.

Table 3.11

Emissions considering two fuel variables: moisture content and wood surface.

Fuel	**Dry (15%)**		**Damp (25%)**		**Wet (35%)**	
	Split	**Unsplit**	**Split**	**Unsplit**	**Split**	**Unsplit**
Emission factor (g/kg)	**2.3 ± 0.5**	**3.6 ± 1.3**	**4.8 ± 1.1**	**9.0 ± 3.2**	**6.5 ± 1.5**	**9.2 ± 2.9**
Emission factor (g/MJ)	**0.28 ± 0.06**	**0.55 ± 0.27**	**0.62 ± 0.16**	**1.32 ± 0.54**	**0.82 ± 0.15**	**1.85 ± 0.69**
Emission rate (g/hr)	**8.0 ± 1.9**	**9.8 ± 3.4**	**13.3 ± 2.1**	**18.5 ± 6.7**	**13.8 ± 2.6**	**16.6 ± 5.1**
Number of tests	**30**	**25**	**30**	**20**	**25**	**25**

4 Best and worst performance

We investigate the characteristics of the best and the worst performance with an aim to encourage good and target poor practice to reduce emissions. The 155 tests are divided into three groups: the lowest 25% emissions (best), the highest 25% emissions (worst) and the remaining samples (middle). The emission factors are 1.5 ± 0.1 g/kg (or 0.19 ± 0.02 g/MJ), 4.3 ± 0.3 g/kg (or 0.58 ± 0.04 g/MJ) and 12.5 ± 1.8 g/kg (or 2.09 ± 0.44 g/MJ) for the best, middle and worst group, respectively. The emission rates are 4.4 ± 0.3, 10.7 ± 0.7 and 26.0 ± 3.2 g/hr for the best, middle and worst group, respectively.

Table 4.1 lists the percentage of different burners and fuel parameters for the three groups and the dataset of 155 tests for per kg emission factors. The proportion of dry, damp and wet wood is 77%, 21% and 3% for the best group, but 5%, 38% and 56% for the worst. Low emissions closely link to dry wood while high emissions are more likely due to burning damp or wet wood. The effects of other variables are not as significant as moisture content. Out of the 95 tests for the two new burners, only eight test results have emissions less than the NES standard of 1.5 g/kg. This is not unexpected, as real life operation of wood burners will vary significantly from the standard test method. However, it has implications for determining the best options to reduce emissions from domestic home heating because wood burners can emit high levels of particulate regardless of whether they meet the national standards.

The results of per MJ emission factors and emission rates are listed in Tables H1.1 and H1.2 (Appendix H). The best group of per MJ emission factors or emission rates also closely links to dry wood, and the worst group to damp or wet wood. The effects of other variables are not as significant as moisture content. Note, as discussed earlier these results should be interpreted with care, as not all the same tests were run for each burner or combination of variables.

Table 4.1

Percentage of different burners and fuel parameters for the best and the worst emissions for per kg emission factors*.

Variable	Parameter	Samples of lowest 25% emissions (average 1.5 g/kg)	Samples of highest 25% emissions (average 12.5 g/kg)	Remaining samples (average 4.3 g/kg)	Whole dataset (155 samples)
Moisture content	Dry (15%)	77 %	5 %	30 %	35 %
	Damp (25%)	21 %	38 %	35 %	32 %
	Wet (35%)	3 %	56 %	35 %	32 %
Wood surface	Split	62 %	44 %	57 %	55 %
	Unsplit	38 %	56 %	43 %	45 %
Burner	Masport LE3000	33 %	18 %	32 %	29 %
	Metro Eco	44 %	36 %	25 %	32 %
	Masport Belvedere	23 %	46 %	43 %	39 %
Wood species	Pine	26 %	62 %	47 %	45 %
	Blue gum	49 %	26 %	34 %	35 %
	Macrocarpa	26 %	13 %	19 %	19 %
Log size	Small	36 %	38 %	40 %	39 %
	Large	64 %	62 %	60 %	61 %

* The total of three groups may not add up 100 % due to rounding of numbers.

5 Emission factors and emission rates

5.1 Auckland results

Emission factors, emission rates and burn rates from the woodburner testing are listed in Tables 5.1 and 5.2 for individual burners, two new burners together and all three burners, using the whole dataset. In the calculation, the moisture content of dry, damp and wet wood are 15%, 25% and 35% (wet weight), respectively.

As discussed in Section 3.3, the whole dataset is considered to contain better information about the performance of individual burners than the subset of the data, but extreme care must be taking when comparing emissions of the burners based on all 31 combinations because the difference in fuel parameters for individual burners may contribute to the difference in their emissions. In addition, the average emissions of the two NES-compliant burners, Masport LE3000 and Metro Eco, should be considered as some possible indication of the emissions from the NES-compliant burners tested, but not from “generic NES-compliant burners”. In fact, emissions from Masport LE3000 and Metro Eco vary significantly.

As shown earlier, the cycle (daily) average emission factors, emission rates or burn rates are calculated as weighted averages of start up, high burn and low burn. The other average values are the arithmetic means of the daily averages, including those in Tables 5.1 and 5.2. For comparison, the testing results are also calculated as weighted averages of start up, high burn and low burn for the whole dataset. The results (see Appendix I) are close to those in Tables 5.1 and 5.2, except for the emission factors g/MJ which values are relatively low.

Table 5.1

Emission factors from the woodburner testing.

Burner	Emission factor (g/kg)		Emission factor (g/MJ)
	Dry weight	Wet weight	
Masport LE3000	4.0 ± 0.9	3.0 ± 0.7	0.54 ± 0.16
Metro Eco	6.2 ± 1.7	4.3 ± 1.1	0.97 ± 0.39
Masport Belvedere	6.5 ± 1.3	4.7 ± 1.0	1.03 ± 0.22
Masport LE3000 and Metro Eco	5.2 ± 1.0	3.7 ± 0.7	0.76 ± 0.22
All three burners	5.7 ± 0.8	4.1 ± 0.6	0.87 ± 0.16

Table 5.2

Burn rates and emission rates from the woodburner testing.

Burner	Burn rate (kg/hr)		Emission rate (g/hr)
	Dry weight	Wet weight	
Masport LE3000	3.1 ± 0.2	3.9 ± 0.2	11.2 ± 2.0
Metro Eco	2.5 ± 0.2	3.4 ± 0.1	13.6 ± 3.0
Masport Belvedere	2.3 ± 0.1	3.1 ± 0.1	13.8 ± 2.8
Masport LE3000 and Metro Eco	2.8 ± 0.1	3.6 ± 0.1	12.5 ± 1.8
All three burners	2.6 ± 0.1	3.4 ± 0.1	13.0 ± 1.5

5.2 Comparison with other real life testing

This section includes a comparison of Auckland emission factors with other real life testing results for NES compliant and other burners. Tested burners that meet the NES emission standard are grouped as NES compliant, otherwise they are labelled as 'other'.

Table 5.3 shows the results for the NES compliant burners. It is considered that the emission factor of the Christchurch study may not be robust due to the small sample size (Scott, 2005). The results for Auckland are similar to Tokoroa, Nelson, Rotorua and Taumarunui. Therefore, the measured emission factor for Auckland appears to be broadly consistent with other NES compliant real life emissions factors measured in NZ.

Table 5.3

Comparison of emission factors from real life testing for NES compliant burners (g/kg).

Testing	Emission factor	Number of burners	Number of tests	Reference
Auckland	5.2	2	95	This study
Christchurch	15.5	4	29	Scott, 2005
Tokoroa	4.6	9	50	Wilton et al., 2006
Nelson, Rotorua and Taumarunui	4.6	18	120	Smith et al., 2007

Table 5.4 shows the results for other burners tested that are not compliant with the NES. The Auckland result is less than half of the Tokoroa result (12 burners). In Australia, the standard for wood heater particulate emissions limit is 4 g/kg. Therefore, a Launceston result is also listed in Table 5.4. The measurement at Launceston was for PM_{10} (particulate matter less than 10 microns in diameter), but is compared directly since most particles from wood burners are below 10 microns in size (Kinsey et al., 2009). The emission factor for Auckland is also lower than Launceston. Only one non-

compliant burner was tested in Auckland and the results do not appear to be representative on the basis of the other studies.

Table 5.4

Comparison of emission factors from real life testing for other burners (g/kg).

Testing	Emission factor	Number of burners	Number of tests	Reference
Auckland	6.5	1	60	This study
Christchurch	14.3	2	14	Scott, 2005
Tokoroa	14.0	12	96	Wilton et al., 2006
Launceston	9.4	17	21	Meyer et al., 2008

Assuming that the results from Tokoroa (see table 5.4) and Nelson, Rotorua and Taumarunui (and also Tokoroa, see table 5.3) are representative of old and new burners, emissions from the old burners could be three times as high, compared to the new burners. This is much higher than the 25% difference from the Auckland study. Please note that different test procedures for these studies may be a contributing factor for the difference of the test results (see earlier discussions).

6 Conclusions and discussion

Two types of dataset were used to investigate the effect of burner, wood species, moisture content, wood surface and size on emissions. The subset of data which include only the tests with the same other four variables illustrate the role of the variable under consideration (ranging from 35 to 120 tests depending on the variable). The whole dataset which includes all the 155 tests demonstrates the contribution of the variables of interest for real life operations. In general, the two datasets provided consistent results. There were, however, some inconsistencies due to the limited test number of the subset of data or the confounding effects of variables in the whole dataset. There were also considerable variations of emissions from the five tests of each combination. Evidence from both datasets was considered when drawing conclusions.

Key results

- Variables significantly affecting emissions include the burner, burner operation, wood moisture content, cut and species.
    - Wet or damp wood emits much higher pollution than dry wood. Compared to dry wood, wet or damp wood increases the emission factors by more than a factor of two, and the emission rates by more than 70%.
    - The emission factors of high burn are the lowest. Compared to high burn, start up and low burn increase the emission factors by more than 50% and the emission rates by more than 30%.
    - The emission factors (per kg or MJ) for unsplit wood are 60% higher, compared to split wood. However, the emission rates of split and unsplit wood are not significantly different.
    - The effects of wood species on emissions were not conclusive. The per kg emission factors of pine are more than 20% higher than those of blue gum, and the emission rates are more than 40% higher, but the per MJ emission factors are not significantly different. There was no significant difference in emissions between macrocarpa and pine or blue gum.
    - The old burner generally had higher emissions than the two new ones based on the tests that were carried out.
    - Log size was not found to be a significant variable affecting emissions in these tests.

- Low emissions closely link to dry wood while high emissions link to wet or damp wood.
- The average emission factors for this study are 5.2 ± 1.0 g/kg or 0.76 ± 0.22 g/MJ for the two new burners, and 6.5 ± 1.3 g/kg or 1.03 ± 0.22 g/MJ for the old burner.
- The average emission rates are 12.5 ± 1.8 g/hr for the two new burners, and 13.8 ± 2.8 g/hr for the old burner.
- The average burn rates are 2.8 ± 0.1 kg/hr (dry wood) or 3.6 ± 0.1 kg/hr (wet wood) for the two new burners, and 2.3 ± 0.1 kg/hr (dry wood) or 3.1 ± 0.1 kg/hr (wet wood) for the old burner.

Our test cycle of start up, high burn and low burn was designed to simulate real life operations in Auckland. The average of emissions from the three conditions is used to represent the mean for the cycle. Since emissions were measured for each operating condition, it is possible to calculate emissions for variations in home heating patterns in Auckland or elsewhere, for example, a day of 14 hour burner use including 10 hour low burn, by using our dataset.

Previous real life testing in New Zealand suggests an emissions factor of 4.6 g/kg for new burners and 14.0 g/kg for old ones. The emissions from the two new burners (5.2 ± 1.0 g/kg) are comparable, but unexpectedly low for the old one (6.5 ± 1.3 g/kg). Care should be taken with interpreting these results as only three burners were tested.

Acknowledgements

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Appendix A: Adapted testing methodology by Mallett

Spectrum Laboratories Ltd Adapted Testing Methodology from Canterbury Solid Fuel Burner Testing Methodology for Simulating the Full Operational Cycle

Part 1 – Freestanding logburners

Version 8

24 October 2008

Author: Tim Mallett

(Adapted from version 5 by Nick Abbott, Jan 06)

Following comments from Paul Sintes, Nick Abbot, and John Todd, and preliminary testing at ARS on 24/25 September 2007

1. INTRODUCTION

1.1 Background

The purpose of this document is to detail a test method (the "Canterbury method"), for measuring the amount of particulates emitted from a wood-fired residential heater[2] under specified operating regimes that include "start-up" phase, refuelling, and 4 - 5 hours of operation at various heat output settings.

It is noted that the current standard test methods (AS/NZS 4012 and 4013) use a tightly prescribed operating regime that does not include "start-up" emissions, or emission during reloading, utilises a large ember bed, and leaves the air supply on "high" after refuelling until 20 % of the load has been consumed. Each load consists of a prescribed number of pieces of a prescribed size and moisture content. These are typically selected to avoid knotty or resinous wood, and shaped to an octagonal profile. While this all helps to achieve consistency between runs, it means that the 4012/4013 test result does not reliably differentiate burners with low "real life" emissions from those with higher "real life" emissions.

By measuring a wider range of emissions from the appliance, including start-up and refuelling, using a less-favourable firing regime that that used in 4012/4013, it is hoped that the resulting g/kg and g/MJ values will reflect the possible performance of the appliance when used in "real life". The question of what value might be used as a

[2] This includes appliances with pollution control equipment or an automatic burn-rate control system installed.

criterion to “pass” the test, and how the results of such a test might be used to determine which burners can be installed in a given area, is a separate issue, and will be addressed in a separate document. The purpose of this document is to describe the test method only.

It is assumed that any appliance tested to this method would first be tested to AS/NZS 4012/4013 and a report prepared on that test (including the description of the appliance and the labelling requirements). Subsequent reporting of the “Canterbury Standard” test results would only need to report the specifics of the test procedure and the results obtained.

Originally it was hoped that a “real life” test method could be developed, that would reflect the likely “real life” emissions from the current list of authorised woodburners, and distinguish new woodburners that emit substantially less in real life than the existing burners. In practice this proved to be a difficult task, especially given the constraints of limited time in the lab, and the desire that the test be similar for all burners. For every burner there is a range of operating conditions that will result in that burner failing to sustain combustion. This generally results from creating too small an ember bed, loading too large a piece of wood, turning the air supply down too low too quickly, or any combination of these. However the precise combination of these variables that will cause the fire to go out is likely to be different for each burner, depending on its size, air supply, thermal mass, draught, etc. Therefore it is not possible to specify a single test regime that will sustain combustion for every currently authorised burner, but will also reflect the “worst” (i.e. highest particulate emitting) combination of operator behaviours for that burner.

The solution adopted here is to specify a single test regime, applicable to all woodburners, that is likely to produce the highest emissions while still representing “reasonable” behaviours. It is acknowledged that many currently authorised burners won’t sustain combustion for the entire test (i.e. they’ll go out). However it is also anticipated that designers of new woodburners will adapt their designs so that new appliances will complete the test, and produce low emissions in this “worst case” procedure. In doing so, they will also produce woodburners that are unlikely to emit more than the test result when operated in the home by a reasonable operator. Where any currently authorised burners do complete the test, this test regime should also differentiate new appliances with lower “real life” emissions from those currently authorised appliances.

1.2 Overview

The method is intended for use under laboratory controlled conditions, using the calorimeter room and sampling train prescribed in AS/NZS4012/4013, in a laboratory that is accredited to use those standard methods.

The test has three phases – “start-up”, the “main run” using high setting, main run using low setting (if available). Hard wood test is removed. The test would be run twice, on consecutive days, to improve the reliability of the final result and give an indication of the variability of the appliance. This is important as there is scope for considerable variation in the nature of the fuel burned, even within the specified parameters, and the two runs will help to smooth this effect.

The test procedure is intended to reflect the behaviour of an “average” operator, who generally complies with the manufacturer’s instructions (where plausible) regarding the operation and fuel specifications.

1.3 Assumptions

The fundamental assumptions of the method for measuring particulate emissions are the same as for AS/NZS 4012/4013, namely that:

(i) all of the particulate matter presented to the sampling system is generated by the heater;

(ii) dilution of the flue gas models the particulate formation processes that take place under normal household use;

(iii) the material classed as particulate matter acts like a gas during collection by the sampling system; and

(iv) material not retained as particulate matter would be in the vapour phase in actual use.

2. DESCRIPTION OF TEST FACILITY, INSTRUMENTATION, AND HEATER INSTALLATION

The test facility for use in this method is as fully described in AS/NZS 4013 “Domestic Solid Fuel Burning Appliances - Method for determination of flue gas emission”, Sections 2 and 3.

The test equipment and instrumentation, its calibration and the accuracy of measurements shall be as detailed in AS/NZS 4012 Sections 2, 3 and 4.

The heater shall be installed as described in AS/NZ 4013 Section 6.

Note that this document relates to freestanding logburners only.

Operating Procedures removed.

2.1 General

The operation of the test facility and techniques for measuring particulates, temperature, excess oxygen, etc. shall be as specified in AS/NZ 4013 “Domestic Solid Fuel Burning Appliances - Method for determination of flue gas emission”, Sections 2, 3 and 4.

2.2 Condition and ash layer

Prior to the test, the heater shall be conditioned for at least 10 hours at a high burn rate (this may be satisfied as part of the requirements for testing to AS/NZS 4012/4013). Before commencing the tests, a 25mm layer of wood ash shall be spread over the fire-box floor.

2.3 Heat output settings

For appliances with variable heat output control settings (continuous or discrete) the following shall apply:

“High” firing rate shall mean the appliance heat output control(s) set to achieve maximum burning rate;

“Low” firing rate shall be with the heater’s heat output controls set to achieve minimum burning rate

For appliances with no heat output settings, the specifications regarding “High” and “Low” shall not apply, and the appliance shall be operated at its single setting for the total time specified in the procedure.

Note – The “heat output control” means any adjustable controls that the operator can alter to change the heat output from the appliance. This may include controls on primary air flow, fuel feed rate (in the case of pellet burners, for example), or set points for appliances with automated air supply settings.

2.4 Fuel moisture content

This shall be determined as specified in AS/NZ 4014.2 Appendix A, “Method for Determination of Moisture Content”.

2.5 Sampling

For each of the two days of testing, heater performance data shall be measured and reported for the following periods:

(i) the “start-up” phase (see below),

(ii) the period on high burn setting,

(iii) the period on low burn setting.

Hardwood phase is removed.

3. OPERATING PROCEDURE

3.1 Fuel properties and dimensions

3.1.1 Species and shape

Except where specified otherwise, the wood used shall be pinus radiata, macrocarpa, and blue gum logs, purchased from a commercial firewood supplier in Auckland.

The pieces shall include bark (where present) and shall include knots, resinous areas, etc. Pieces shall be selected at random from the purchased firewood, without any specific selection for “clean burning” pieces free of knots etc. However the wood used in the test shall be, as far as possible, free from decay and mould.

3.1.2 Moisture

The test fuel shall have an average moisture content between 15% ± 3% for seasoned wood and 25% ± 3% for unseasoned wood, on a wet basis. Every piece of wood used shall be tested for moisture content prior to use.

3.1.3 Piece length

For fireboxes with a maximum dimension longer than 500 mm, the length of each piece used (including kindling) shall be 350 mm, plus or minus 35 mm.

For fireboxes with a maximum dimension between 300 mm and 400 mm, the length of each piece used (including kindling) shall be 260 mm, plus or minus 25 mm.

For fireboxes with a maximum dimension less than 300 mm, the length of each piece used (including kindling) shall be 75% of the longest dimension of the firebox, plus or minus 10 mm.

3.2 Firewood mass

3.2.1 Large fireboxes

For fireboxes with a maximum dimension longer than 500 mm:

(i) The kindling load shall be sufficient to establish a reasonable ember bed comprising a total mass of 2.5 kg ± 10%.

(ii) The intermediate 1 load shall comprise 5 pieces with a total mass of 1.5 kg ± 150 g.

(iii) The intermediate 2 load shall comprise 4 pieces with a total mass of 2.5 kg ± 200 g.

(iv) The main load for a small load shall comprise a 90 X 90mm piece with a mass of 2 kg ± 200 g cut into two uniform pieces.

(v) The main load for a large load shall comprise a 140 mm X 140 mm piece with a mass of 3 kg ± 200 g cut into two uniform pieces.

3.2.2 Small fireboxes

For fireboxes with a maximum dimension between 300 mm and 500 mm:

(i) The kindling load shall be sufficient to establish a reasonable ember bed comprising a total mass of 2.0 kg ± 10%.

(ii) The intermediate 1 load shall comprise 4 pieces with a total mass of 1.2 kg ± 120 g.

(iii) The intermediate 2 load shall comprise 3 pieces with a total mass of 2.0 kg ± 200 g.

(iv) The main load shall comprise one or two piece with a mass 1.5 kg ± 150 g (to be discussed after first trial test).

3.2.3 Individual piece masses

For the kindling and intermediate loads the mass of any individual piece shall not be more than 25% above or below the average mass per piece for that load.

3.3 Start-up

3.3.1 The heater shall be set by placing five whole (full double page) pieces of newspaper, crumpled into balls, near the centre of the firebox floor. The pieces of kindling (as specified above) shall be placed somewhat randomly over the newspaper, either in a "tepee" formation or lying horizontally over the paper as if thrown in. Air controls shall be set to high output, and the newspaper is then lit in one place near the front of the fire. The door shall be rested against the firebox with the handle in the "closed" position, but not latched, to allow additional air to enter the firebox.

3.3.2 When the kindling is well alight (4 minutes), add one "intermediate 1" (I1) load of wood horizontally on top of the burning kindling, roughly parallel with the longest dimension of the firebox (regardless of the manufacturer's instructions), with at least two pieces on top of the first two, at a slight angle. Close the door completely, and leave the heat output setting (if present) on "high".

3.3.3 When only 50% of the total mass (kindling plus I1) remains, add the "intermediate 2" (I2) load, also horizontally on top of the existing load, at a slight angle to the existing load (not more than 45 degrees from the longest dimension) with at least one piece on top of the first two at a slight angle to them. Close the door immediately and leave the setting on "high".

3.3.4 When the remaining mass falls to 40% of the I2 load mass (approximately 1.00 kg remaining), add the first "Main load" (M1) piece. Start-up shall be considered complete 5 minutes after the first M1 piece has been added. At this point the filter shall be changed, and the run statistics noted.

3.4 Main burn period

3.4.1 High burn phase

After start-up has completed, the fire shall be left set to "high", and refuelled with one "M1" piece of wood every time the mass reaches 40% of the I2 mass (i.e., after a mass of fuel equal to the M1 piece has burned). Each new piece of wood shall be placed near the centre of the firebox, approximately parallel with the longest axis of the firebox (regardless of the manufacturer's instructions), on top of the existing ember bed and burning pieces.

During re-loading the door shall be open for less than 30 seconds, and the heat output controls shall not be altered.

Just before the first scheduled refuelling after 2 hours of "high burn" period, the filter shall be changed, and the run parameters recorded.

3.4.2 Low burn phase

The appliance shall then be reloaded, and the air setting shall be set to low. The heater shall then be operated at low setting for approximately 2 hours, and refuelled every time the mass remaining falls to 40% of the I2 mass. If the fire is struggling to maintain a flame after reloading, reasonable steps as would be undertaken by a reasonable operator can be taken. Any such steps are to be recorded on the test run sheet.

Just before the first scheduled refuelling after 2 hours of "low burn" period, the filter shall be changed, and the run parameters recorded.

3.4.3 The tests shall be conducted twice on consecutive days for each small and large load cycle.

4. DATA TO BE REPORTED

4.1 Details of the heater under test as required by AS/NZS 4013

4.2 The name and address of the testing agency and the name of the person responsible for the test

4.3 A list of the dates and times for the test and a photograph of the heater under test

4.4 All raw and reduced test data shall be included with the test results

4.5 The following data shall be included in the test report for each output setting:

i. the charcoal bed weight at each refuelling as a percentage of the maximum load,

ii. the weight of each fuel load added, kg,

iii. the average moisture content of the each fuel load, % wet basis,

iv. the flue gas temperature immediately prior to each refuelling, °C,

v. the average flue gas temperature for each output setting, °C,

vi. the average burn rate for each output setting, kg/h,

vii. all data relating to the dilution tunnel and particulate measuring train as required in AS/NZS 4013.

4.6 A total emission in grams/kg fuel (dry basis). Reference to MJ is deleted.

4.6.1 each of start-up, high burn rate, low burn rate, for each day of testing, and Hardwood deleted.

4.6.2 the whole of the three phases, for each day of testing, and

4.6.3 the whole of the six phases.

Appendix B: Emissions testing results

Figure B1.1

A record of a test result.

11-2-08
0059
Main Burn
High

Gas Meter Start: 213.524 Gas meter finish: 216.251

Run number: 2 Barometer: / Humidity: 71

MI added @ 12.5 @ 11.0 @ 9.5 @ 8.0

Time	Flue temp	Firebox Temp	Avg power	Power out	Weight	Efficiency	
0850	540	327	/	8.76	12.92		1
0900	537	318	7.72	8.43	12.34		2
0910	521	314	8.01	8.16	11.70		3
0920	507	298	8.08	8.08	11.14		4
0930	511	315	8.11	8.30	10.58		5
0940	511	307	8.14	8.17	10.10		6
0950	461	326	8.16	8.26	9.74		7
1000	512	333	8.17	8.28	9.12		8
1010	476	308	8.15	7.91	8.70		9
1020	453	305	8.12	7.62	8.32		10
1030	440	287	8.06	7.53	7.78		11
1040	447	284	7.99	7.13	7.46		12
1050	444	262	7.96	6.89	7.12		13
							14
		Fuel	used	5.8	kg		15

Start power	Finish Power	Average. Power	Efficiency	Run Time	Dil/tun volume	Gas m/temp	Dil/Tun temp	Baro meter
8.76	6.89	7.90	/	120	552.150	25.6	57.3	1001.3

Note: The average power for a burn cycle in a test cannot vary by more than 15% when expressed as a percentage of the average of all burn cycles at the same burn rate. Actual variation: ____________ %

The calculated efficiency for any burn cycle cannot vary by more than 10% from the average efficiency of the rest of the burn cycles at the same burn rate in a test. Actual variation ____________ %

S:\HomeHeatingTestCentre\Forms\Fuel Efficiency Power Output Emission Run Test data.doc

Emission 0.386

Table B1.1

Measured emission factors (g/kg, dry weight). Dry, damp and wet correspond to a wet weight moisture content of 15%, 25% and 35%, respectively.

No	Burner and fuel	Start up	High burn	Low burn	Mean*
1	LE3000 small split dry pine 1	2.2	2.5	1.3	2.2
2	LE3000 small split dry pine 2	2.3	1.3	2.0	1.8
3	LE3000 small split dry pine 3	6.5	1.8	1.5	3.1
4	LE3000 small split dry pine 4	3.0	4.1	0.7	3.1
5	LE3000 small split dry pine 5	3.1	1.7	2.0	2.2
6	LE3000 large split dry pine 1	1.6	2.2	0.6	1.7
7	LE3000 large split dry pine 2	1.3	0.7	0.6	0.8
8	LE3000 large split dry pine 3	4.2	4.0	1.4	3.4
9	LE3000 large split dry pine 4	3.9	5.7	2.1	4.3
10	LE3000 large split dry pine 5	3.9	3.6	1.0	3.1
11	LE3000 small split damp pine 1	1.6	1.4	2.0	1.6
12	LE3000 small split damp pine 2	3.0	0.9	2.4	1.8
13	LE3000 small split damp pine 3	4.3	3.1	1.3	3.0
14	LE3000 small split damp pine 4	3.0	3.3	4.7	3.5
15	LE3000 small split damp pine 5	3.7	2.8	2.7	3.0
16	LE3000 large split damp pine 1	5.6	4.0	4.7	4.7
17	LE3000 large split damp pine 2	1.2	2.7	3.5	2.4
18	LE3000 large split damp pine 3	4.3	2.5	3.0	3.2
19	LE3000 large split damp pine 4	4.5	1.3	2.5	2.5
20	LE3000 large split damp pine 5	2.8	3.3	2.1	2.8
21	LE3000 small split dry macrocarpa 1	4.2	0.4	5.1	3.0
22	LE3000 small split dry macrocarpa 2	6.4	0.4	6.0	4.1
23	LE3000 small split dry macrocarpa 3	1.3	0.5	1.6	1.0
24	LE3000 small split dry macrocarpa 4	2.2	0.3	7.5	2.7
25	LE3000 small split dry macrocarpa 5	2.1	0.4	1.6	1.2
26	LE3000 large split dry macrocarpa 1	4.5	0.5	1.4	2.3
27	LE3000 large split dry macrocarpa 2	2.7	0.2	2.7	1.7
28	LE3000 large split dry macrocarpa 3	1.1	0.1	4.4	1.5
29	LE3000 large split dry macrocarpa 4	0.8	0.5	1.2	0.8
30	LE3000 large split dry macrocarpa 5	1.1	0.4	0.6	0.7
31	LE3000 small unsplit dry macrocarpa 1	16.8	17.2	14.6	16.2
32	LE3000 small unsplit dry macrocarpa 2	7.8	2.7	10.1	6.6
33	LE3000 small unsplit dry macrocarpa 3	4.0	1.0	9.8	4.2
34	LE3000 small unsplit dry macrocarpa 4	6.3	2.7	2.7	3.9
35	LE3000 small unsplit dry macrocarpa 5	5.1	0.3	11.1	4.5
36	LE3000 large split wet pine 1	7.7	4.1	3.6	5.1
37	LE3000 large split wet pine 2	3.8	9.8	6.6	6.8
38	LE3000 large split wet pine 3	7.6	3.0	31.5	10.6
39	LE3000 large split wet pine 4	2.3	0.9	17.0	4.6
40	LE3000 large split wet pine 5	2.4	2.8	23.5	7.8
41	LE3000 small split wet pine 1	8.1	0.8	2.5	3.5
42	LE3000 small split wet pine 2	6.8	3.4	15.6	7.1
43	LE3000 small split wet pine 3	3.6	4.1	32.7	11.0
44	LE3000 small split wet pine 4	4.6	1.9	18.5	6.6
45	LE3000 small split wet pine 5	17.2	5.0	8.8	9.9
46	Metro Eco large split dry macrocarpa 1	13.4	2.1	1.3	5.3
47	Metro Eco large split dry macrocarpa 2	12.1	2.2	4.3	5.3
48	Metro Eco large split dry macrocarpa 3	9.5	4.1	4.1	5.9
49	Metro Eco large split dry macrocarpa 4	2.6	0.5	2.1	1.5
50	Metro Eco large split dry macrocarpa 5	2.6	1.6	2.3	2.1
51	Metro Eco large split damp macrocarpa 1	1.0	0.3	3.9	1.4
52	Metro Eco large split damp macrocarpa 2	1.2	0.3	4.6	1.5
53	Metro Eco large split damp macrocarpa 3	12.1	1.5	8.9	5.7
54	Metro Eco large split damp macrocarpa 4	14.3	1.8	15.1	9.3
55	Metro Eco large split damp macrocarpa 5	9.4	0.8	12.2	5.7

Table B1.1 (cont)

No	Burner and fuel	Start up	High burn	Low burn	Mean*
56	Metro Eco large split dry blue gum 1	2.8	0.4	2.7	1.5
57	Metro Eco large split dry blue gum 2	0.9	0.3	1.3	0.6
58	Metro Eco large split dry blue gum 3	2.7	0.3	1.4	1.2
59	Metro Eco large split dry blue gum 4	2.3	0.2	1.3	1.1
60	Metro Eco large split dry blue gum 5	2.1	0.9	0.7	1.2
61	Metro Eco large split damp blue gum 1	2.6	1.8	2.4	2.2
62	Metro Eco large split damp blue gum 2	3.0	0.3	4.4	1.8
63	Metro Eco large split damp blue gum 3	3.1	2.6	7.2	4.0
64	Metro Eco large split damp blue gum 4	5.9	8.0	6.4	6.9
65	Metro Eco large split damp blue gum 5	7.0	3.5	9.1	6.3
66	Metro Eco large unsplit dry blue gum 1	4.9	1.7	0.9	2.7
67	Metro Eco large unsplit dry blue gum 2	1.4	0.2	1.0	0.8
68	Metro Eco large unsplit dry blue gum 3	2.5	1.2	0.6	1.6
69	Metro Eco large unsplit dry blue gum 4	2.0	0.6	3.2	1.6
70	Metro Eco large unsplit dry blue gum 5	2.0	0.4	2.2	1.3
71	Metro Eco large unsplit damp blue gum 1	5.2	0.6	0.8	2.2
72	Metro Eco large unsplit damp blue gum 2	11.1	1.6	6.6	6.5
73	Metro Eco large unsplit damp blue gum 3	4.3	1.2	9.2	4.4
74	Metro Eco large unsplit damp blue gum 4	3.9	0.1	2.6	2.1
75	Metro Eco large unsplit damp blue gum 5	3.5	1.0	6.9	3.4
76	Metro Eco large split damp pine 1	13.6	3.4	9.2	7.9
77	Metro Eco large split damp pine 2	7.8	3.7	5.0	5.4
78	Metro Eco large split damp pine 3	8.5	1.8	2.6	4.5
79	Metro Eco large split damp pine 4	22.6	4.5	4.6	10.6
80	Metro Eco large split damp pine 5	6.5	2.1	7.5	4.8
81	Metro Eco large split wet blue gum 1	2.2	0.4	4.7	1.8
82	Metro Eco large split wet blue gum 2	3.0	0.6	16.5	4.4
83	Metro Eco large split wet blue gum 3	9.9	0.6	18.3	7.9
84	Metro Eco large split wet blue gum 4	12.6	0.5	14.6	8.1
85	Metro Eco large split wet blue gum 5	11.0	0.3	10.8	5.2
86	Metro Eco large split wet macrocarpa 1	7.5	0.8	9.1	4.9
87	Metro Eco large split wet macrocarpa 2	38.7	1.2	11.9	18.2
88	Metro Eco large split wet macrocarpa 3	10.1	0.9	10.3	6.1
89	Metro Eco large split wet macrocarpa 4	15.4	1.5	6.3	7.2
90	Metro Eco large split wet macrocarpa 5	22.3	1.3	9.9	10.9
91	Metro Eco large unsplit wet blue gum 1	21.6	26.0	28.2	24.4
92	Metro Eco large unsplit wet blue gum 2	12.2	14.0	33.3	16.5
93	Metro Eco large unsplit wet blue gum 3	10.7	29.9	19.2	18.7
94	Metro Eco large unsplit wet blue gum 4	25.3	16.6	13.1	19.2
95	Metro Eco large unsplit wet blue gum 5	23.1	30.1	23.0	25.0
96	Belvedere large unsplit dry pine 1	1.2	1.5	6.3	2.1
97	Belvedere large unsplit dry pine 2	1.7	1.6	8.1	2.8
98	Belvedere large unsplit dry pine 3	2.3	2.5	12.2	3.5
99	Belvedere large unsplit dry pine 4	2.1	0.1	6.0	1.8
100	Belvedere large unsplit dry pine 5	3.8	3.4	2.3	3.4
101	Belvedere small unsplit dry pine 1	3.3	2.2	3.8	3.0
102	Belvedere small unsplit dry pine 2	18.1	2.0	3.6	8.2
103	Belvedere small unsplit dry pine 3	2.9	11.4	3.9	6.4
104	Belvedere small unsplit dry pine 4	8.9	2.2	4.5	5.0
105	Belvedere small unsplit dry pine 5	3.5	1.7	1.4	2.2

Table B1.1 (cont)

No	Burner and fuel	Start up	High burn	Low burn	Mean*
106	Belvedere large unsplit damp pine 1	52.2	4.9	19.1	27.8
107	Belvedere large unsplit damp pine 2	9.5	25.1	36.1	21.0
108	Belvedere large unsplit damp pine 3	5.2	4.5	26.3	10.0
109	Belvedere large unsplit damp pine 4	**	10.3	20.7	13.9
110	Belvedere large unsplit damp pine 5	16.3	7.8	30.3	16.1
111	Belvedere small unsplit damp pine 1	4.3	5.0	20.5	6.5
112	Belvedere small unsplit damp pine 2	10.0	7.3	2.6	6.8
113	Belvedere small unsplit damp pine 3	3.6	10.0	23.7	10.0
114	Belvedere small unsplit damp pine 4	13.9	15.0	29.7	16.7
115	Belvedere small unsplit damp pine 5	16.9	3.0	14.2	10.9
116	Belvedere large unsplit wet blue gum 1	3.0	21.0	4.1	6.0
117	Belvedere large unsplit wet blue gum 2	1.2	4.3	4.3	3.0
118	Belvedere large unsplit wet blue gum 3	0.7	6.2	5.5	3.7
119	Belvedere large unsplit wet blue gum 4	2.6	3.3	6.7	4.0
120	Belvedere large unsplit wet blue gum 5	1.3	8.2	10.9	5.2
121	Belvedere small unsplit wet blue gum 1	2.4	5.5	8.2	4.8
122	Belvedere small unsplit wet blue gum 2	3.5	6.9	12.9	7.4
123	Belvedere small unsplit wet blue gum 3	5.9	1.8	7.1	4.7
124	Belvedere small unsplit wet blue gum 4	6.1	7.1	10.1	7.3
125	Belvedere small unsplit wet blue gum 5	2.9	5.7	10.0	5.5
126	Belvedere large unsplit wet pine 1	2.0	4.8	2.4	2.9
127	Belvedere large unsplit wet pine 2	2.9	3.4	4.1	3.3
128	Belvedere large unsplit wet pine 3	2.4	3.2	4.5	3.1
129	Belvedere large unsplit wet pine 4	4.0	3.4	7.0	4.4
130	Belvedere large unsplit wet pine 5	2.7	1.8	6.9	3.1
131	Belvedere small unsplit wet pine 1	14.8	17.8	12.1	15.2
132	Belvedere small unsplit wet pine 2	9.5	6.9	24.1	11.5
133	Belvedere small unsplit wet pine 3	5.0	5.2	34.7	10.9
134	Belvedere small unsplit wet pine 4	5.3	4.7	6.2	5.2
135	Belvedere small unsplit wet pine 5	15.0	4.1	36.9	14.3
136	Belvedere large split damp pine 1	2.0	7.3	18.0	8.2
137	Belvedere large split damp pine 2	5.2	5.9	7.3	6.0
138	Belvedere large split damp pine 3	3.3	6.3	2.4	4.5
139	Belvedere large split damp pine 4	3.5	9.6	34.9	13.3
140	Belvedere large split damp pine 5	1.6	4.1	15.3	6.0
141	Belvedere small split wet blue gum 1	1.6	2.8	4.7	2.9
142	Belvedere small split wet blue gum 2	2.2	2.3	4.9	3.0
143	Belvedere small split wet blue gum 3	3.3	2.8	4.4	3.3
144	Belvedere small split wet blue gum 4	3.6	2.5	6.0	3.6
145	Belvedere small split wet blue gum 5	3.2	1.7	4.2	2.8
146	Belvedere small unsplit damp blue gum 1	2.5	4.2	8.7	4.9
147	Belvedere small unsplit damp blue gum 2	2.2	0.8	2.2	1.7
148	Belvedere small unsplit damp blue gum 3	1.6	8.6	8.0	5.1
149	Belvedere small unsplit damp blue gum 4	3.8	5.4	7.0	5.2
150	Belvedere small unsplit damp blue gum 5	2.9	7.3	7.1	5.4
151	Belvedere small unsplit dry blue gum 1	1.5	0.7	4.5	1.7
152	Belvedere small unsplit dry blue gum 2	0.9	1.0	5.5	2.1
153	Belvedere small unsplit dry blue gum 3	0.8	1.1	4.5	1.7
154	Belvedere small unsplit dry blue gum 4	0.6	0.8	1.1	0.8
155	Belvedere small unsplit dry blue gum 5	1.0	1.0	5.3	2.0

* Calculated by dividing the total emissions by the total weight of wood burnt.

** The measurement was not available as the sample pump was not started.

Table B1.2

Measured emission factors (g/MJ). Dry, damp and wet correspond to a wet weight moisture content of 15%, 25% and 35%, respectively.

No	Burner and fuel	Start up	High burn	Low burn	Mean*
1	LE3000 small split dry pine 1	0.79	0.29	0.10	0.27
2	LE3000 small split dry pine 2	1.38	0.12	0.13	0.21
3	LE3000 small split dry pine 3	2.65	0.20	0.11	0.38
4	LE3000 small split dry pine 4	1.18	0.48	0.05	0.37
5	LE3000 small split dry pine 5	1.30	0.16	0.14	0.25
6	LE3000 large split dry pine 1	0.65	0.24	0.04	0.20
7	LE3000 large split dry pine 2	0.49	0.08	0.05	0.11
8	LE3000 large split dry pine 3	1.65	0.50	0.10	0.43
9	LE3000 large split dry pine 4	1.24	0.58	0.17	0.49
10	LE3000 large split dry pine 5	1.44	0.44	0.07	0.39
11	LE3000 small split damp pine 1	0.46	0.16	0.10	0.17
12	LE3000 small split damp pine 2	1.11	0.10	0.17	0.21
13	LE3000 small split damp pine 3	1.75	0.29	0.07	0.32
14	LE3000 small split damp pine 4	1.22	0.33	0.29	0.38
15	LE3000 small split damp pine 5	1.36	0.26	0.23	0.35
16	LE3000 large split damp pine 1	1.81	0.39	0.70	0.67
17	LE3000 large split damp pine 2	0.50	0.26	0.23	0.27
18	LE3000 large split damp pine 3	1.65	0.23	0.24	0.36
19	LE3000 large split damp pine 4	1.57	0.15	0.18	0.30
20	LE3000 large split damp pine 5	1.41	0.31	0.15	0.31
21	LE3000 small split dry macrocarpa 1	1.60	0.03	0.44	0.36
22	LE3000 small split dry macrocarpa 2	2.19	0.03	0.47	0.48
23	LE3000 small split dry macrocarpa 3	0.48	0.05	0.13	0.13
24	LE3000 small split dry macrocarpa 4	0.79	0.03	0.66	0.36
25	LE3000 small split dry macrocarpa 5	0.81	0.06	0.12	0.16
26	LE3000 large split dry macrocarpa 1	1.36	0.04	0.11	0.26
27	LE3000 large split dry macrocarpa 2	0.94	0.01	0.20	0.19
28	LE3000 large split dry macrocarpa 3	0.57	0.01	0.39	0.21
29	LE3000 large split dry macrocarpa 4	0.28	0.06	0.12	0.11
30	LE3000 large split dry macrocarpa 5	0.37	0.05	0.06	0.09
31	LE3000 small unsplit dry macrocarpa 1	10.59	2.25	2.18	3.38
32	LE3000 small unsplit dry macrocarpa 2	3.21	0.32	1.40	1.07
33	LE3000 small unsplit dry macrocarpa 3	1.39	0.15	1.14	0.69
34	LE3000 small unsplit dry macrocarpa 4	2.68	0.38	0.25	0.61
35	LE3000 small unsplit dry macrocarpa 5	1.71	0.04	1.12	0.66
36	LE3000 large split wet pine 1	2.51	0.49	0.26	0.64
37	LE3000 large split wet pine 2	1.32	1.18	0.58	0.93
38	LE3000 large split wet pine 3	2.26	0.27	2.23	1.19
39	LE3000 large split wet pine 4	0.80	0.09	1.06	0.52
40	LE3000 large split wet pine 5	0.84	0.26	2.23	1.01
41	LE3000 small split wet pine 1	3.10	0.08	0.18	0.40
42	LE3000 small split wet pine 2	2.47	0.36	0.93	0.85
43	LE3000 small split wet pine 3	1.17	0.31	3.16	1.33
44	LE3000 small split wet pine 4	2.04	0.21	1.43	0.87
45	LE3000 small split wet pine 5	6.25	0.62	0.77	1.36
46	Metro Eco large split dry macrocarpa 1	5.51	0.20	0.08	0.56
47	Metro Eco large split dry macrocarpa 2	4.61	0.25	0.36	0.65
48	Metro Eco large split dry macrocarpa 3	3.65	0.34	0.21	0.60
49	Metro Eco large split dry macrocarpa 4	0.85	0.06	0.15	0.19
50	Metro Eco large split dry macrocarpa 5	0.81	0.18	0.15	0.24
51	Metro Eco large split damp macrocarpa 1	0.28	0.04	0.35	0.19
52	Metro Eco large split damp macrocarpa 2	0.50	0.04	0.35	0.20
53	Metro Eco large split damp macrocarpa 3	4.40	0.23	0.68	0.83
54	Metro Eco large split damp macrocarpa 4	4.62	0.25	2.01	1.50
55	Metro Eco large split damp macrocarpa 5	3.90	0.11	1.12	0.86

Table B1.2 (cont)

No	Burner and fuel	Start up	High burn	Low burn	Mean*
56	Metro Eco large split dry blue gum 1	1.17	0.05	0.25	0.23
57	Metro Eco large split dry blue gum 2	0.39	0.04	0.11	0.10
58	Metro Eco large split dry blue gum 3	0.88	0.04	0.15	0.18
59	Metro Eco large split dry blue gum 4	1.04	0.03	0.11	0.15
60	Metro Eco large split dry blue gum 5	0.73	0.10	0.05	0.14
61	Metro Eco large split damp blue gum 1	0.53	0.08	0.10	0.13
62	Metro Eco large split damp blue gum 2	1.30	0.05	0.34	0.27
63	Metro Eco large split damp blue gum 3	0.61	0.36	0.92	0.60
64	Metro Eco large split damp blue gum 4	2.37	1.26	0.75	1.22
65	Metro Eco large split damp blue gum 5	3.06	0.56	1.12	1.08
66	Metro Eco large unsplit dry blue gum 1	1.95	0.14	0.09	0.34
67	Metro Eco large unsplit dry blue gum 2	0.53	0.02	0.09	0.10
68	Metro Eco large unsplit dry blue gum 3	1.02	0.10	0.05	0.21
69	Metro Eco large unsplit dry blue gum 4	0.78	0.07	0.16	0.19
70	Metro Eco large unsplit dry blue gum 5	1.09	0.04	0.13	0.15
71	Metro Eco large unsplit damp blue gum 1	1.68	0.06	0.06	0.26
72	Metro Eco large unsplit damp blue gum 2	4.84	0.15	0.36	0.72
73	Metro Eco large unsplit damp blue gum 3	1.68	0.12	0.87	0.60
74	Metro Eco large unsplit damp blue gum 4	1.21	0.01	0.23	0.27
75	Metro Eco large unsplit damp blue gum 5	1.53	0.11	0.73	0.49
76	Metro Eco large split damp pine 1	5.80	0.27	0.35	0.75
77	Metro Eco large split damp pine 2	1.90	0.29	0.22	0.50
78	Metro Eco large split damp pine 3	3.09	0.15	0.14	0.45
79	Metro Eco large split damp pine 4	11.84	0.38	0.24	1.07
80	Metro Eco large split damp pine 5	2.70	0.18	0.41	0.50
81	Metro Eco large split wet blue gum 1	0.55	0.04	0.22	0.17
82	Metro Eco large split wet blue gum 2	0.69	0.07	1.04	0.52
83	Metro Eco large split wet blue gum 3	3.59	0.05	1.55	0.91
84	Metro Eco large split wet blue gum 4	5.85	0.05	1.20	1.04
85	Metro Eco large split wet blue gum 5	3.47	0.03	0.52	0.58
86	Metro Eco large split wet macrocarpa 1	2.20	0.07	0.53	0.49
87	Metro Eco large split wet macrocarpa 2	11.35	0.11	0.50	1.80
88	Metro Eco large split wet macrocarpa 3	2.99	0.10	0.62	0.72
89	Metro Eco large split wet macrocarpa 4	5.46	0.15	0.49	0.83
90	Metro Eco large split wet macrocarpa 5	7.67	0.11	0.85	1.28
91	Metro Eco large unsplit wet blue gum 1	11.55	5.16	2.87	5.41
92	Metro Eco large unsplit wet blue gum 2	3.93	1.69	3.44	2.68
93	Metro Eco large unsplit wet blue gum 3	4.35	4.62	4.64	4.57
94	Metro Eco large unsplit wet blue gum 4	8.57	3.53	1.51	4.00
95	Metro Eco large unsplit wet blue gum 5	11.85	8.24	4.50	6.82
96	Belvedere large unsplit dry pine 1	0.50	0.17	0.59	0.32
97	Belvedere large unsplit dry pine 2	0.78	0.19	0.69	0.43
98	Belvedere large unsplit dry pine 3	1.06	0.23	0.81	0.52
99	Belvedere large unsplit dry pine 4	0.77	0.01	0.53	0.28
100	Belvedere large unsplit dry pine 5	1.93	0.40	0.22	0.56
101	Belvedere small unsplit dry pine 1	1.75	0.22	0.24	0.38
102	Belvedere small unsplit dry pine 2	6.33	0.19	0.22	0.90
103	Belvedere small unsplit dry pine 3	1.11	1.39	0.28	0.90
104	Belvedere small unsplit dry pine 4	3.99	0.22	0.54	0.72
105	Belvedere small unsplit dry pine 5	1.49	0.18	0.09	0.26

Table B1.2 (cont)

No	Burner and fuel	Start up	High burn	Low burn	Mean*
106	Belvedere large unsplit damp pine 1	15.70	0.52	1.80	3.84
107	Belvedere large unsplit damp pine 2	3.59	2.56	6.34	3.98
108	Belvedere large unsplit damp pine 3	2.05	0.45	3.73	1.65
109	Belvedere large unsplit damp pine 4	**	0.97	2.34	1.39
110	Belvedere large unsplit damp pine 5	8.96	0.80	3.79	2.84
111	Belvedere small unsplit damp pine 1	1.84	0.60	1.26	1.03
112	Belvedere small unsplit damp pine 2	4.53	0.76	0.24	0.92
113	Belvedere small unsplit damp pine 3	1.64	1.27	2.19	1.67
114	Belvedere small unsplit damp pine 4	6.10	1.72	2.38	2.69
115	Belvedere small unsplit damp pine 5	8.07	0.27	1.08	1.38
116	Belvedere large unsplit wet blue gum 1	1.55	3.05	1.03	1.78
117	Belvedere large unsplit wet blue gum 2	0.49	0.64	0.82	0.66
118	Belvedere large unsplit wet blue gum 3	0.37	1.15	1.58	1.10
119	Belvedere large unsplit wet blue gum 4	1.35	0.46	1.60	0.97
120	Belvedere large unsplit wet blue gum 5	0.70	0.88	2.05	1.19
121	Belvedere small unsplit wet blue gum 1	1.02	0.62	0.89	0.77
122	Belvedere small unsplit wet blue gum 2	1.60	1.01	2.12	1.49
123	Belvedere small unsplit wet blue gum 3	3.23	0.24	0.88	0.79
124	Belvedere small unsplit wet blue gum 4	2.92	0.77	1.18	1.23
125	Belvedere small unsplit wet blue gum 5	1.15	0.58	1.32	0.91
126	Belvedere large unsplit wet pine 1	1.31	0.62	0.40	0.64
127	Belvedere large unsplit wet pine 2	1.62	0.33	0.35	0.52
128	Belvedere large unsplit wet pine 3	1.33	0.36	0.32	0.45
129	Belvedere large unsplit wet pine 4	1.88	0.32	0.61	0.64
130	Belvedere large unsplit wet pine 5	0.99	0.15	0.67	0.45
131	Belvedere small unsplit wet pine 1	7.41	2.22	1.19	2.49
132	Belvedere small unsplit wet pine 2	5.40	0.95	2.24	2.03
133	Belvedere small unsplit wet pine 3	1.91	0.70	3.43	1.74
134	Belvedere small unsplit wet pine 4	2.50	0.63	0.55	0.82
135	Belvedere small unsplit wet pine 5	7.46	0.43	3.46	2.23
136	Belvedere large split damp pine 1	0.49	0.62	2.31	1.04
137	Belvedere large split damp pine 2	1.65	0.53	0.61	0.71
138	Belvedere large split damp pine 3	1.02	0.62	0.15	0.50
139	Belvedere large split damp pine 4	1.20	0.97	5.12	2.01
140	Belvedere large split damp pine 5	0.93	0.49	1.32	0.88
141	Belvedere small split wet blue gum 1	1.52	0.54	0.64	0.65
142	Belvedere small split wet blue gum 2	1.69	0.31	0.64	0.57
143	Belvedere small split wet blue gum 3	1.73	0.47	0.37	0.55
144	Belvedere small split wet blue gum 4	2.04	0.44	0.70	0.73
145	Belvedere small split wet blue gum 5	1.99	0.32	0.49	0.58
146	Belvedere small unsplit damp blue gum 1	1.36	0.32	1.20	0.75
147	Belvedere small unsplit damp blue gum 2	1.01	0.10	0.16	0.23
148	Belvedere small unsplit damp blue gum 3	0.31	0.65	0.71	0.57
149	Belvedere small unsplit damp blue gum 4	0.95	0.37	0.65	0.57
150	Belvedere small unsplit damp blue gum 5	0.89	0.47	0.38	0.48
151	Belvedere small unsplit dry blue gum 1	0.80	0.08	0.37	0.25
152	Belvedere small unsplit dry blue gum 2	0.35	0.10	0.63	0.31
153	Belvedere small unsplit dry blue gum 3	0.33	0.11	0.37	0.23
154	Belvedere small unsplit dry blue gum 4	0.30	0.10	0.09	0.11
155	Belvedere small unsplit dry blue gum 5	0.50	0.10	0.49	0.28

* Calculated by dividing the total emissions by the total heat released.

** The measurement was not available as the sample pump was not started.

Table B1.3

Measured emission rates (g/hr). Dry, damp and wet correspond to a wet weight moisture content of 15%, 25% and 35%, respectively.

No	Burner and fuel	Start up	High burn	Low burn	Mean*
1	LE3000 small split dry pine 1	15.7	12.4	2.6	8.7
2	LE3000 small split dry pine 2	21.7	4.3	2.9	5.7
3	LE3000 small split dry pine 3	49.9	7.5	2.9	11.5
4	LE3000 small split dry pine 4	22.2	18.7	1.4	11.7
5	LE3000 small split dry pine 5	24.5	5.7	4.1	7.6
6	LE3000 large split dry pine 1	12.7	9.6	1.2	6.5
7	LE3000 large split dry pine 2	9.7	3.0	1.2	3.2
8	LE3000 large split dry pine 3	26.3	19.7	3.0	13.5
9	LE3000 large split dry pine 4	25.0	23.9	5.2	16.2
10	LE3000 large split dry pine 5	30.1	18.7	2.1	13.3
11	LE3000 small split damp pine 1	11.1	3.5	3.4	4.6
12	LE3000 small split damp pine 2	18.7	2.3	3.7	6.0
13	LE3000 small split damp pine 3	32.0	11.4	2.5	10.6
14	LE3000 small split damp pine 4	15.3	10.1	8.3	10.7
15	LE3000 small split damp pine 5	22.1	10.2	5.4	9.8
16	LE3000 large split damp pine 1	36.8	9.3	8.9	14.0
17	LE3000 large split damp pine 2	7.9	7.5	6.3	7.2
18	LE3000 large split damp pine 3	30.3	9.0	6.0	10.6
19	LE3000 large split damp pine 4	27.3	4.5	6.9	9.2
20	LE3000 large split damp pine 5	15.7	11.1	5.0	9.7
21	LE3000 small split dry macrocarpa 1	23.1	0.6	9.3	8.4
22	LE3000 small split dry macrocarpa 2	36.3	1.0	13.6	11.2
23	LE3000 small split dry macrocarpa 3	6.6	1.8	3.4	3.5
24	LE3000 small split dry macrocarpa 4	12.1	0.8	14.3	7.8
25	LE3000 small split dry macrocarpa 5	9.6	1.5	3.0	4.1
26	LE3000 large split dry macrocarpa 1	30.8	2.0	2.2	6.6
27	LE3000 large split dry macrocarpa 2	15.5	0.7	5.8	5.1
28	LE3000 large split dry macrocarpa 3	5.9	0.4	6.0	5.1
29	LE3000 large split dry macrocarpa 4	5.3	1.7	1.8	2.9
30	LE3000 large split dry macrocarpa 5	5.7	1.8	1.0	2.3
31	LE3000 small unsplit dry macrocarpa 1	96.4	74.6	26.8	38.4
32	LE3000 small unsplit dry macrocarpa 2	42.5	11.8	17.8	20.0
33	LE3000 small unsplit dry macrocarpa 3	16.6	3.6	24.8	14.0
34	LE3000 small unsplit dry macrocarpa 4	38.1	10.9	4.7	12.1
35	LE3000 small unsplit dry macrocarpa 5	27.3	1.1	20.1	13.7
36	LE3000 large split wet pine 1	45.4	6.7	6.6	12.0
37	LE3000 large split wet pine 2	20.9	26.3	13.2	15.5
38	LE3000 large split wet pine 3	47.2	5.9	37.6	19.9
39	LE3000 large split wet pine 4	11.6	2.6	17.7	9.9
40	LE3000 large split wet pine 5	14.9	8.0	30.0	15.9
41	LE3000 small split wet pine 1	52.3	2.3	2.5	8.6
42	LE3000 small split wet pine 2	44.5	9.0	17.2	14.2
43	LE3000 small split wet pine 3	24.2	7.3	18.3	20.2
44	LE3000 small split wet pine 4	25.5	5.8	21.8	16.0
45	LE3000 small split wet pine 5	121.0	10.4	10.3	24.6
46	Metro Eco large split dry macrocarpa 1	80.3	4.4	1.5	17.4
47	Metro Eco large split dry macrocarpa 2	75.6	6.5	6.5	19.0
48	Metro Eco large split dry macrocarpa 3	61.2	9.6	5.0	17.5
49	Metro Eco large split dry macrocarpa 4	16.0	1.5	3.9	4.7
50	Metro Eco large split dry macrocarpa 5	17.0	6.7	3.8	6.7
51	Metro Eco large split damp macrocarpa 1	7.4	1.1	5.5	4.3
52	Metro Eco large split damp macrocarpa 2	8.1	0.8	7.9	4.6
53	Metro Eco large split damp macrocarpa 3	85.9	4.0	12.6	18.8
54	Metro Eco large split damp macrocarpa 4	98.2	6.0	25.5	25.4
55	Metro Eco large split damp macrocarpa 5	63.3	2.1	18.3	15.5

Table B1.3 (cont)

No	Burner and fuel	Start up	High burn	Low burn	Mean*
56	Metro Eco large split dry blue gum 1	16.3	1.2	3.5	5.2
57	Metro Eco large split dry blue gum 2	5.8	1.0	2.1	2.2
58	Metro Eco large split dry blue gum 3	19.8	1.2	2.5	4.1
59	Metro Eco large split dry blue gum 4	14.2	0.8	2.2	3.6
60	Metro Eco large split dry blue gum 5	14.5	2.9	1.6	3.9
61	Metro Eco large split damp blue gum 1	12.8	5.5	4.8	6.1
62	Metro Eco large split damp blue gum 2	18.1	1.0	5.9	5.0
63	Metro Eco large split damp blue gum 3	20.1	9.0	14.3	8.5
64	Metro Eco large split damp blue gum 4	40.2	33.5	13.3	15.8
65	Metro Eco large split damp blue gum 5	55.7	11.9	19.4	19.0
66	Metro Eco large unsplit dry blue gum 1	21.2	6.0	1.8	6.4
67	Metro Eco large unsplit dry blue gum 2	8.5	0.8	1.6	2.4
68	Metro Eco large unsplit dry blue gum 3	11.7	5.0	1.1	3.7
69	Metro Eco large unsplit dry blue gum 4	7.1	1.8	6.8	3.9
70	Metro Eco large unsplit dry blue gum 5	6.7	1.4	3.4	3.4
71	Metro Eco large unsplit damp blue gum 1	15.1	1.5	2.1	4.8
72	Metro Eco large unsplit damp blue gum 2	47.8	6.1	8.3	13.7
73	Metro Eco large unsplit damp blue gum 3	11.0	2.9	14.7	10.2
74	Metro Eco large unsplit damp blue gum 4	13.6	0.2	4.1	4.5
75	Metro Eco large unsplit damp blue gum 5	15.8	2.9	17.1	8.0
76	Metro Eco large split damp pine 1	51.4	6.6	14.8	18.7
77	Metro Eco large split damp pine 2	41.5	7.1	5.3	13.0
78	Metro Eco large split damp pine 3	37.3	3.9	3.8	11.3
79	Metro Eco large split damp pine 4	86.7	9.3	6.5	28.7
80	Metro Eco large split damp pine 5	27.4	4.9	11.5	12.3
81	Metro Eco large split wet blue gum 1	13.0	1.3	3.3	4.0
82	Metro Eco large split wet blue gum 2	14.7	1.7	13.6	9.2
83	Metro Eco large split wet blue gum 3	61.6	1.4	21.7	17.1
84	Metro Eco large split wet blue gum 4	79.8	1.6	17.4	17.7
85	Metro Eco large split wet blue gum 5	68.7	0.7	13.5	12.3
86	Metro Eco large split wet macrocarpa 1	45.6	1.6	11.1	9.1
87	Metro Eco large split wet macrocarpa 2	196.5	1.4	15.4	30.8
88	Metro Eco large split wet macrocarpa 3	57.2	1.6	13.0	12.5
89	Metro Eco large split wet macrocarpa 4	72.3	2.3	5.1	15.6
90	Metro Eco large split wet macrocarpa 5	141.2	1.9	8.6	21.8
91	Metro Eco large unsplit wet blue gum 1	141.4	49.7	16.7	36.0
92	Metro Eco large unsplit wet blue gum 2	75.6	36.2	63.6	27.3
93	Metro Eco large unsplit wet blue gum 3	46.8	49.8	19.0	32.5
94	Metro Eco large unsplit wet blue gum 4	121.5	28.0	9.4	34.9
95	Metro Eco large unsplit wet blue gum 5	109.1	63.4	24.2	49.2
96	Belvedere large unsplit dry pine 1	6.5	3.2	10.1	5.7
97	Belvedere large unsplit dry pine 2	9.9	3.9	11.4	7.3
98	Belvedere large unsplit dry pine 3	12.1	7.5	16.4	7.2
99	Belvedere large unsplit dry pine 4	13.2	0.2	8.8	5.0
100	Belvedere large unsplit dry pine 5	28.3	9.1	3.7	8.3
101	Belvedere small unsplit dry pine 1	20.2	3.2	6.6	7.1
102	Belvedere small unsplit dry pine 2	110.1	4.8	5.2	23.7
103	Belvedere small unsplit dry pine 3	17.8	20.2	5.3	16.3
104	Belvedere small unsplit dry pine 4	38.4	3.4	7.4	15.6
105	Belvedere small unsplit dry pine 5	20.3	3.0	1.9	7.6

Table B1.3 (cont)

No	Burner and fuel	Start up	High burn	Low burn	Mean*
106	Belvedere large unsplit damp pine 1	232.8	11.7	27.2	64.3
107	Belvedere large unsplit damp pine 2	43.9	50.1	58.6	39.0
108	Belvedere large unsplit damp pine 3	23.2	8.4	24.3	21.8
109	Belvedere large unsplit damp pine 4	**	22.7	20.6	16.1
110	Belvedere large unsplit damp pine 5	81.0	13.9	36.5	31.3
111	Belvedere small unsplit damp pine 1	19.3	12.6	32.7	13.6
112	Belvedere small unsplit damp pine 2	43.4	14.7	2.5	19.4
113	Belvedere small unsplit damp pine 3	16.7	15.0	25.6	19.2
114	Belvedere small unsplit damp pine 4	72.6	37.8	39.3	31.3
115	Belvedere small unsplit damp pine 5	75.2	7.5	23.4	23.6
116	Belvedere large unsplit wet blue gum 1	13.2	57.6	3.8	8.7
117	Belvedere large unsplit wet blue gum 2	3.9	10.9	4.3	5.3
118	Belvedere large unsplit wet blue gum 3	3.0	13.5	6.6	7.4
119	Belvedere large unsplit wet blue gum 4	11.7	7.4	8.1	7.5
120	Belvedere large unsplit wet blue gum 5	5.0	25.6	9.7	7.6
121	Belvedere small unsplit wet blue gum 1	8.8	10.9	7.2	9.2
122	Belvedere small unsplit wet blue gum 2	11.9	12.8	8.7	16.4
123	Belvedere small unsplit wet blue gum 3	19.6	4.4	7.0	11.9
124	Belvedere small unsplit wet blue gum 4	23.3	15.6	14.6	13.5
125	Belvedere small unsplit wet blue gum 5	9.6	11.1	13.5	10.2
126	Belvedere large unsplit wet pine 1	5.4	6.3	1.9	5.3
127	Belvedere large unsplit wet pine 2	10.1	5.4	3.0	5.2
128	Belvedere large unsplit wet pine 3	7.6	3.5	7.4	5.8
129	Belvedere large unsplit wet pine 4	10.6	7.4	6.3	7.3
130	Belvedere large unsplit wet pine 5	7.1	2.5	14.1	4.9
131	Belvedere small unsplit wet pine 1	50.9	9.5	15.9	28.3
132	Belvedere small unsplit wet pine 2	49.3	9.2	25.3	20.3
133	Belvedere small unsplit wet pine 3	24.7	7.6	45.3	23.9
134	Belvedere small unsplit wet pine 4	23.0	6.1	8.3	10.8
135	Belvedere small unsplit wet pine 5	71.4	3.1	31.9	25.6
136	Belvedere large split damp pine 1	8.2	12.2	19.9	20.5
137	Belvedere large split damp pine 2	22.0	11.5	11.5	15.3
138	Belvedere large split damp pine 3	15.6	15.2	4.2	12.3
139	Belvedere large split damp pine 4	17.0	14.6	34.0	34.8
140	Belvedere large split damp pine 5	7.8	5.9	16.3	16.9
141	Belvedere small split wet blue gum 1	5.8	3.9	5.9	7.9
142	Belvedere small split wet blue gum 2	9.2	2.8	3.4	7.2
143	Belvedere small split wet blue gum 3	12.9	5.2	4.0	8.2
144	Belvedere small split wet blue gum 4	16.5	3.5	4.6	8.0
145	Belvedere small split wet blue gum 5	15.0	2.1	2.8	7.0
146	Belvedere small unsplit damp blue gum 1	11.5	6.4	9.7	11.3
147	Belvedere small unsplit damp blue gum 2	8.5	1.4	2.0	4.2
148	Belvedere small unsplit damp blue gum 3	7.8	20.2	8.1	9.3
149	Belvedere small unsplit damp blue gum 4	23.3	17.3	12.7	11.2
150	Belvedere small unsplit damp blue gum 5	14.9	12.3	4.9	12.2
151	Belvedere small unsplit dry blue gum 1	7.1	1.9	7.6	5.3
152	Belvedere small unsplit dry blue gum 2	4.4	2.0	9.5	5.9
153	Belvedere small unsplit dry blue gum 3	3.4	3.0	5.8	4.8
154	Belvedere small unsplit dry blue gum 4	3.0	1.9	1.3	2.6
155	Belvedere small unsplit dry blue gum 5	4.3	2.5	8.5	5.6

* Calculated by dividing the total emissions by the total hours of operation.

** The measurement was not available as the sample pump was not started.

Appendix C: Distribution of emissions and statistical approaches

Figure C1.1

Distribution of measured emission factors with a mean of 5.7 g/kg and a median of 4.3 g/kg.

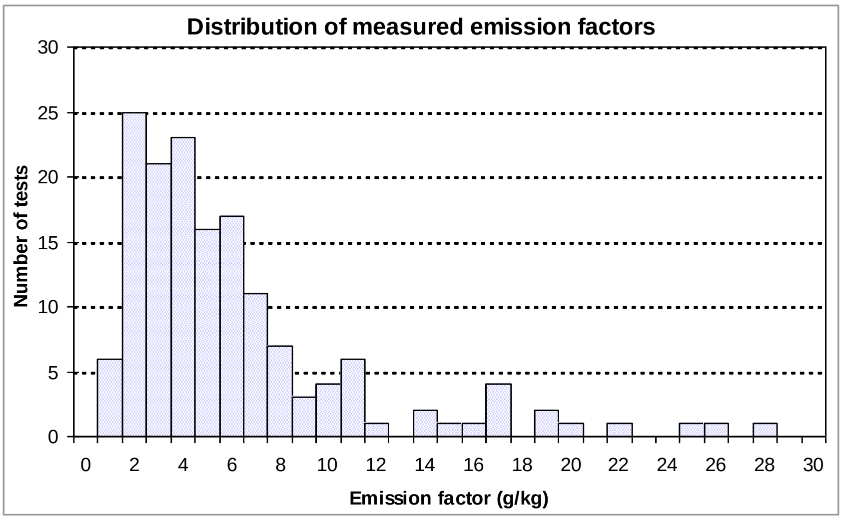


Figure C1.2

Distribution of measured emission factors with a mean of 0.87 g/MJ and a median of 0.57 g/MJ.

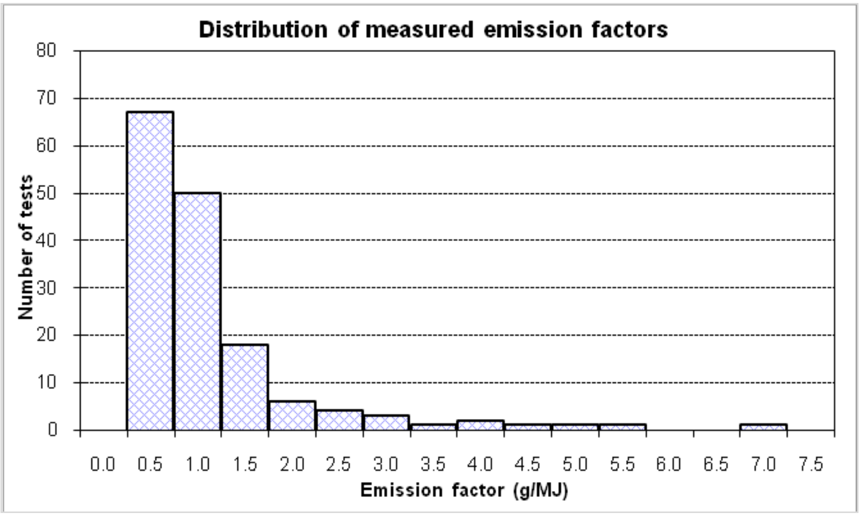
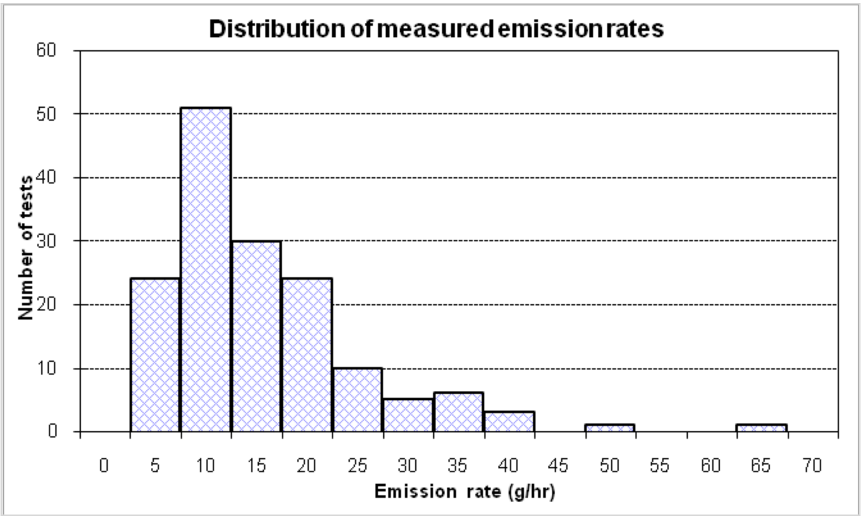


Figure C1.3

Distribution of measured emission rates with a mean of 13.0 g/hr and a median of 10.6 g/hr.



Statistical approaches

The Wilcoxon Signed Ranks test and the Friedman test are statistical procedures to test for the significance of differences between two and more related samples, respectively. They are non-parametric tests which make no assumptions about the distribution of the data. The Wilcoxon Signed Ranks test is used to test for the difference of the emissions between two phases of burner operation, e.g., start up and high burn. The Friedman test is used to test for the difference of the emissions among the three phases of burner operation, i.e., start up, high burn and low burn.

For other variables, i.e., the burner model, wood species, moisture content, wood surface and size, the Mann-Whitney test and the Kruskal-Wallis test are used. They are non-parametric procedures to test for the significance of differences between two or more independent samples, respectively, with no assumptions about the distribution of the data. The Mann-Whitney test is used to test for the difference of the emissions between two parameters for a variable, e.g., dry wood and wet wood for the variable moisture content. The Kruskal-Wallis test is used to test for the difference of the emissions among more than two parameters for a variable, e.g., dry wood, damp wood and wet wood for the variable moisture content.

Appendix D: Emissions from different burners

Figure D1.1

Emissions of Masport LE3000, Metro Eco and Masport Belvedere burning large split damp pine.

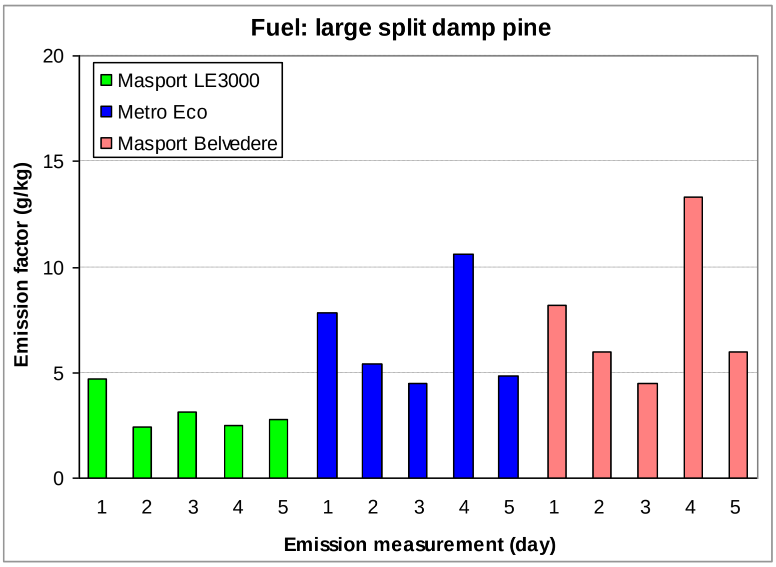


Figure D1.2

Emissions of Masport LE3000 and Metro Eco burning large split dry macrocarpa.

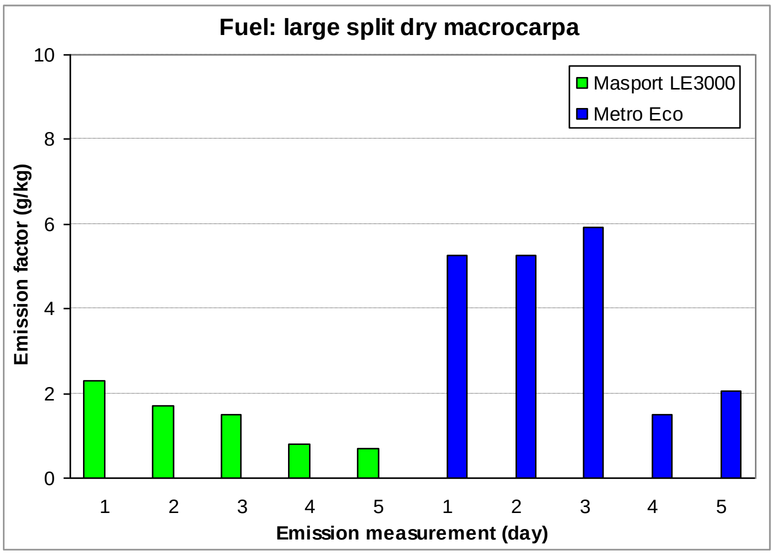
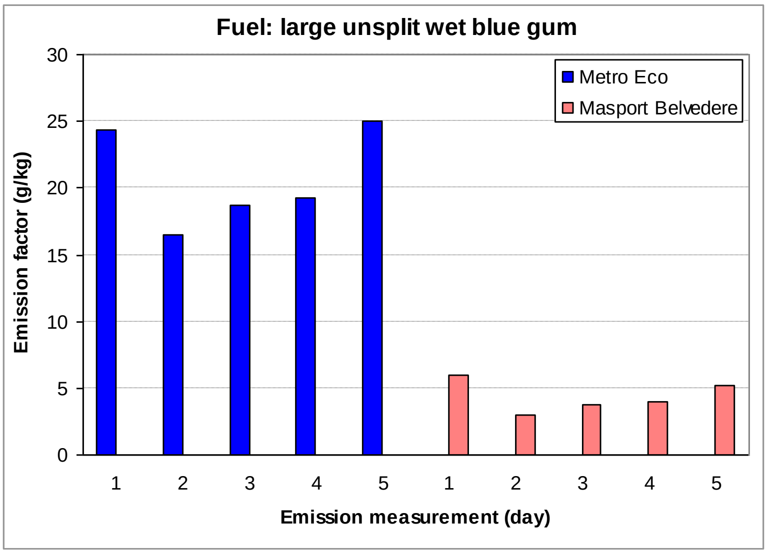


Figure D1.3

Emissions of Metro Eco and Masport Belvedere burning large unsplit wet blue gum.



Appendix E: Effects of moisture content on emissions

Figure E1.1

Emissions from Masport LE3000 burning dry, damp or wet small split pine.

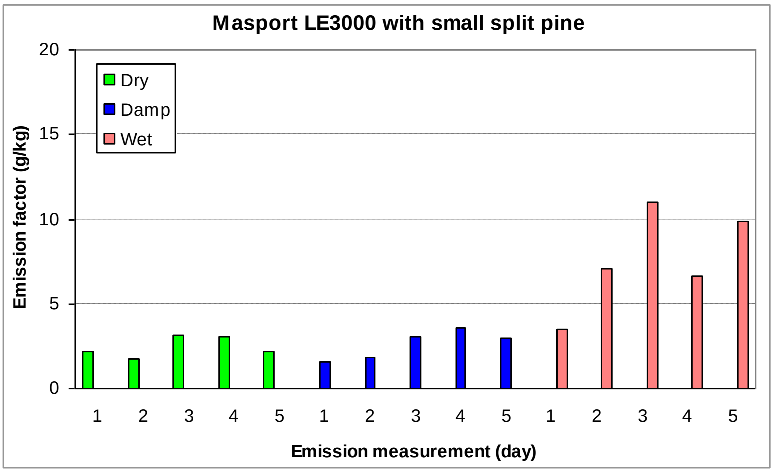


Figure E1.2

Emissions from Masport LE3000 burning dry, damp or wet large split pine.

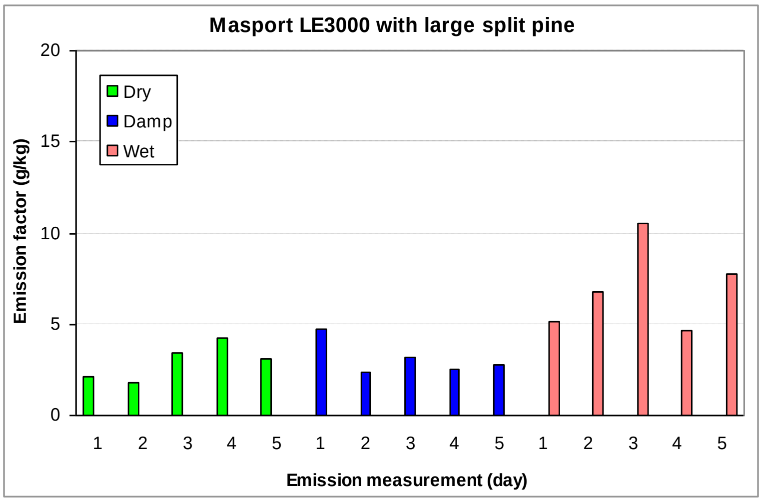


Figure E1.3

Emissions from Metro Eco burning dry, damp or wet large split blue gum.

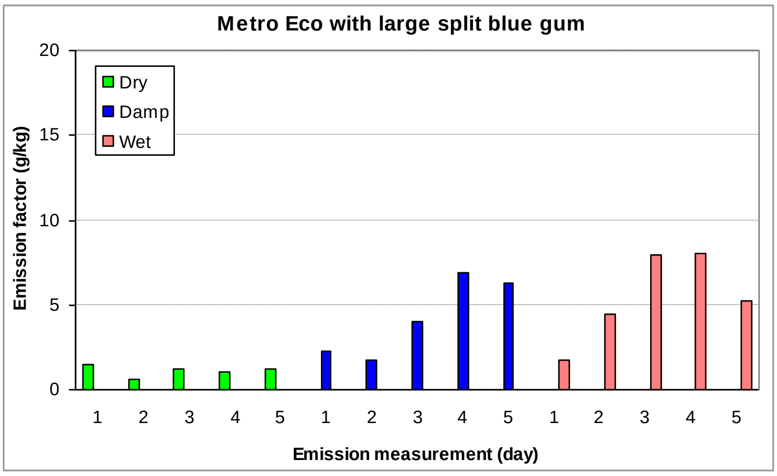


Figure E1.4

Emissions from Metro Eco burning dry, damp or wet large unsplit blue gum.

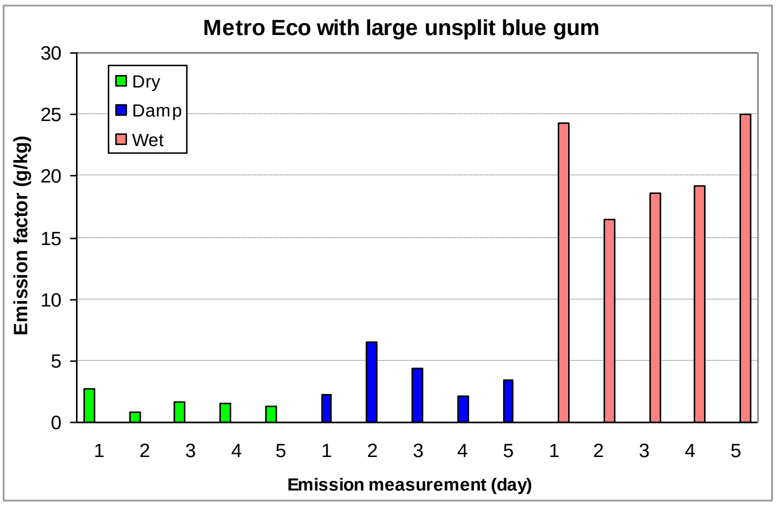


Figure E1.5

Emissions from Metro Eco burning dry, damp or wet large split macrocarpa.

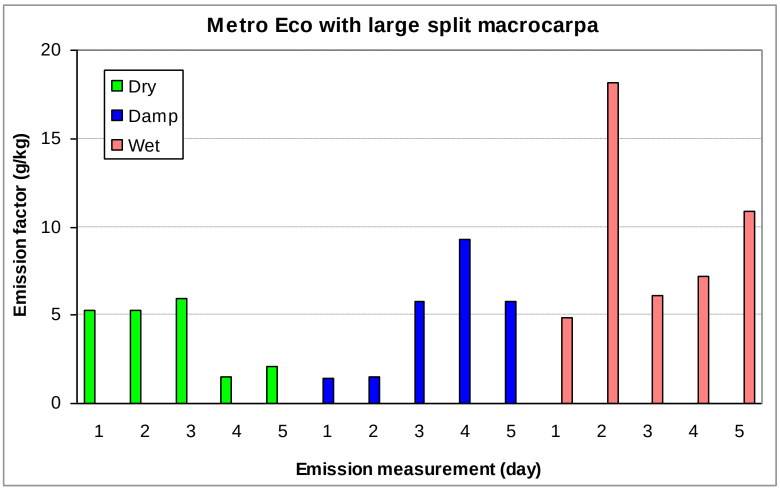


Figure E1.6

Emissions from Masport Belvedere burning dry, damp or wet small unsplit pine.

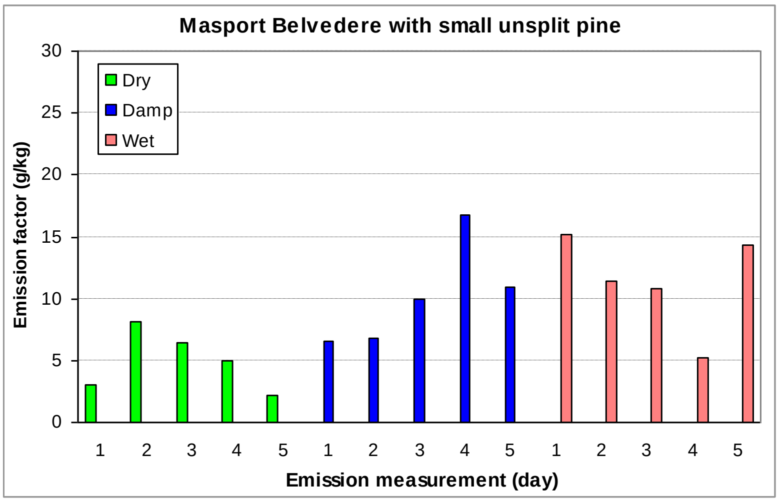


Figure E1.7

Emissions from Masport Belvedere burning dry, damp or wet large unsplit pine.

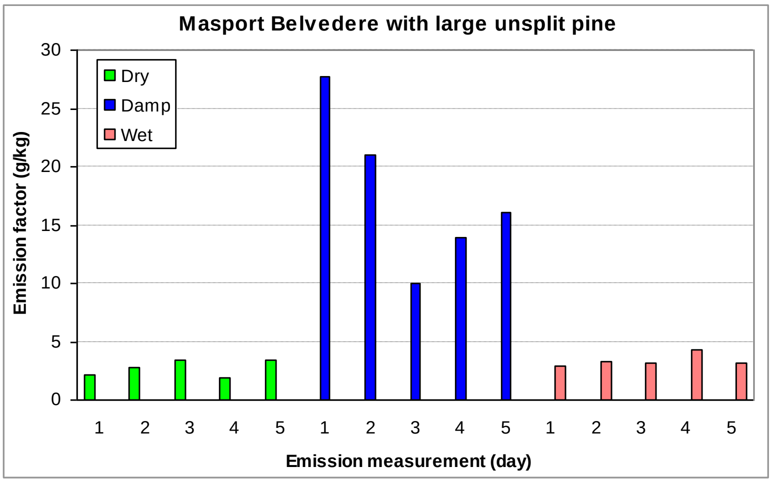
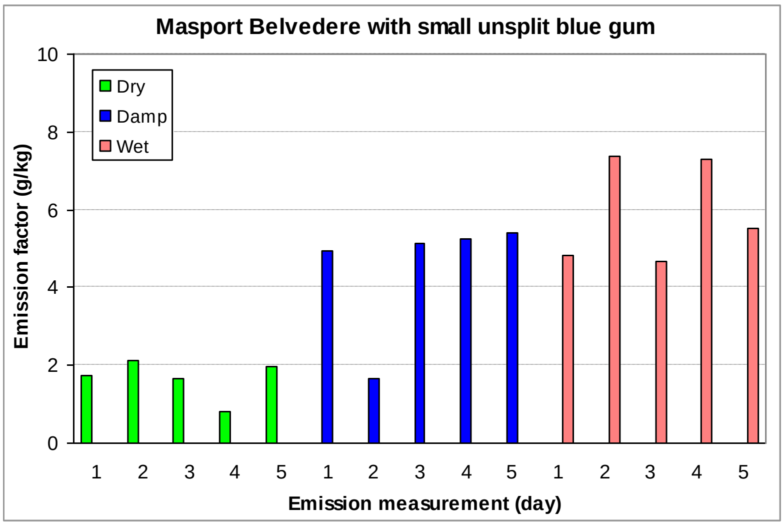


Figure E1.8

Emissions from Masport Belvedere burning dry, damp or wet small unsplit blue gum.



Appendix F: Emissions of different wood species

Figure F1.1

Emissions from Masport Belvedere burning small unsplit dry wood.

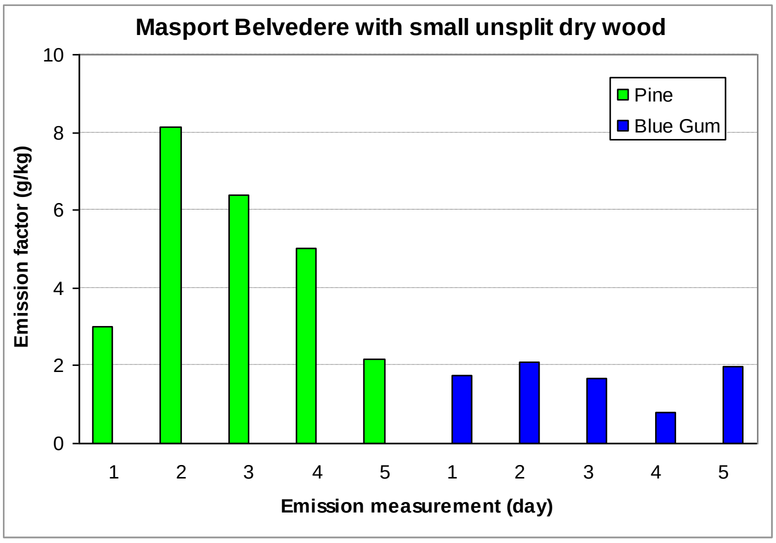


Figure F1.2

Emissions from Masport Belvedere burning small unsplit damp wood.

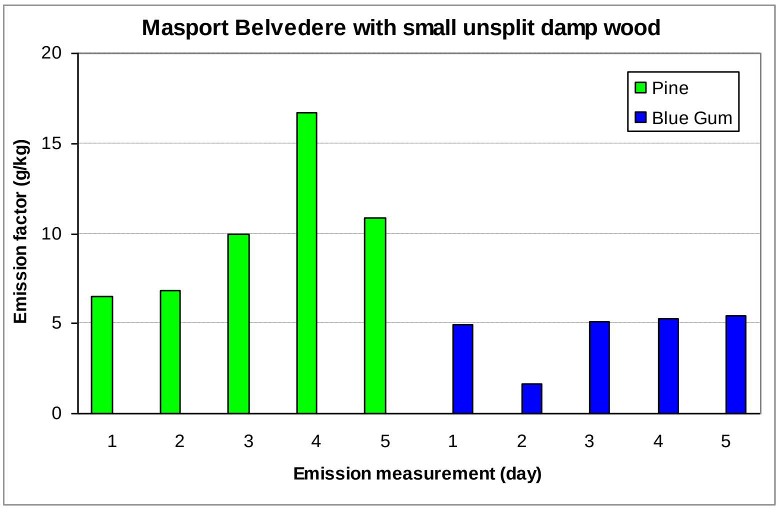


Figure F1.3

Emissions from Masport Belvedere burning small unsplit wet wood.

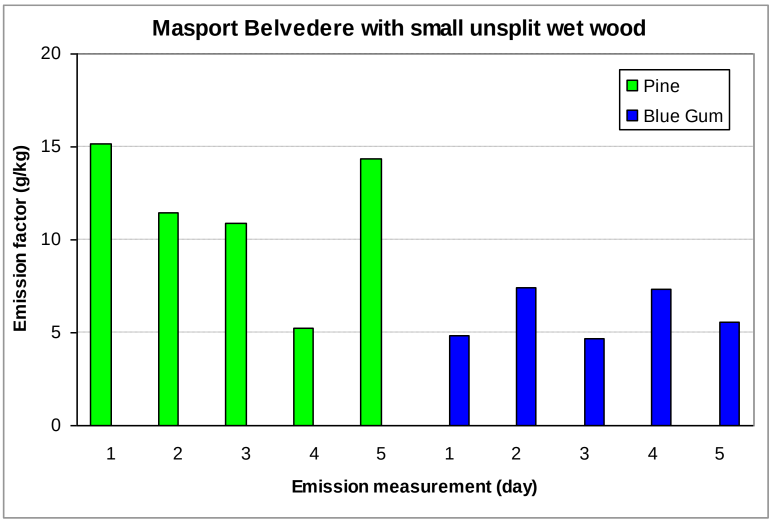


Figure F1.4

Emissions from Metro Eco burning large split dry wood.

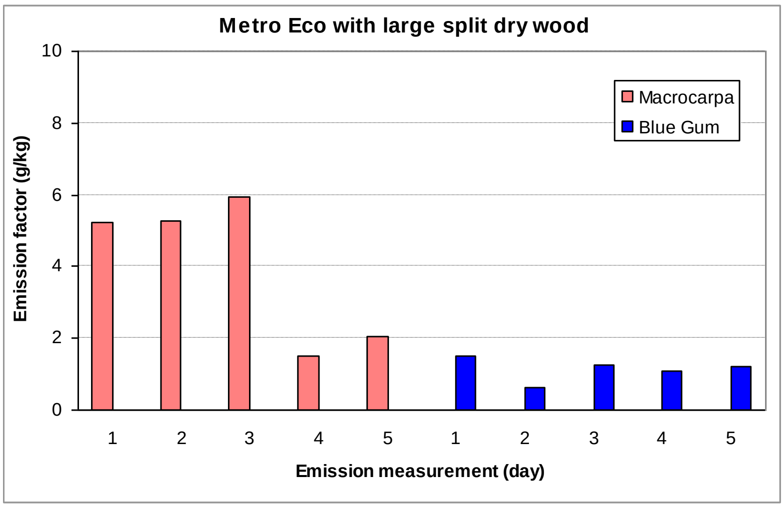


Figure F1.5

Emissions from Metro Eco burning large split damp wood.

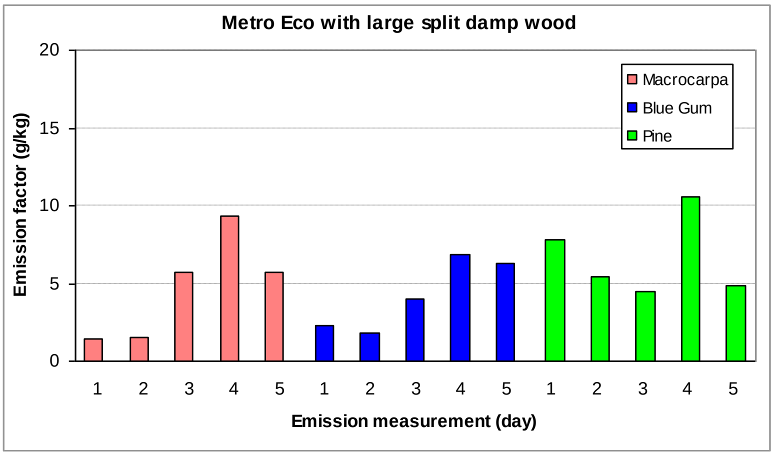


Figure F1.6

Emissions from Metro Eco burning large split wet wood.

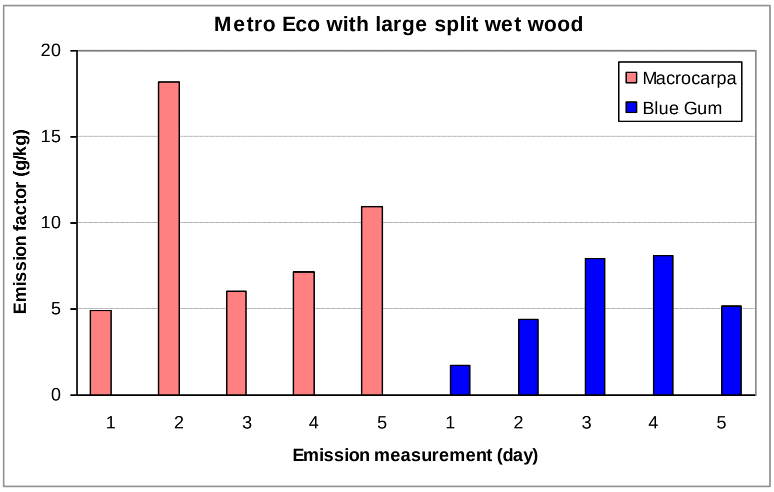


Figure F1.7

Emissions from Masport LE3000 burning small split dry wood.

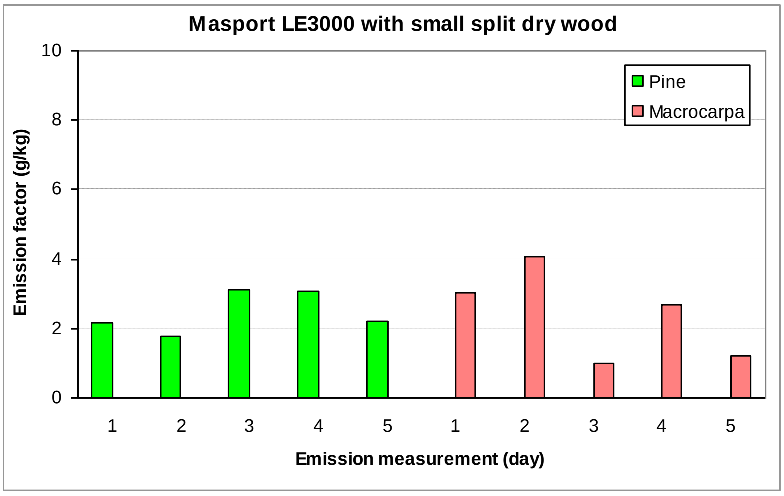


Figure F1.8

Emissions from Masport LE3000 burning large split dry wood.

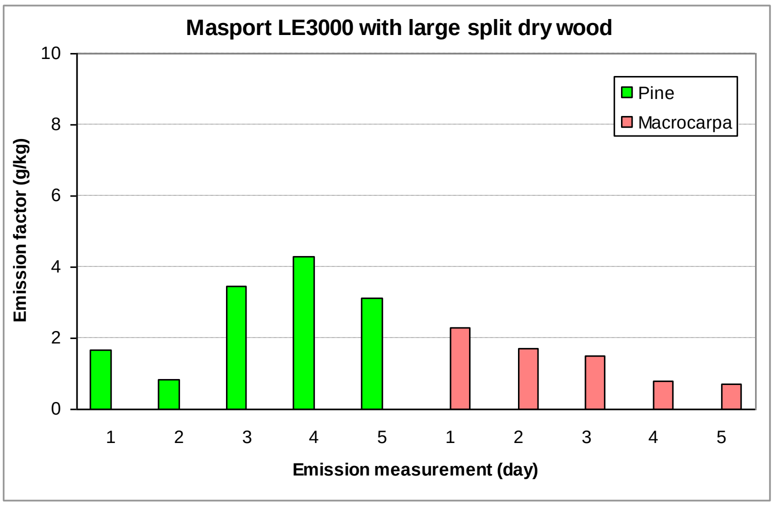
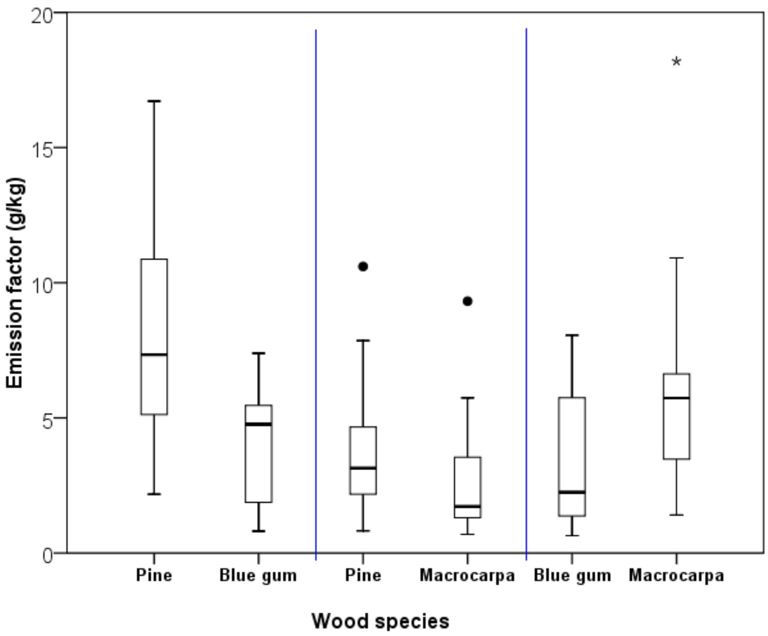


Figure F1.9

Emissions for the paired wood types (pine, blue gum or macrocarpa) for the same burner (Masport LE3000, Metro Eco or Masport Belvedere) and the same other fuel characteristics (i.e., size, cut, and seasoning).



Emissions of South Island wood

In order to further investigate the effects of wood species on emissions, additional testing for large split damp (25% moisture) South Island wood (pine, douglas fir and willow) and lower North Island pine was carried out for the Metro Eco burner. The testing was funded by Ministry for the Environment. The results are shown in Figures F1.9 and F1.10, and Tables F1.1, F1.2, F1.3 and F1.4. For comparison, the measurements of Auckland-sourced pine, blue gum and macrocarpa are also shown in Figure E1.10 and Table E1.4. It appears that emissions vary among South Island pine, lower North Island pine and Auckland-sourced pine. However, when including all the wood used in the testing, the difference between the south island wood (pine, douglas fir and willow; 3.4 ± 0.4 g/kg, 0.58 ± 0.11 g/MJ or 15.3 ± 2.4 g/hr) and the Auckland-sourced wood (pine, blue gum and macrocarpa; 5.2 ± 1.5 g/kg, 0.68 ± 0.23 g/MJ or 13.8 ± 4.2 g/hr) is not statistically significant ($p>0.05$, the Mann-Whitney test).

Figure F1.10

Emissions of lower North Island pine, South Island pine, douglas fir and willow, and Auckland-sourced macrocarpa, blue gum and pine.

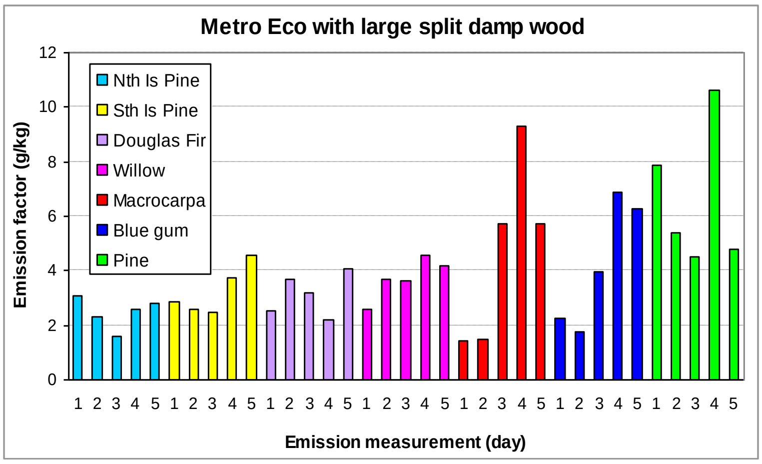


Table F1.1

Emission factors of Metro Eco with large split damp South Island wood (g/kg, dry weight).

No	Wood	Start up	High burn	Low burn	Mean*
1	South island pine (day 1)	4.2	1.0	5.8	2.9
2	South island pine (day 2)	4.6	0.5	4.4	2.6
3	South island pine (day 3)	5.0	0.8	3.4	2.5
4	South island pine (day 4)	7.7	0.6	5.6	3.7
5	South island pine (day 5)	6.5	0.8	9.4	4.6
6	Douglas fir (day 1)	3.8	0.4	5.5	2.5
7	Douglas fir (day 2)	7.9	0.3	5.1	3.7
8	Douglas fir (day 3)	6.5	0.4	4.9	3.2
9	Douglas fir (day 4)	4.4	0.3	3.3	2.2
10	Douglas fir (day 5)	6.8	0.2	8.7	4.1
11	Lower north island pine (day 1)	4.5	2.2	3.0	3.1
12	Lower north island pine (day 2)	4.7	0.7	3.4	2.3
13	Lower north island pine (day 3)	3.8	0.3	2.1	1.6
14	Lower north island pine (day 4)	3.7	0.6	5.0	2.6
15	Lower north island pine (day 5)	5.0	0.7	4.8	2.8
16	Willow (day 1)	4.8	0.5	4.5	2.6
17	Willow (day 2)	8.0	1.0	4.7	3.7
18	Willow (day 3)	5.0	1.6	6.8	3.6
19	Willow (day 4)	6.2	2.2	6.9	4.6
20	Willow (day 5)	10.2	1.7	3.1	4.2

* Calculated by dividing the total emissions by the total weight of wood burnt.

Table F1.2

Emission factors of Metro Eco with large split damp South Island wood (g/MJ).

No	Wood	Start up	High burn	Low burn	Mean*
1	South island pine (day 1)	3.68	0.14	0.27	0.42
2	South island pine (day 2)	2.66	0.07	0.54	0.43
3	South island pine (day 3)	2.45	0.11	0.29	0.37
4	South island pine (day 4)	4.73	0.08	0.64	0.61
5	South island pine (day 5)	3.69	0.12	1.16	0.77
6	Douglas fir (day 1)	1.87	0.05	0.52	0.36
7	Douglas fir (day 2)	5.99	0.04	0.60	0.60
8	Douglas fir (day 3)	3.86	0.05	0.53	0.49
9	Douglas fir (day 4)	2.20	0.03	0.34	0.31
10	Douglas fir (day 5)	3.72	0.02	0.87	0.57
11	Lower north island pine (day 1)	2.57	0.21	0.30	0.39
12	Lower north island pine (day 2)	2.00	0.09	0.30	0.32
13	Lower north island pine (day 3)	1.65	0.04	0.19	0.23
14	Lower north island pine (day 4)	1.56	0.10	0.67	0.46
15	Lower north island pine (day 5)	3.35	0.10	0.49	0.42
16	Willow (day 1)	3.30	0.09	0.52	0.46
17	Willow (day 2)	7.20	0.15	0.67	0.70
18	Willow (day 3)	4.14	0.29	0.74	0.71
19	Willow (day 4)	6.11	0.43	1.16	1.04
20	Willow (day 5)	7.68	0.37	0.35	0.87

* Calculated by dividing the total emissions by the total heat released.

Table F1.3

Emission rates of Metro Eco with large split damp South Island wood (g/hr).

No	Wood	Start up	High burn	Low burn	Mean*
1	South island pine (day 1)	24.8	2.6	4.1	8.6
2	South island pine (day 2)	24.1	1.8	9.4	11.5
3	South island pine (day 3)	27.1	3.2	5.8	10.9
4	South island pine (day 4)	49.1	2.3	11.4	17.0
5	South island pine (day 5)	35.4	3.2	20.4	20.8
6	Douglas fir (day 1)	22.6	1.4	8.1	9.9
7	Douglas fir (day 2)	42.7	1.2	12.2	16.5
8	Douglas fir (day 3)	36.5	1.5	11.2	14.8
9	Douglas fir (day 4)	25.6	1.0	7.4	9.9
10	Douglas fir (day 5)	38.3	0.8	19.6	19.4
11	Lower north island pine (day 1)	24.0	7.4	6.9	13.3
12	Lower north island pine (day 2)	25.5	2.9	6.9	10.9
13	Lower north island pine (day 3)	21.8	1.3	4.4	7.8
14	Lower north island pine (day 4)	19.0	2.8	14.3	13.8
15	Lower north island pine (day 5)	24.6	3.1	10.5	13.2
16	Willow (day 1)	29.9	2.4	9.9	12.8
17	Willow (day 2)	46.6	4.1	11.4	18.3
18	Willow (day 3)	29.8	6.8	13.5	17.6
19	Willow (day 4)	34.3	8.6	16.8	21.4
20	Willow (day 5)	53.3	7.0	6.3	19.3

* Calculated by dividing the total emissions by the total hours of operation.

Table F1.4

Test results of Metro Eco with large split damp wood (lower North Island pine, South Island pine, douglas fir and willow, and Auckland-sourced macrocarpa, blue gum and pine).

Wood	**Emission factor (g/kg)**	**Emission factor (g/MJ)**	**Emission rate (kg/hr)**
Lower North Island pine	2.5 ± 0.7	0.36 ± 0.11	11.8 ± 3.1
South Island pine	3.2 ± 1.1	0.52 ± 0.21	13.8 ± 6.2
Douglas fir	3.1 ± 1.0	0.46 ± 0.16	14.1 ± 5.2
Willow	3.7 ± 0.9	0.75 ± 0.27	17.9 ± 4.0
Macrocarpa	4.7 ± 4.1	0.71 ± 0.68	13.7 ± 11.4
Blue gum	4.2 ± 2.9	0.66 ± 0.60	10.9 ± 7.7
Pine	6.6 ± 3.2	0.66 ± 0.32	16.8 ± 9.0

Appendix G: Emissions of split and unsplit wood

Figure G1.1

Emissions from Masport Belvedere burning small wet blue gum.

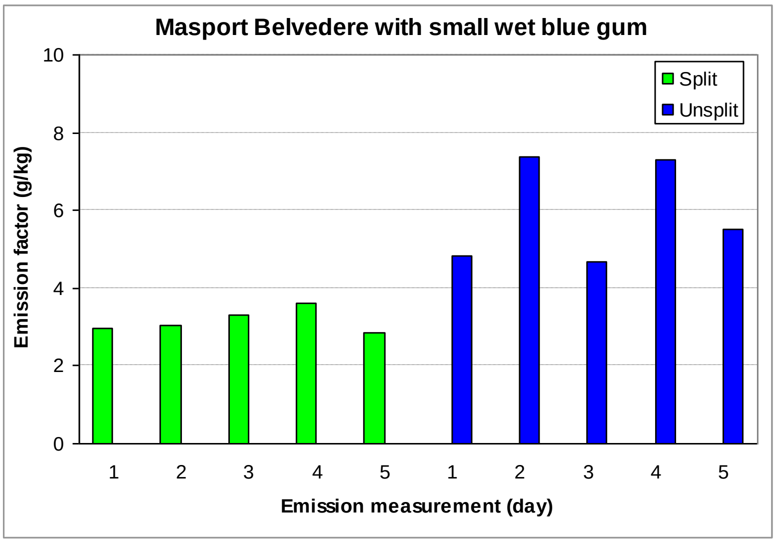


Figure G1.2

Emissions from Masport Belvedere burning large damp pine.

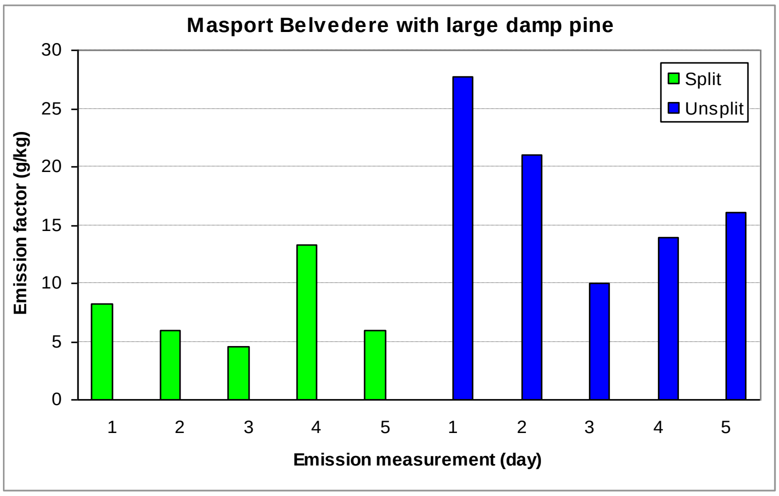


Figure G1.3

Emissions from Masport LE3000 burning small dry macrocarpa.

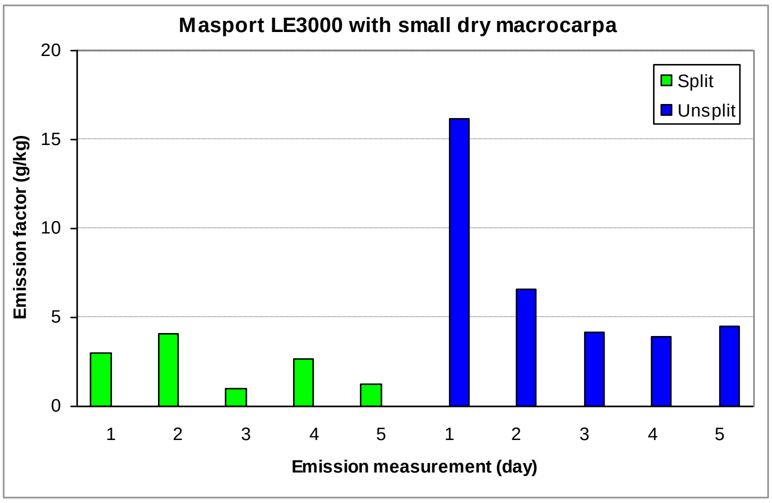


Figure G1.4

Emissions from Metro Eco burning large dry blue gum.

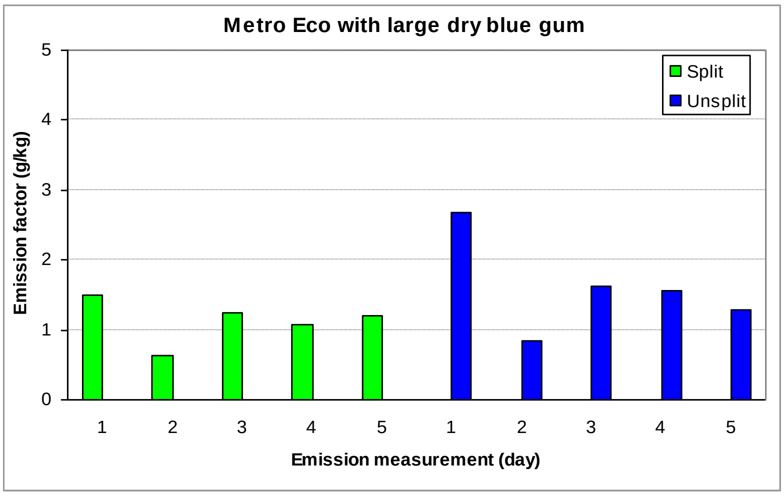


Figure G1.5

Emissions from Metro Eco burning large damp blue gum.

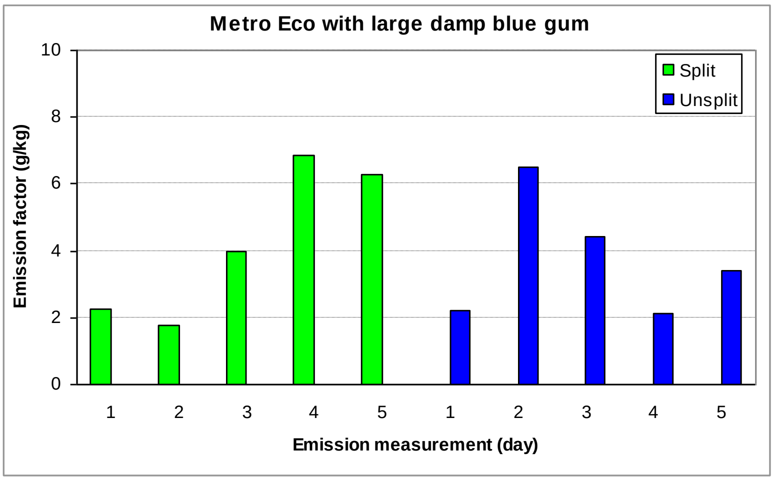
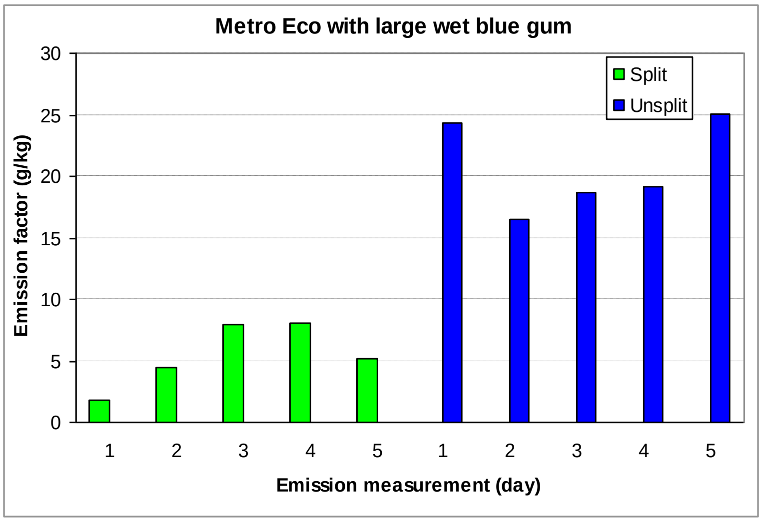


Figure G1.6

Emissions from Metro Eco burning large wet blue gum.



Appendix H: Best and worst emissions

Table H1.1

Percentage of different burners and fuel parameters for the best and the worst emissions for per MJ emission factors*.

Variable	Parameter	Samples of lowest 25% emissions (average 0.19 g/MJ)	Samples of highest 25% emissions (average 2.09 g/MJ)	Remaining samples (average 0.58 g/MJ)	Whole dataset (155 samples)
Moisture content	Dry (15%)	72 %	5 %	32 %	35 %
	Damp (25%)	26 %	38 %	32 %	32 %
	Wet (35%)	3 %	56 %	35 %	32 %
Wood surface	Split	69 %	33 %	58 %	55 %
	Unsplit	31 %	67 %	42 %	45 %
Burner	Masport LE3000	38 %	15 %	31 %	29 %
	Metro Eco	46 %	31 %	26 %	32 %
	Masport Belvedere	15 %	54 %	43 %	39 %
Wood species	Pine	26 %	51 %	52 %	45 %
	Blue gum	46 %	36 %	30 %	35 %
	Macrocarpa	28 %	13 %	18 %	19 %
Log size	Small	31 %	36 %	44 %	39 %
	Large	69 %	64 %	56 %	61 %

* The total of three groups may not add up 100 % due to rounding of numbers.

Table H1.2

Percentage of different burners and fuel parameters for the best and the worst emissions for emission rates*.

Variable	Parameter	Samples of lowest 25% emissions (average 4.4 g/hr)	Samples of highest 25% emissions (average 26.0 g/hr)	Remaining samples (average 10.7 g/hr)	Whole dataset (155 samples)
Moisture content	Dry (15%)	64 %	15 %	31 %	35 %
	Damp (25%)	21 %	41 %	34 %	32 %
	Wet (35%)	15 %	44 %	35 %	32 %
Wood surface	Split	51 %	46 %	61 %	55 %
	Unsplit	49 %	54 %	39 %	45 %
Burner	Masport LE3000	26 %	13 %	39 %	29 %
	Metro Eco	41 %	44 %	22 %	32 %
	Masport Belvedere	33 %	44 %	39 %	39 %
Wood species	Pine	26 %	54 %	51 %	45 %
	Blue gum	51 %	23 %	34 %	35 %
	Macrocarpa	23 %	23 %	16 %	19 %
Log size	Small	28 %	36 %	45 %	39 %
	Large	72 %	64 %	55 %	61 %

* The total of three groups may not add up 100 % due to rounding of numbers.

Appendix I: Weighted averages

Table I1.1

Emission factors from the woodburner testing (weighted averages).

Burner	Emission factor (g/kg)		Emission factor (g/MJ)
	Dry weight	Wet weight	
Masport LE3000	3.6	2.9	0.45
Metro Eco	5.5	4.1	0.68
Masport Belvedere	6.1	4.5	0.91
Masport LE3000 and Metro Eco	4.5	3.5	0.56
All three burners	5.0	3.8	0.67

Table I1.2

Burn rates and emission rates from the woodburner testing (weighted averages).

Burner	Burn rate (kg/hr)		Emission rate (g/hr)
	Dry weight	Wet weight	
Masport LE3000	3.1	3.9	11.2
Metro Eco	2.5	3.3	13.8
Masport Belvedere	2.3	3.1	13.8
Masport LE3000 and Metro Eco	2.8	3.6	12.6
All three burners	2.6	3.4	13.0