ULTRA-LOW EMISSION BURNERS - A CATALYST FOR INNOVATION!

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Abstract

Many towns and cities around the world suffer from poor air quality in winter, a major contributor being particulate emissions from domestic wood burners. New Zealand is no exception with a number of towns and cities regularly exceeding the New Zealand National Environmental Standard for Air Quality (NESAQ) for PM_{10} on multiple days each winter. Since the early 2000s Environment Canterbury (ECan) has proactively taken action to improve air quality in the Canterbury region. In 2013, in order to further improve winter air quality, ECan introduced a new pseudo real-life wood burner authorisation test method known as Canterbury Method One (CM1). Appliances passing the CM1 test method qualify as Ultra-low Emitting Enclosed Burners (ULEBs) and are the only wood log burning appliances allowed to be installed into houses within clean air zones and gazetted airsheds in Canterbury. This paper discusses the steps taken and progress made by ECan in reducing the impact of particulate emissions from domestic wood burners, reviews the rationale for developing ULEBs, compares the CM1 test method to the incumbent regulatory test standards, discusses how industry responded to the challenge set, and examines the design trends and the particulate emission performance of ULEBs authorised to date. Finally, the paper reviews how Canterbury's Air Regional Plan (CARP) has enabled ULEB technology development and their impact on airsheds.

Keywords: ULEB, ECan, Particulate, CM1

1. Introduction

Worldwide, air pollution from domestic heating is a major contributor to winter air quality issues, adverse health effects and premature deaths (WHO 2015).

New Zealand has defined 71 airsheds which are known, or have the potential, to have air quality which exceeds the particulate matter (PM_{10}) levels as prescribed in the National Environmental Standards for Air Quality (NESAQ) (MfE 2014).

During the years 2014 – 2016, 30 of these airsheds recorded at least 1 high pollution day by exceeding the NESAQ for 24-hour average PM_{10} (MfE 2018a).

Canterbury has 8 airsheds, 6 of which recorded at least one high pollution day in 2018 (ECan 2018).

2. Christchurch's historical air pollution problem

The city of Christchurch has a long history of poor air quality.

Like many New Zealand towns and cities, on calm, clear nights Christchurch has an inversion layer that easily traps smoke from solid fuel home heating.

From the 1950s through to the early 2000s, Christchurch residents relied heavily on open fires and older style enclosed wood burners as a heating source, resulting in large numbers of high-pollution days per year over many decades. In was estimated in 2009 that domestic home heating contributed to 70-81% of PM_{10} in the Christchurch airshed (ECan 2011).

Many of the commonly used older style wood burners were capable of being turned down and could be left to smoulder overnight allowing easy reignition the next morning. Coal was still being used in open fires as well as in older style enclosed burners and multi-fuel burning appliances.

3. Environment Canterbury's goal to clear the air

In 2002 Environment Canterbury (ECan) intensified efforts to clean the air in Christchurch, first via its Natural Resources Regional Plan (NRRP) notified in 2002, and then later through the Canterbury Air Regional Plan (CARP) notified in 2013.

At the time the city was generally reporting about 40 to 60 high-pollution nights per year (see Appendix A) (ECan 2019).

The NRRP considered that up to 90% of Canterbury's winter air pollution problem was caused by domestic small-scale heating appliances.

In response to this, ECan adopted the following multifaceted approach to lower the level of emissions into airsheds from home heating:

- Introduced a tougher appliance emission limit of 1 g/kg (2002);
- Banned the use of coal for home heating (2002);
- Launched the Clean Heat Project (2003 – 2011);
- Banned open fires (2007);
- Introduced a behavioural change programme (2014) which included the Trusted Good Wood Merchants scheme, public workshops, in-home demonstrations on better burning techniques, free kindling promotions and providing wood to poorer households;
- Banned older style and MfE unapproved wood burners older than 15 years (from 2018); and
- Used the regional air plans to phase out the use of older style wood burners; i.e. can now only replace with an Ultra-Low Emitting Enclosed Burner (ULEB) in clean air zones and gazetted airsheds.

The Clean Heat Project offered a range of incentives towards replacement with new low-emission or zero-emission forms of heating, which was predominately heat pumps at that time. The Clean Heat Project ended in 2011 after having overseen the replacement of heating in 19,450 homes.

4. Government sets targets for air quality

The Ministry for the Environment (MfE) developed the NESAQ in 2004. The NESAQ identified 23 airshed towns and cities around New Zealand that did not meet the World Health Organization (WHO) standard of no more than one exceedance per annum of a PM_{10} level of 50 µg/m^3, based on a 24-hour average reading. Some of these towns and cities (including Christchurch) were charged with not having greater than three exceedances per annum by 2016 and only one exceedance by 2020. Other towns and cities with less polluted airsheds had to meet a standard of one exceedance per annum by 2016.

Table 1. Wood burner particulate emission limits

	Standards/Regulations	ECan
	(g/kg)	**(g/kg)**
1992	5.5 (NZS 7403:1992)	
1997		3
1999	4 (AS/NZS 4013:1999)	
2000		1.5
2002		1
2004	1.5 (NESAQ)	

The NESAQ also set an emission standard for wood burners of 1.5 g/kg, higher than the 1 g/kg set by ECan in 2002.

A summary of New Zealand and ECan particulate emission limits can be found above in Table 1.

5. ECan ushers in a new era

There has been a consistently strong voice from the Canterbury community arguing to retain the ability for people to be able to stay warm using wood as a home heating fuel. This has been based on several factors including:

- The ability to gather one's own heating fuel and have some control over the ability to keep warm at a viable cost;
- The fact that wood is a renewable resource while other forms of home heating are not necessarily so;
- Independence from any vagaries in the electricity network which impacts on all other forms of home heating;
- The perceived simple pleasure and effectiveness of a wood fire; and
- The argument that as wood is carbon neutral, global warming is a far greater threat to the planet than air pollution.

These arguments were recognised by ECan Commissioners, specifically Commissioner Bedford who was the lead Commissioner for the Air Portfolio, following the 2010/11 earthquakes along with a desire to preserve the ability of Cantabrians to keep warm post-earthquakes.

The prevailing regulations post-earthquakes meant that homeowners could not install a new wood burner into a new home or into an existing home that did not already have a current operational wood burner. In late 2012 ECan Commissioners asked the Canterbury Earthquake Recovery Minister (Hon Gerry Brownlee) to use his special powers under the Canterbury Earthquake Recovery Act 2011 to change the Canterbury Air Plan. The objective was to allow the installation of wood burners into new situations provided that they met an emission level of 0.5 g/kg as measured on a real-life basis.

By creating a new class of wood burning appliance, the ULEB, it was recognised that air pollution was still a problem while acknowledging the desire to continue allowing wood as a home heating fuel.

The ULEB emission performance standard was set at 38 mg/MJ (equivalent to 0.5 g/kg and 65% efficiency) when tested under simulated real-life conditions. This was slightly below the 40 mg/MJ performance standard required of pellet fires in the NRRP.

ECan's science team was asked to run some airshed scenarios to determine the likely impact on the airshed of allowing ULEBs to be installed, both as replacements for older burners and in houses that did not have wood burners.

As there was no reliable information on the likely number of ULEBs that would/could be installed in 'new' homes (homes that did not currently have a wood burner), three scenarios were modelled. These assumed (i) no ULEBs installed, (ii) 500 ULEBs per year installed in 'new' homes, and (iii) 1,000 ULEBs installed in 'new' homes. In addition, a scenario was modelled that assumed a rule that, from 2019, when a complying burner reached 15 years old it could only be replaced with a ULEB or pellet burner.

It was known that the actual emissions from wood burners were several times higher than those determined from laboratory testing to the standard AS/NZS 4013. Between 2005 and 2009, four real life emissions studies were completed around New Zealand on wood burners that had been tested in the laboratory as being compliant with the National Environmental Standard (NES) of 1.5 g/kg. The studies were:

- 2005, Christchurch (Scott 2005);
- 2006, Tokoroa (Kelly et al 2007);
- 2007, Nelson, Rotorua, Taumarunui (Smith et al 2008); and
- 2009, Christchurch (Wilton et al 2012).

The study outcomes are summarised in Figure 1.

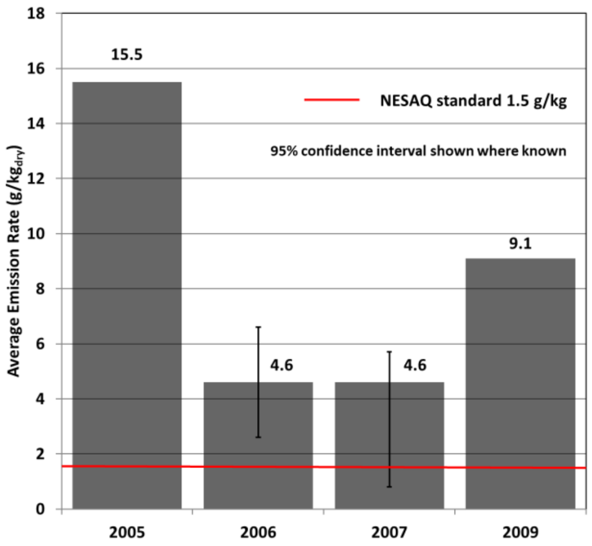

Figure 1. Historical real-life emission studies.

It can be seen from Figure 1 that the real-life emission studies suggested that NESAQ compliant wood burners had real-life emission factors that were between 3.1 and 10.3 times higher than the NESAQ performance standard.

Airshed modelling indicated that the Christchurch airshed could allow for the installation of ULEBs into new houses provided enough older style or low-emission burners (LEBs) were removed to offset the new ULEBs. This was based on the assumption that LEBs were to be replaced after 15 years with ULEBs (not LEBs) and on some assumptions around the retirement of existing burners, including 20% of people with an expired LEB choosing to install a heat pump (or other non-emitting heating device).

If such a ULEB performance standard was to be implemented, it would require a new test method based on measuring emissions from operating a wood burner under real-life conditions using firewood of a species and condition most likely to be used by the average householder. It would also require capturing particulate emissions from all stages of the operation of the fire, including the relatively high particulate emitting start-up period.

6. Pitching ULEBs to the home heating industry

ECan proposed the ULEB concept to wood burner industry leaders in 2013. Feedback at that time was that it would be "very difficult, if not impossible" to design a wood burner to meet this level of real-life particulate emissions.

New Zealand Home Heating Association president Gavin Edwards was particularly unhappy with ECan's new stance saying "People need to understand that ULEB will never happen. We have 11 manufacturers with the association and not one of them is going to spend millions of dollars on research and design to get a small point [sic] of the market, which Christchurch is." (Stuff 2014a).

7. Canterbury Method 1 (CM1)

The Canterbury Method, or CM1, was developed in late 2012, and evolved from the real-life emissions work that was done by ECan air quality scientist Dr Angie Scott in the early 2000s. The method is based on the thermal efficiency and particulate emission measurement methods defined in the Australia and New Zealand wood burner testing standards AS/NZS 4012 and AS/NZS 4013, but changing the appliance operating methodology to more closely replicate 'real life' operation.

There is often confusion (not only just by the public) as to what the objective of wood burner test standards are and what the resultant emission rates mean. A common misconception has been that AS/NZS 4012/4013 laboratory performance results are indicative of those which can be expected to occur in real-life in the home.

The AS/NZS 4012/4013 test standards are designed to improve replicability by tightly controlling the operating variables. This allows the operating performance of different appliances to be compared against each other as opposed to providing an estimate of expected real-life operating performance.

In contrast, the objective of CM1 is to approximate the real-life operation of a wood burner. Inherent in doing this is accepting that the results will be less replicable (i.e. have greater variability) than those achieved by AS/NZS 4012/4013.

The CM1 test methodology differs from AS/NZS 4012/4013 in the following broad ways:

- Emissions are measured over the entire duration of the test including the relatively smoky start-up phase;
- A realistic range of firewood types as might be purchased from a firewood merchant is used including seasoned (low moisture) pine, partially seasoned pine and hardwood;
- The firewood used includes bark as would be expected when purchasing wood from a merchant; and
- Ember bed depth is greater than that required by AS/NZS 4012.

Results from various phases of the testing are averaged to give the overall test performance. Two days of testing results are averaged to give the appliance emission and efficiency performance.

The CARP, which replaced the NRRP in 2017, defines a ULEB as an appliance that meets an emission factor of 38 mg/MJ (equivalent to 0.5 g/kg and 65% efficiency) when tested to simulated real life conditions. In addition to the CARP performance requirement, a ULEB must also satisfy the NESAQ thermal efficiency performance requirement of ≥ 65% when tested to AS/NZS 4012 (see Figure 2 below).

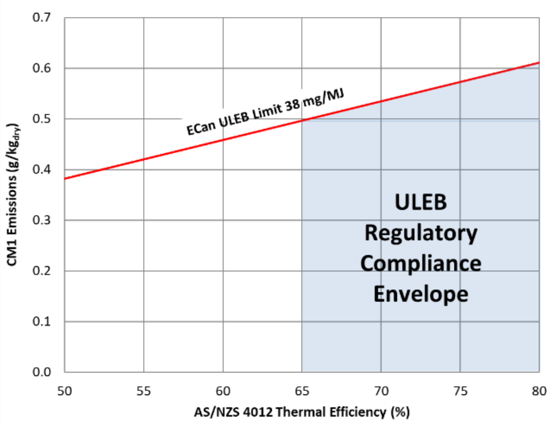

Figure 2. ULEB regulatory compliance envelope.

[1] A wood burner that is inserted into an existing masonry or prefabricated wood fireplace

8. The ULEB era

The first ULEB authorised on the 10th of December 2014 was the Jayline Waltherm Air. From then until June 2019 a total of 21 space heating wood burning ULEBs have been authorised in addition to 8 wood burning hot water central heating appliances.

The remainder of this paper is concerned only with the space heating wood burner ULEBs.

It is evident from Figure 3 below that the number of wood burner models being authorised each year has increased steadily since 2014. The first three ULEBs authorised were European technologies. In December 2015 the first New Zealand designed and built ULEB, the Tropicair Duo, was authorised signalling the local home heating industry were investing in research and development to meet the challenge of developing ULEB appliances.

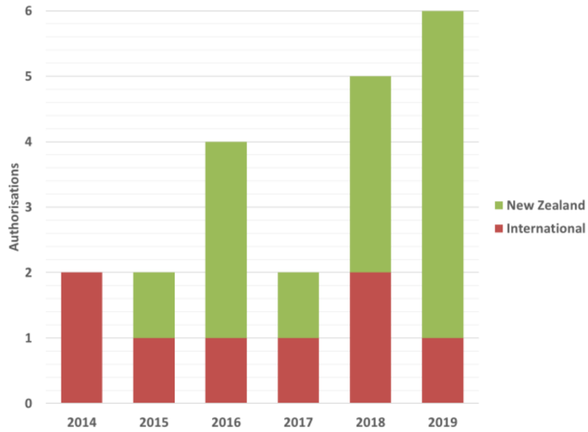

Figure 3. Number and origins of ULEBs.

The past few years have seen considerable effort and design innovation by the New Zealand manufacturers which has resulted in there now being 13 New Zealand designed and built ULEBs authorised compared to 8 international appliances.

Over the 6 years since ULEB authorisations began, some clear changes in ULEB design have also occurred. The initial appliances authorised were all dual chamber downdraft types. However, since 2017 less complex single chamber ULEB designs, more closely resembling conventional wood burners, have been developed, including the first insert[1] model which was authorised in 2019.

Another ULEB design feature is the number of heat settings on an appliance. Changes in the number of heat settings over time is shown below in Figure 5.

In any appliance, the most complete combustion, and the lowest particulate emissions, occurs when a fuel load is burning with a plentiful combustion air supply. This is also the operating condition that results in the lowest thermal efficiency as increased air supply rates also result in increased flue gas heat losses. In contrast reducing the combustion air supply increases particulate emissions and thermal efficiency (due to reduced flue gas heat losses). Emissions performance and thermal efficiency are therefore always being traded off against each other.

Figure 4. ULEB design trends.

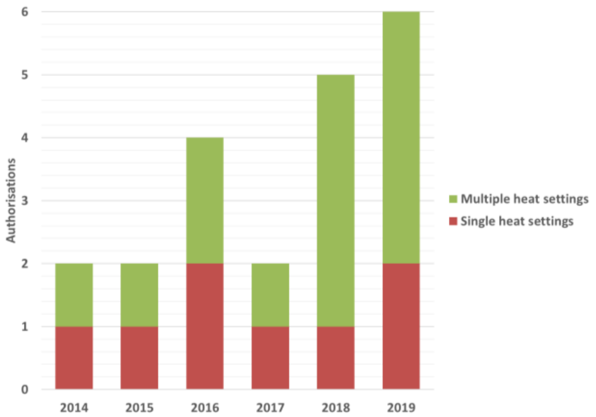

Figure 5. ULEB heat settings.

It can be seen from Figure 5 that 8 of the 21 authorised ULEBs have been designed with only one combustion air setting in order to meet the ULEB performance criteria.

Figures 4 and 5 do not convey all the ways in which manufacturers have met the ULEB challenge. Four North American single chamber appliances, that incorporate a catalytic combustor to minimise particulate emissions, have been approved. The catalytic combustor burns unburnt gases and particulate matter before they travel up the flue. Convection fans have also been used on some appliances to improve heat transfer from the appliance to room air (compared with natural convection), thereby improving thermal efficiency.

The reduction in manufacturing complexity, along with increased competition, has led to a reduction in cost to the consumer. The first ULEB on the market, the Jayline Waltherm Air, retailed for approximately $10,000 in 2014 (Stuff 2014b). In May 2019, the majority of ULEBs in Christchurch retailed between $3,600 and $6,000.

A comparison of CM1 and AS/NZS 4013 emission factors for authorised ULEB appliances is shown below in Figure 6. Each dot represents an individual appliance. As expected, emissions from the pseudo real-life CM1 test are generally higher than those from AS/NZS 4013. It is apparent however that around 30% have the opposite trend. The reason for this is currently unknown but is likely to be due to a combination of the increased variability of the CM1 test and differences in the fuelling methods between the test methods. Investigations into the cause(s) of the anomalous results are ongoing.

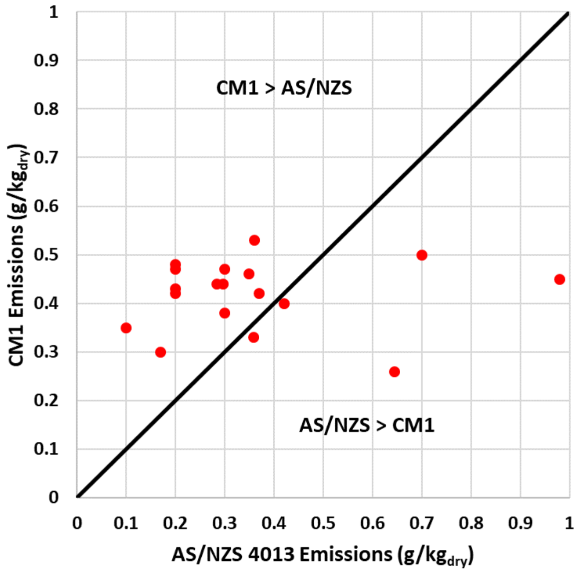

Figure 6. Comparison of wood burner test methods.

9. Real life testing of ULEBs

In 2017 and 2018, two further real-life testing studies were commissioned, one by Bay of Plenty Regional Council in Rotorua (10 Tropicair Duos) and one by ECan in Waimate (4 Masport Mystiques). The laboratory testing results for these appliances are summarised in Table 2.

Table 2. Woodburner laboratory emissions

	AS/NZS 4013:2014	CM1
	(g/kg)	(g/kg)
Tropicair Duo	0.10	0.35
Masport Mystique	0.17	0.30

The results of these recent studies are shown below in Figure 7 alongside those of previous studies.

It is clear from Figure 7 that the real-life emissions of the ULEBs tested are significantly lower that the

NESAQ compliant wood burners previously studied. It is noted that the real-life emissions are still 2.9 to 5.3 times higher than the pseudo real-life emission rates measured via CM1 and 10 times higher than the AS/NZS 4013 results.

10. A cleaner airshed

Since 2002, there has been a dramatic improvement in the ambient air quality of Christchurch as can be seen in Appendix A.

As discussed above in Section 2, it was estimated in 2009 that domestic home heating contributed to 70-81% of PM_{10} in the Christchurch airshed (ECan 2011).

The number of high pollution days has dropped from sixty in 1999 to four in 2018, but still above the three exceedances Christchurch is allowed by the NESAQ. Similarly, the highest daily PM_{10} concentrations have reduced from 288 μg/m³ in 2001 down to 63 μg/m³ in 2017 demonstrating the success of the measures ECan have taken to reduce emissions from home heating.

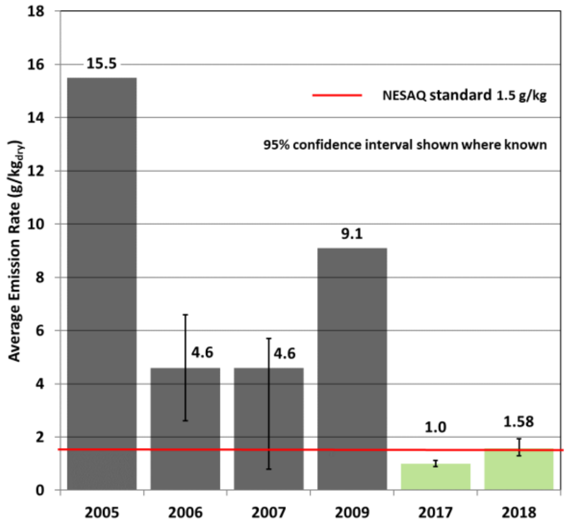

Figure 7. Summary of New Zealand real life testing studies.

As 99% of PM_{10} emitted from home heating in New Zealand is estimated to be $PM_{2.5}$ (MfE 2018b), measures taken to reduce PM_{10} are also expected to be effective in reducing $PM_{2.5}$ within airsheds.

ECan is confident that the measures in the CARP will continue to reduce home heating emissions and allow Canterbury airsheds to meet national air quality standards in the coming years.

Conclusions

Christchurch has historically had an air pollution problem, largely as a result of particulate emissions from domestic wood burning appliances.

Since the early 2000s, ECan has made significant progress in reducing the impact of home heating emissions on the Christchurch airshed.

The CM1 test methodology is designed to more closely approximate homeowner use of wood burners than AS/NZS 4012.

The New Zealand domestic heating industry has risen to the challenge of producing appliances with low emissions through research and design, contributing significantly to the now 29 authorised ULEBs on the market.

The real-life performance of ULEBs tested to date is encouraging with the Rotorua and Waimate real-life studies resulting in real-life emission performance much lower than those obtained in previous studies with NES compliant woodburners.

The costs of ULEBs have reduced due to designs becoming simpler and a wider range of models being authorised and available on the market.

Councillor Bedford's vision for allowing people to stay warm by burning wood whilst simultaneously reducing winter air pollution is well on the way to being achieved.

Acknowledgments

The authors would like to acknowledge the late ECan Commissioner Bedford who championed the ULEB concept. Without his vision and determination, neither the regulators nor the public would have an ultra-low emission wood burning option available.

Glenn Seymour's encyclopaedic knowledge of ECan's air quality journey from the Clean Heat Scheme through until the present day has proven an invaluable resource.

ECan's air science staff, in particular Tim Mallet and Dr Angie Scott, for their contribution to the science and understanding of wood burner emissions.

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Appendix A - Christchurch airshed data (ECan 2019)