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# Estimation of Domestic Fire Emissions in 2006

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# Estimation of Domestic Fire Emissions in 2006

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**Prepared for**
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October 2010

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# Contents

# Executive Summary

The Auckland Emissions Inventory is a critical component of ARC's air quality management programme. The inventory identifies key pollution sources and how they are likely to change over space and time. This allows us to develop policy which focusses on the main sources of pollution and to test which methods to reduce emissions are likely to be most effective.

The Auckland Air Emissions Inventory: 2004 (ARC, 2006a) estimated that, in the Auckland region, domestic fire emissions account for approximately 60 per cent of particulate emissions over winter and 37 per cent on an annual basis. The 2004 inventory identified a number of areas of uncertainty in the domestic fire emissions estimate and recommended further work to address these. This report provides updated domestic fire $PM_{10}$ emissions estimates based on work that has been undertaken to reduce these uncertainties. The results of this report are used to update the domestic home heating component of the emissions inventory for 2006.

## Methodology

For the 2006 inventory, information about solid fuel burning appliances and home heating fuel use are updated based on the results of a comprehensive home heating survey that was undertaken during 2007 (ARC 2101b). The overall number of households burning wood is based on 2006 Census data.

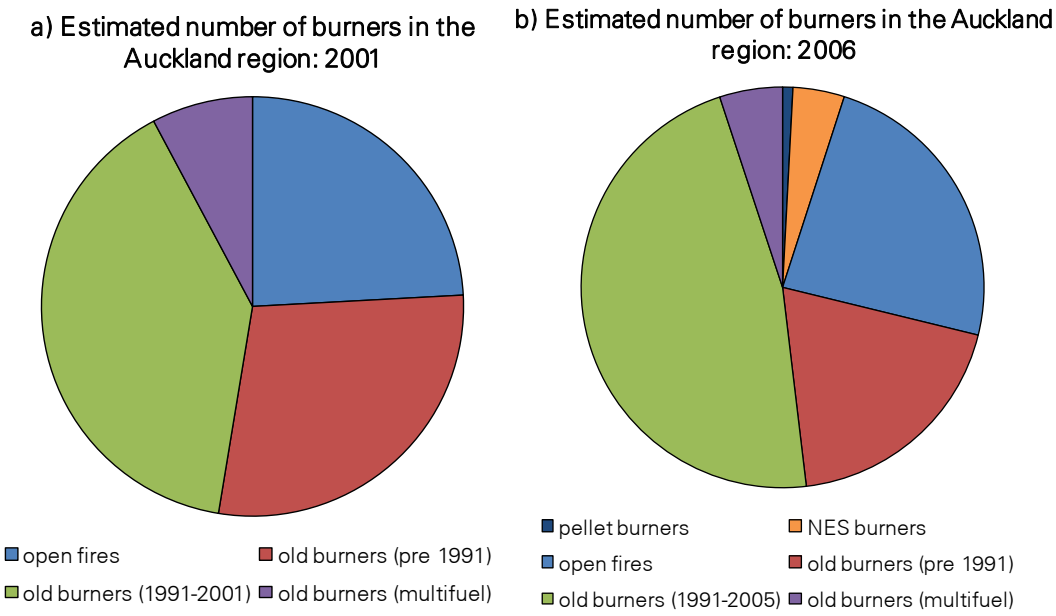
Woodburner $PM_{10}$ emission factors are updated based on the results of recent emission testing carried out in New Zealand, particularly the ARC's emission testing results. Emission factors for other burners and other contaminants are updated based on review of international emission factors.

Emission projections are based on analysis of trends between the 2001 and 2007 home heating surveys. This provides realistic data about the rate of installation and retirement of solid fuel burning appliances.

This methodology represents a significant improvement in domestic fire emission estimates and projections in comparison to that for the previous inventory.

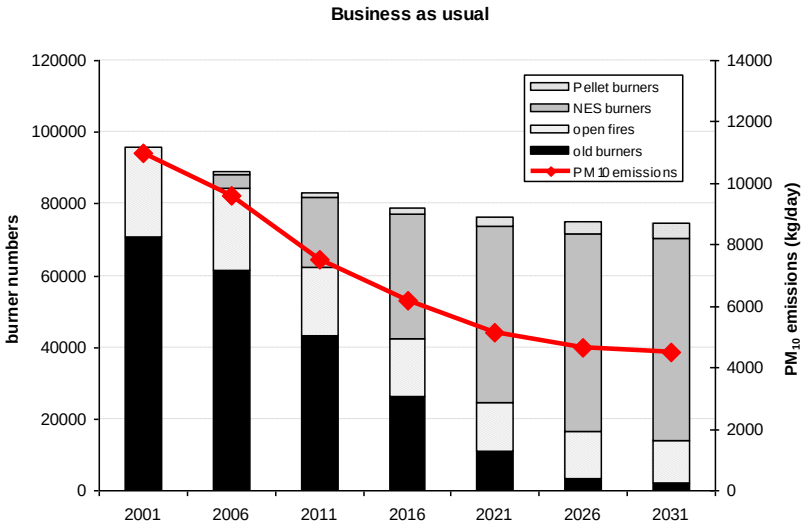
## Results

It is estimated that there were approximately 78,000 old woodburners (manufactured pre-2005), 26,000 open fires, 4500 woodburners compliant with the National Environmental Standards (manufactured post-2005) and 900 pellet burners in the Auckland region, resulting in $PM_{10}$ emissions of approximately 13 tonnes per winter weekday in 2006.




Based on the same methodology, it is estimated that there were approximately 88,000 woodburners and 28,000 open fires in Auckland in 2001, resulting in an estimated $PM_{10}$ emission reduction of 13 per cent between 2001 and 2006.

The business as usual (BAU) emission projection scenario is based on the assumption that recent trends continue. Under this scenario it is predicted that $PM_{10}$ emissions gradually reduce to less than half of 2006 emissions by 2031 as older woodburners are replaced with modern (lower emission) woodburners, and the overall number of households burning solid fuel reduces. The BAU projection will provide a baseline for analysis of further emission reduction measures that may be necessary to achieve compliance with the $PM_{10}$ ambient standard.



## Uncertainty and Sensitivity

The updated emission estimates and projections represent a significant improvement compared with the previous inventory. Sensitivity analysis has demonstrated that the projected rate of emission reduction is sensitive to some of the key assumptions, in particular;

- The rate of retirement of older woodburners could be slower than assumed in the business as usual scenario;
- There is some uncertainty about whether emissions from modern woodburners will increase over time as they age;
- A realistic range of variables has been developed for sensitivity analysis of these assumptions. These will need to be considered in the development of any policy to achieve emission reduction targets.

## Recommendations

Further work recommended to improve certainty in emission estimates and projections includes:

- Repeat the home heating survey and update projections at least for every census year;
- Track woodburner and open fire installations and removals through the building consent process;
- Undertake real-life emission testing of NES compliant[1] wood burners on a regular basis to check how their performance changes over time;
- Undertake sensitivity analysis for quantitative evaluation of any policy. The variables considered in Appendix: 3 provide a basis for this analysis.

[1] Woodburners that comply with the National Environmental Standards for Air Quality

# 1 Introduction

This report outlines updates to the domestic home heating component of the Auckland emissions inventory, which was last updated in 2004 (ARC, 2006a).

The 2004 inventory identified a number of areas of uncertainty in the domestic fire emissions estimate and recommended further work to address these. This report provides updated domestic fire emissions estimates for 2006 based on work that has been undertaken to reduce these uncertainties. Updated emission projections to 2031 for a business as usual scenario are also provided.

## 1.1 Background

The 2004 Auckland Air Emissions Inventory (ARC, 2006a) estimated that, in the Auckland region, domestic fire emissions account for approximately 60 per-cent of particulate emissions over winter and 37 per cent on an annual basis. Transport and industry were identified as the other major sources of $PM_{10}$ (particulates less than 10 micrometres in diameter) emissions accounting for 47 per cent and 14 per cent respectively on an annual basis.

The Proposed Auckland Regional Plan: Air, Land and Water (PARP:ALW) recognises that "*In order for Auckland Region's urban areas to have no breaches of the standards* (National Environmental Standards for Air Quality) *or targets* (Auckland Regional Air Quality Targets), *$NO_2$* (nitrogen dioxide), *$PM_{10}$ and $PM_{2.5}$* (particulates less than 2.5 micrometres in diameter) *emissions from domestic fires and mobile sources, in particular motor vehicles, need to decrease significantly.*"

The PARP:ALW proposes development of an Auckland Regional Air Quality Management Strategy to quantify the reductions that are required as accurately as possible, to evaluate the options, including costs and benefits, and to specify actions. The PARP:ALW also states that,

*"The development of an Auckland Regional Air Quality Management Strategy will involve the following steps:*

- *Ongoing ambient air quality and meteorological monitoring at sites that are representative of Urban, Rural and Industrial Air Quality Management Areas;*
- *Regular review of the Auckland Regional Emissions Inventory, which identifies key sources and how they change over space and time;*
- *Atmospheric dispersion modelling studies and exposure assessments to determine*

*the spatial extent and frequency of areas where pollution levels exceed target values and their impacts;*

- *Analysis of current trends and projection for future trends in emissions;*
- *Analysis of the options for improving air quality and their cost effectiveness; and*
- *Determining community views on the desirable level of air quality and the options for improving it."*

This report relates to the review of the Auckland Regional Emissions Inventory, as well as the analysis of current trends and projection for future trends in emissions.

The 2004 update of the Auckland Regional Emissions Inventory (ARC, 2006). identified uncertainties in the domestic heating emission estimate and recommended further work to:

- Reduce uncertainty in the estimated amount of wood burnt in the region,
- Improve domestic heating emissions factors, and
- Update projections to reflect the National Environmental Standards for Air Quality (AQNES) and validate key assumptions.

Work has been undertaken to address these information gaps. The 2007 domestic heating survey (ARC, 2010b) was designed to reduce the uncertainty in the amount of wood burnt in the region and to validate key assumptions in domestic fire emission projections. A number of studies have also been undertaken to improve domestic heating emission factors, including woodburner testing undertaken in 2009 (ARC 2010a).

## 1.2 Objectives

The objective of this report is to estimate domestic fire emissions. This includes appliance numbers, emission factors, and fuel consumption for 2006; as well as projected appliance numbers to 2033. This information is used to update the domestic home heating component of the Auckland regional emissions inventory. An upgrade of the inventory is underway to provide a comprehensive update of emissions for the Auckland region with a base year of 2006.

This update is based primarily on the 2007 home heating survey (ARC 2010b) and the ARC emission testing of woodburners (ARC 2010a). This work has been undertaken to reduce uncertainty in emission estimates and projections.

ARC has also developed a Domestic Fire Emission Prediction Model (DFEPM). The model has been developed to provide updated projections and to analyse options for improving air quality and their cost effectiveness. This report documents the

assumptions and methodology adopted in the DFEPM for a business as usual (BAU) scenario. Preliminary estimates of appliance numbers and $PM_{10}$ emissions are included in this report to allow for trend analysis, sensitivity analysis and comparison with previous inventories. Sensitivity analysis has been undertaken for the BAU scenario to identify the most important assumptions, and provide greater certainty in future emission trends.

## 1.3 Contents of this report

This report outlines the methodology for estimation of domestic heating appliance numbers (Section 3), emission factors (Section 4), and fuel use (Section 5) for 2006. The assumptions and methodology for projection of appliance numbers and emissions in the DFEPM is also presented for a BAU scenario in Section 6.

Results for 2006 and the BAU projection are presented in Section 7. This report considers emisions from domestic solid fuel burning. Other domestic sources, including emissions from gas or liquid fuels, rubbish burning and lawnmowing are not considered.

The focus of this report is $PM_{10}$ emissions from domestic fires. The emissions inventory upgrade will estimate other pollutant emissions for domestic fires based on the assumptions and methodology outlined in this report.

Uncertainty in the 2006 emission estimate is discussed in Appendix 1. Sensitivity of the BAU scenario to the key assumptions is evaluated in Appendix 3.

# 2 Method

This section outlines the overall method for estimation of 2006 domestic heating emissions. The DFEPM, which has been used to project emissions to 2033, is also described in this section.

## 2.1 Estimation of domestic heating emissions

Domestic heating emissions are estimated for each type of appliance as:

*Emission (g) = number of appliances x emission factor (g/kg fuel used) x fuel use (kg)*

Appliance numbers are estimated for 2006 based on the results of the 2007 home heating survey (ARC, 2010b) and census data as described in Section 3. The selection of emission factors for each appliance type is discussed in Section 4. Estimation of fuel use, based on the 2007 home heating survey, is discussed in Section 5.

## 2.2 2007 home heating survey

A comprehensive home heating survey was undertaken during 2007 to improve our understanding of emissions from domestic heating (ARC, 2010b). The results of the telephone survey are reported for 10 areas of Auckland (Figure 2-1). The 10 survey areas are unchanged from the previous survey (Wilton, 2002) to allow for direct comparison of results.

A diary survey was undertaken in addition to the telephone survey. Information from the diary survey was used to calculate hourly burn rate and average wood weight. The use of this information in emission estimates is discussed in Section 5.1 of this report. The home heating surveys are described fully in the 2007 Home heating survey results report (ARC, 2010b).

**Table 1:** Study areas 1 – 10

| Area No. | Survey Area | Occupied dwellings 2006 | Number surveyed |
|---|---|---|---|
| 1 | Papakura District | 30,237 | 630 |
| 2 | Franklin District | 34,332 | 684 |
| 3 | Manukau City, South West | 31,410 | 860 |
| 4 | Manukau City, North East | 35,436 | 799 |
| 5 | Auckland City, East | 73,389 | 1086 |
| 6 | Auckland City, West | 63,627 | 914 |
| 7 | Waitakere City, East | 50,907 | 559 |
| 8 | Waitakere City, West | 5574 | 403 |
| 9 | North Shore City | 64,047 | 741 |
| 10 | Rodney District | 45,090 | 555 |

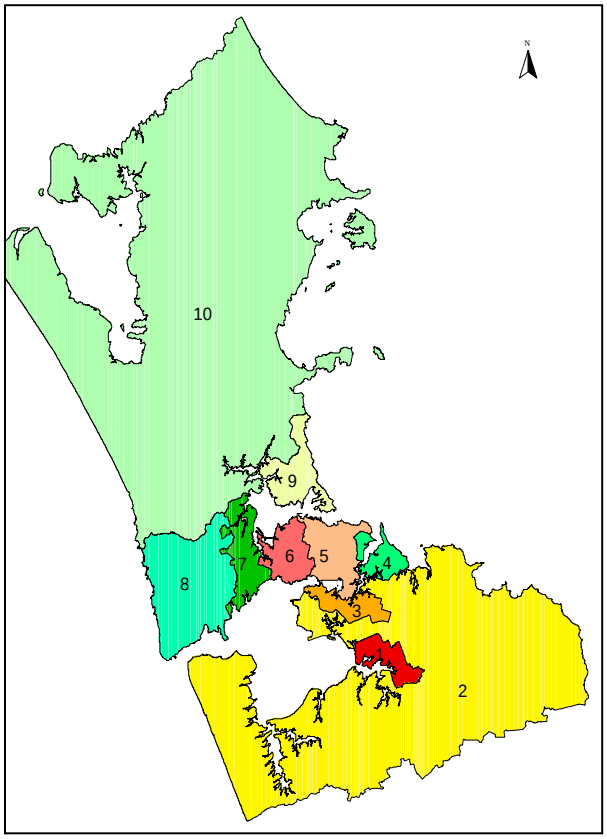



Figure 2-1: The ten survey areas

## 2.3 Domestic Fire Emission Prediction Model

The ARC has developed the Domestic Fire Emission Prediction Model (DFEPM) to predict emissions and analyse policy options. This report includes preliminary estimates of burner numbers and $PM_{10}$ emissions from DFEPM, which are based on the assumptions and methodology outlined in this report. The emissions inventory upgrade will adopt the same methodology and assumptions, although the calculations are undertaken using spatial data rather than aggregated totals for the ten survey areas. It will also estimate emissions of other pollutants from domestic fires, and emissions from other sources of pollution.

DFEPM includes a BAU projection which is based on the assumption that recent trends continue. It is assumed that emission factors and fuel consumption for each appliance do not change over time. Emissions change over time due to changes in the number and type of burners. The assumptions are described in Section 6.2. The calculations are described in detail in the DFEPM user notes. Emissions from coal are not included in DFEPM, or in any analysis of trends or projections in this report because the use of coal is minor compared to wood burning in Auckland. Unless otherwise stated all projections in this report relate to the Auckland urban airshed only. The DFEPM allows users to model either the Auckland urban airshed (Figure 2-2) or the entire region. However, the assumptions and trends in appliance types and numbers (based on survey results) are the same for either analysis.

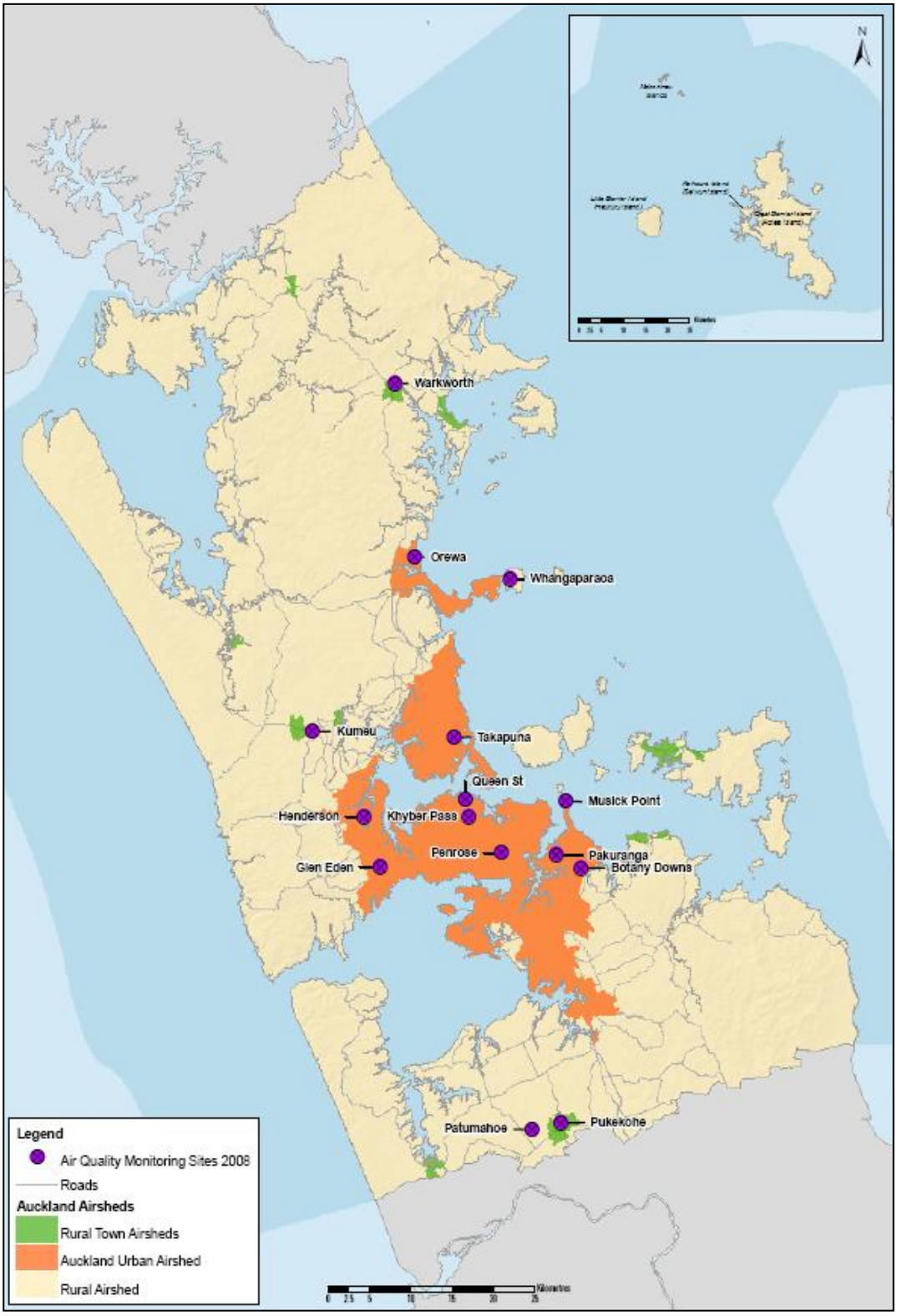



Figure 2-2: Auckland airsheds

## 2.4 Uncertainty and margin of error

The previous inventory (ARC, 2006a) identified that there was significant uncertainty in fuel usage estimates and emission factors for domestic heating emissions. There has been considerable work to reduce these uncertainties as discussed in Appendix: 1.

Emission projections are primarily based on results of the home heating survey. Margin of error and uncertainty associated with the survey are discussed in the home heating survey report (ARC, 2010b). Margin of error has also been calculated in this report for the estimated number of appliances in each category (in 2001 and 2006) using the methodology described in the home heating survey report. The margin of error for estimated appliance numbers is reported in Appendix: 4.

# 3 Solid fuel burning appliances

This section outlines the methodology for estimating the number of solid fuel burning appliances of each type. Wood burning appliances are estimated for both 2001 and 2006 to examine trends.

## 3.1 Appliance types

The appliance types included are:

- Open fire,
- Woodburner,
- Multi-fuel burner, and
- Pellet burner.

Woodburners are further categorised by age. Most significantly, woodburners installed from 2005 (NES woodburners) are assumed to comply with the design standard for new woodburners specified by the National Environmental Standards for Air Quality (AQNES).

The number of each type of appliance is estimated as:

| *number of appliances = HH x PT x PA* |
|---|

Where:

HH = no. of households using specified fuel (wood or coal) for heating (from the Census)

PT = Proportion of households using each appliance type (from the home heating survey)

PA = Proportion of appliance in age group (from the home heating survey)

The overall number of households using wood or coal is based on the Census because this the most accurate data available. However, the Census does not provide data on the type, or age, of appliances so this is based on the results of the 2007 home heating survey (ARC 2010b).

## 3.2 Wood burning appliances

For 2006, the overall number of households burning wood is based on 2006 Census data. The proportion of households with each type and age of appliance is based on the results of the 2007 home heating survey (ARC, 2010b).

It is assumed that households with pellet burners are not included in the number of households burning wood from the Census. Based on the 2007 home heating survey, there are very few (less than one per cent) pellet burners so this assumption will not significantly impact results.

The overall number of households burning wood is based on the Census for 2001, and the proportion of each burner type and age is based on the 2002 home heating survey (Wilton, 2002). It is estimated that there were approximately 88,000 old woodburners and 28,000 open fires in 2001 (Figure 3-1a).

Wood burning appliances numbers are estimated for 2006 using the same methodology. It is estimated that there were approximately 78,000 old woodburners (pre-2005), 26,000 open fires, 4500 NES woodburners (post-2005) and 900 pellet burners in the Auckland region in 2006 (Figure 3-1b).

Estimated appliance numbers for each of the 10 survey areas in 2001 and 2006 are included in Appendix: 4.

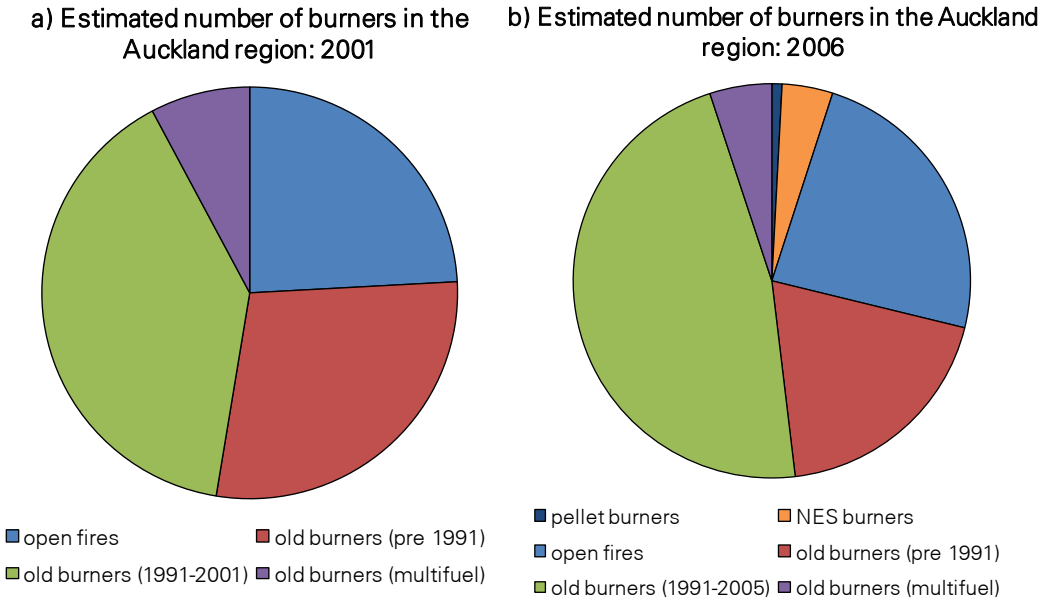



Figure 3-1 a) appliance numbers in 2001, and b) appliance numbers in 2006

## 3.3 Coal burning appliances

Emissions from coal burning are estimated for 2006 and will be included in the emissions inventory upgrade. However, coal burning appliances are not included in the DFEPM and are not considered in any analysis of trends.

The overall number of households burning coal in 2006 is based on census data. The Census indicates that there were approximately 700 households in the Auckland region burning coal exclusively (i.e. not burning wood) in 2006. Based on the results of the survey it is assumed that 29 percent of these households use open fires with the remainder using multifuel burners.

The 2006 Census indicated that there were approximately 17,000 households burning wood *and* coal. They are a subset of the total number of households burning wood. This means that wood *and* coal burner numbers are a subset of the wood burning appliance numbers estimated in Section 3.2. Based on survey results it is assumed that 59 percent of these households use open fires. For the remainder of households the proportion of each type of appliance is assumed to be the same as for wood. It is assumed that these proportions are the same in all areas.

It is assumed that all wood and coal burning households are using multifuel as opposed to woodburners, although the total number of multifuel burners estimated from survey results is only approximately 5000. The emission factors used for coal burnt in a multifuel are the same as burning coal in a woodburner, so the assumption does not affect emission estimates.

# 4 Emission factors

This section outlines the rationale for the selection of emission factors. Woodburner $PM_{10}$ emissions are updated based on the results of recent emission testing carried out in New Zealand. Emission factors for other burners and other contaminants are updated based on review of international emission factors.

## 4.1 Woodburner $PM_{10}$ emission factors

There has been considerable research to determine real-life $PM_{10}$ emission factors from NES woodburners and older woodburners since the publication of the previous (ARC 2006a) emission inventory (Scott, 2005; EW, 2006; MfE, 2007; NIWA, 2008; ARC 2010a). The emission factors reported by these studies are summarised in Table 4-1 below.

The first in-home testing of low emission woodburners in New Zealand (Scott, 2005) reported a mean emission rate of 10.8g/kg (wet weight). Due to the small sample size it was concluded that an emission factor could not be derived for the four woodburners tested, and it was uncertain how representative the emissions were of the residential wood burning population as a whole. However, it was also concluded that the data does provide a general indication of the range of emissions that may be discharged from "low emission" appliances as they are operated in homes. Subsequent studies of in-home or real-life emissions from NES woodburners have consistently reported results of around 4 g/kg. For the 2006 inventory, the ARC emission factor of 3.7g/kg (wet weight) is used for NES woodburners based on emissions tests undertaken by the ARC (ARC, 2010a).

The ARC result for the pre-1994 woodburner (ARC, 2010a) is much lower than those from older woodburners from other tests (Scott, 2005; EW, 2006). However, only one woodburner was tested and this may not be representative of a typical older woodburner. For the 2006 inventory, the Environment Waikato results (EW, 2006) have been used for pre-1994 woodburners.

There is limited information on real-life emissions from woodburners between 1994 and 2005 so a mid-point between pre-1994 woodburners and NES woodburners of 7.2g/kg is assumed. This is similar to the emission factors assumed in the 2004 emission inventory (ARC, 2006a).

Table 4-1: Real life $PM_{10}$ emissions factors for woodburners[1]

| | Emission factor (g/kg, dry weight) | Emission factor (g/kg, wet weight) | Number of woodburners tested | Total number of tests |
|---|---|---|---|---|
| Pre-1994 woodburners (EW, 2006) | 14. (±5.3) | 10.7 (±4.1) | 12 | 95 |
| Pre-1994 woodburners (ARC, 2010a) | 6.5 | 4.7 (±1.0) | 1 | 60 |
| NES woodburners[2] (Scott, 2005) | 15.5 | 10.8 | 4 | 43 (Stage III) |
| NES woodburners (MfE, 2007) | 4.65 (±2.0) | 3.6 (±1.0)[3] | 9 | 60 |
| NES woodburners (NIWA, 2008) | 4.7 | 3.3 (±2.4) | 18 | 120 |
| NES woodburners (ARC, 2010a) | 5.2(±1.0) | 3.7 (±0.7) | 2 | 95 |

## 4.2 Open fire emission factors

While there has been considerable research on real-life emissions from woodburners in New Zealand, there is very limited information available on emissions from open fires. Previous emission inventories have relied on USEPA (AP42) emission factors combined with some very limited Australasian test results. A comprehensive review of AP42 emission factors has recently been published in the US by the Mid-Atlantic Regional Air Management Association (Houck and Eagle, 2006). The review noted that, while some of the emission factors tabulated in AP-42 were used, new sources of data were also used as the AP-42 data lack currency and are limited. The Houck and Eagle emission factors for uncertified and certified cordwood heaters compare reasonably well with the pre-1994 and NES woodburner emission factors used in the 2006 inventory. The emission factors for "fireplaces without inserts burning cordwood" are used in the 2006 inventory for open fires. They are divided by 1.2 to convert to wet wood basis (assuming 20 per cent wood moisture content). The Houck and Eagle emission factors have also been adopted for open fires in the most recent inventory of emissions to air in Christchurch (ECAN, 2008).

[1] Results are reported with a 95% confidence interval where available. In some cases, the confidence interval was not available in the original report.
[2] This study concluded that an emission factor could not be derived for the burners tested; however the result is included here in the information.
[3] This has been calculated based on raw data as the wet weight emission factor is not reported in MfE (2007).

## 4.3 Pellet fire emission factors

Emission factors from Houck and Eagle have been adopted for pellet fires. The $PM_{10}$ emission factor of 1.5g/kg (dry weight, or approximately 1.4 on a wet weight basis assuming 10 per cent pellet moisure content) compares well with the results of real-life emission testing of pellet burners in Tokoroa (MfE, 2007b). The MfE study reported an average emission factor of 1.4 g/kg for three of the burners tested (wet weight, or approximately 1.5 g/kg dry weight assuming 10 per cent pellet moisture content). Inclusion of the one faulty burner that was tested during the study increased the average emission factor to 3.9g/kg (or 4.3g/kg dry weight). It is unlikely that one in four pellet burners would be faulty, so an emission factor of 1.4g/kg is considered reasonable.

## 4.4 Coal emission factors

Emission factors for combustion of coal in open fires and woodburners are the same as those used in the Christchurch 2006 Inventory (ECAN, 2008).

## 4.5 Emission factors for other contaminants

VOC emission factors are based on those from the previous inventory (ARC 2006a). $CO_2$ emission for wood are based on the residential wood emission factor from the New Zealand Greenhouse Gas Inventory[1]. Emission factors for all other species are the same as the Christchurch 2006 Inventory (ECAN, 2008).

## 4.6 Summary of emission factors

The emission factors used in this report are summarised in Table 4-2.

[1] Wood residential emission factor = 104.2 kt $CO_2$/PJ. Assuming a calorific value of 20.2 MJ/kg (pine), emission factor = 2105 g per kg of dry wood. This is equivalent to approximately 1800g/kg on a wet weight basis.

Table 4-2: Domestic fire emission factors (g/kg, wet weight) for different pollutants

| Appliance | $PM_{10}$ | CO | $NO_x$ | $SO_2$ | VOC | $CO_2$ |
|---|---|---|---|---|---|---|
| Open fire (wood) | 12 | 63 | 1.2 | 0.2 | 30 | 1800 |
| Open fire (coal) | 21 | 70 | 4.1 | 5.1 | 15 | 2600 |
| Pre-1991 woodburners | 10.7 | 110 | 1.0 | 0.2 | 39 | 1800 |
| 1991-2004 woodburners | 7.2 | 70 | 0.5 | 0.2 | 21 | 1800 |
| NES woodburners | 3.7 | 30 | 0.5 | 0.2 | 15 | 1800 |
| Multifuel-wood | 10.7 | 110 | 1.0 | 0.2 | 39 | 1800 |
| Multifuel-coal | 19 | 110 | 1.6 | 1.1 | 15 | 2600 |
| Pellet fire | 1.4 | 7.4 | 1.8 | 0.2 | 0.02 | 2000[1] |

[1] $CO_2$ emission factors for pellet burners are based on the assumption that pellets are 10 per cent moisture, compared to 20 per cent assumed for wood.

# 5 Home heating fuel use

This section outlines the estimation of fuel use, which is based on survey results as well as the results of other studies. The estimated amount of fuel used per appliance per day is summarised in Table 5-1.

## 5.1 Wood

In order to calculate the amount of wood burned per day in winter, the following formula is used:

*Fuel use (kg/appliance/day) = H (hour/appliance/day)* BR (kg/hour)* DW/7*

*Where:*

*H= average number of hours an appliance is used per day,*

*BR = average burn rate of appliances,*

*DW=average number of days per week an appliance is used in winter*.

The average burn rate of a woodburner is estimated at around 3.4kg/hour for woodburners based on the results of ARC woodburner testing (ARC, 2010a), and 4.2kg/hour for open fires based on the ECAN diary survey (ECAN, 2007). Survey results showed that open fires were used 4 hours a day for 4 days a week, on average. This compares with an average of 6 hours a day for 5 days a week for woodburners. Therefore, the average fuel use across all areas is estimated at 14 kg for woodburners and 10kg for open fires, for a winter weekday. Survey results show that appliance use is higher during weekends with open fires being used for an average of 6 hours a day, and woodburners for 8 hours a day. This results in average weekend fuel use estimates of 20kg for woodburners and 13kg for open fires, for a winter weekend day.

The diurnal variation of fuel use is assumed to be the same as the 1996 inventory (ARC, 1998), with approximately 80% of fuel consumption occuring in the evening between 4pm and 10pm.

In the 2004 inventory (ARC, 2006a), daily fuel use was estimated based on average log weight and number of logs burnt per day (from the 2002 home heating survey). To allow for direct comparison of results, fuel use has also been estimated based on this methodology for the 2007 home heating survey results (ARC 2010b). The home heating survey report estimates daily wood use based on pieces of wood (from the diary

survey) as 1745 tonnes per day and based on number of hours of burning (from the phone survey) as 1730 tonnes per day. These estimates are in very good agreement, providing confidence in the methodology.

## 5.2 Coal

The 2007 home heating survey (ARC 2010b) suggested that 2% of households across the region burn coal (equivalent to approximately 8000 households). This compares to the Census, which suggests that 3.9% of households burn coal (approximately 17,000 households). The home heating survey sample size for coal burning is relatively small at 133 households. To estimate emissions for the 2006 inventory, the number of households burning coal is based on the Census data. Census data is more accurate than the survey, and provides the basis for spatially allocating emissions.

Household coal consumption is estimated at 1740 tonnes/annum based on sales information provided by Solid Energy NZ Ltd[1]. Solid energy are the major supplier of coal to the Auckland domestic market and are confident that this estimate is robust. This sales estimate equates to approximately 100 kg per household per annum based on the number of households burning coal from the Census.

Average houshold coal use is estimated from the survey as 0.75 buckets of coal per day. In previous inventories, a bucket of coal has been assumed to be 9 kg, and it has been assumed that coal is burnt on all days that the fire is used. This equates to approximately 675 kg per household per annum and results in overestimation of coal consumption at 11,475 tonnes per annum compared to the sales estimate of 1,740 tonnes per annum. The sales estimate should be reliable. The overestimate may be due to one or a combination of factors:

- Anecdotally, coal is used to generate additional heat when burning damp firewood, or on colder nights. This means that people who burn coal may only do so on occasion when supplementary heat is required.
- Daily coal use (or the size of a "bucket") may be lower in Auckland compared to colder climates, because less supplementary heat is required.

To ensure that overall coal consumption is not over-estimated, it is assumed that:

- Coal consumption is 9 kg/day for households that burn coal exclusively. This is based on the assumption that "exclusive" coal users are not influenced by the factors discussed above, and will use a "bucket" per day as indicated by the survey.

[1] Pers comm. From Peter Friar at Solid Energy. 3 September 2008.

- Coal consumption is 1.3 kg/day for households that burn wood and coal. This is "back calcuated" from the 1740 tonnes sales estimate after accounting for consumption by exclusive coal users.

Actual coal consumption on any particular day could be significantly higher, because it is likely that more coal will be burnt on cold days, rather than a small amount being burnt every day.

## 5.3 Fuel use in households burning wood and coal

Survey results indicate that households burning wood and coal consume slightly less wood than households that burn wood exclusively. Since there were only 125 survey responses from households burning wood and coal for the entire region, there is an uncertainty in the estimate of fuel consumption based on the survey results.

For households that burn wood and coal, the estimated amount of wood burnt per day has been reduced according to the energy content of the coal, so that the overall energy consumption is approximately the same as a household burning wood exclusively in each area[1].

## 5.4 Daily fuel use

The estimated amount of fuel burnt per appliance per day in winter is shown in Table 5-1 below.

**Table 5-1: Fuel consumption by area (kg/appliance/day).**

| | | Survey area | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| wood only - weekday | | | | | | | | | | | |
| Woodburner/multifuel | wood | 13 | 19 | 14 | 12 | 10 | 12 | 15 | 17 | 11 | 19 |
| open - wood | wood | 9 | 14 | 12 | 7 | 7 | 9 | 14 | 17 | 9 | 14 |
| Pellet | wood | 5 | 7 | 5 | 4 | 4 | 5 | 6 | 6 | 4 | 7 |
| | | wood only - weekend | | | | | | | | | |
| Woodburner/multifuel | wood | 19 | 22 | 19 | 16 | 14 | 17 | 21 | 24 | 16 | 24 |
| open - wood | wood | 14 | 18 | 15 | 11 | 10 | 12 | 17 | 22 | 12 | 18 |
| Pellet | wood | 7 | 8 | 7 | 6 | 5 | 6 | 8 | 9 | 6 | 9 |

[1] The energy content of coal is estimated at 22 MJ/kg and wood as 10 MJ/kg based on solid fuel characteristics provided in the Energy Data File (MED, 2009).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | wood and coal - weekday | | | | | | | | | |
| Woodburner/multifuel | wood | 11 | 17 | 12 | 10 | 8 | 10 | 13 | 14 | 10 | 16 |
| open fires | wood | 7 | 12 | 11 | 6 | 6 | 7 | 13 | 15 | 7 | 12 |
| Woodburner/multifuel | coal | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| open fires | coal | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | wood and coal - weekend | | | | | | | | | |
| Woodburner/multifuel | wood | 17 | 20 | 16 | 14 | 11 | 15 | 18 | 21 | 14 | 21 |
| open fires | wood | 12 | 16 | 12 | 10 | 8 | 10 | 15 | 19 | 10 | 16 |
| Woodburner/multifuel | coal | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| open fires | coal | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | coal only weekday | | | | | | | | | |
| open fires coal | coal | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 6 | 4 | 6 |
| multifuel coal | coal | 7 | 7 | 6 | 6 | 6 | 7 | 7 | 7 | 6 | 7 |
| | | coal only weekend | | | | | | | | | |
| open fires coal | coal | 8 | 7 | 6 | 7 | 5 | 6 | 6 | 8 | 6 | 8 |
| multifuel coal | coal | 9 | 8 | 8 | 8 | 8 | 10 | 9 | 10 | 9 | 9 |

## 5.5 Annual fuel use

Annual fuel use has been estimated based on seasonal variations from the 2002 home heating survey (Wilton, 2002). To calculate annual emissions, emissions for July are estimated based on estimated daily fuel consumption. Emissions for other months are then calculated based on the seasonal variations shown in Table 5-2 The seasonal variation for multifuel burners and pellet burners is assumed to be the same as for woodburners.

Table 5-2: Seasonal variation in fuel use.

| | Proportion of annual fuel consumption by month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Woodburner/multifuel/pellet | 0% | 0% | 0% | 1% | 11% | 24% | 29% | 28% | 6% | 1% | 0% | 0% |
| open fire | 0% | 0% | 1% | 1% | 10% | 20% | 31% | 28% | 7% | 1% | 0% | 0% |

# 6 Woodburning trends and projections

Recent trends in woodburner emissions and ambient air quality are discussed in this section. The DFEPM business as usual (BAU) projection of likely burner numbers and emissions is based on the assumption that recent trends continue. This section summarises other key assumptions for the BAU projection.

## 6.1 Recent trends

Recent trends in heating have been taken as a starting point for prediction of future trends. Census data, illustrated in Figure 6-1, shows that while dwelling numbers have increased, the number of dwellings heated by wood has decreased over the past ten years. For the Auckland Urban airshed, census data shows that the number of households using wood for heating reduced by approximately eight per cent between 2001 and 2006. Survey area 10 (Rodney) is the only area where the overall use of wood increased between 2001 and 2006.

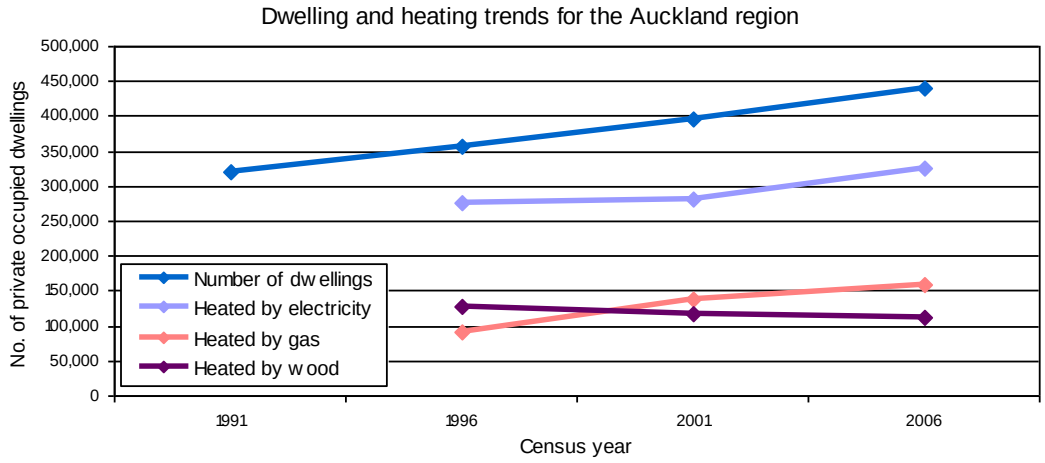



Figure 6-1: Dwelling and heating trends for the Auckland region (source: ARC 2010b)

The number of appliances of each type and age for 2001 and 2006 have been estimated based on survey results and census data as reported in Section 2.3. Trends in the number of old woodburners (pre-2005), open fires and NES woodburners (post 2005), are illustrated in

Figure 6-2, which shows an overall reduction. Appliance numbers for each type, age group, and each of the 10 survey areas are provided in Appendix 1. In most areas, survey results indicate that the number of open fires, multifuel burners and older (pre-

1991) woodburners has reduced while the number of newer woodburners has increased between 2001 and 2006.

Figure 6-2 illustrates the effect on $PM_{10}$ emissions of reduced woodburner numbers and the introduction of NES woodburner standards. According to this estimate, woodburner emissions have reduced by approximately 13 per cent from 2001 to 2006.

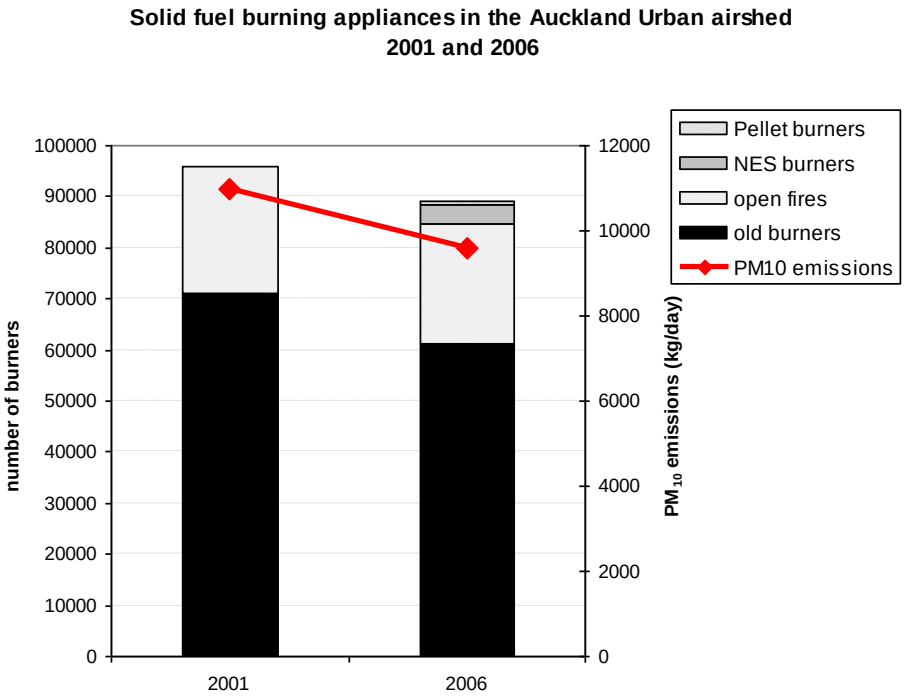



Figure 6-2: Woodburner numbers in 2001 and 2006

Note that, although it is estimated that domestic fire emissions have reduced by 13 per cent between 2001 and 2006, Figure 6-3 shows that annual average $PM_{10}$ levels at Auckland residential monitoring sites have been relatively stable between 2001 and 2006. This is not unexpected, as the estimated reduction in emissions is relatively modest. Ambient air quality is affected by a wide range of factors, including meteorology and other emission sources.

In other regions substantial reductions in domestic heating emissions have resulted in measurable improvements in ambient air quality. For example, Nelson and Christchurch have implemented clean heat programmes, which have significantly improved air quality. In Nelson, ambient monitoring of the Victory Square airshed shows that pollution maximums are getting smaller, and tend to be less than half of what they

were eight years ago[1]. In Christchurch, a detailed analysis of ambient air quality monitoring results suggests that emissions have reduced by approximately 3 to 4% per annum between 1999 and 2006 (NIWA, 2007).

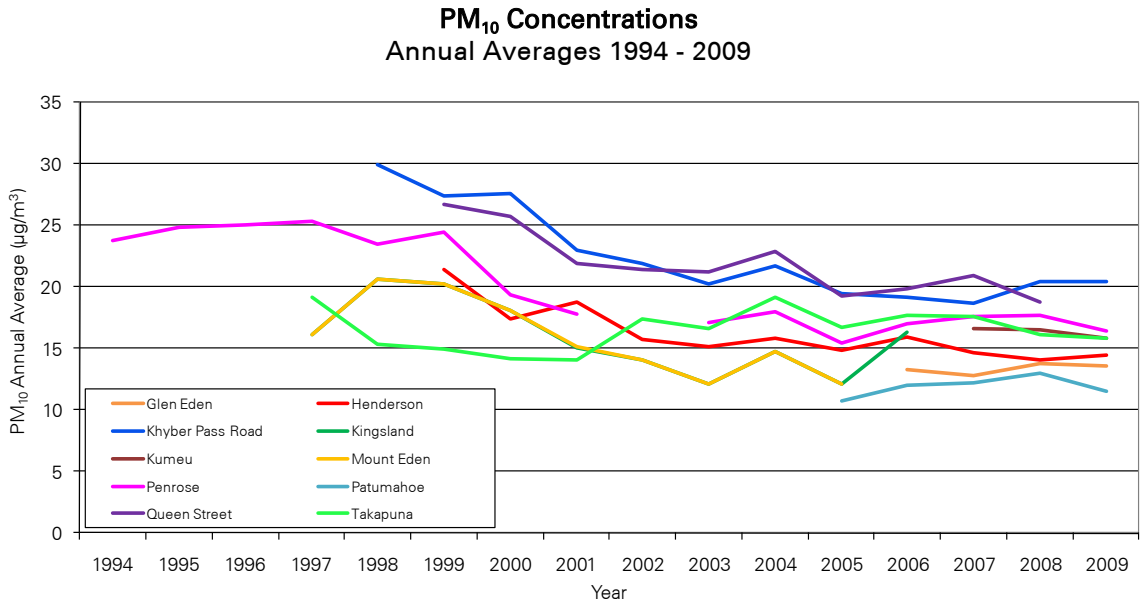



Figure 6-3: Annual average $PM_{10}$ concentrations in Auckland

## 6.2 Key assumptions for business as usual projection

The business as usual projection in DFEPM is based on continuation of the observed change in burner types and numbers between 2001 and 2006. Key assumptions for BAU are summarised as follows:

- The rate of retirement of each burner type is based on the change in burner numbers between 2001 and 2006. The rate of burner retirement remains constant as a proportion of total woodburner numbers.
- The rate of installation of new woodburners is based on the the average rate of woodburner installation since 1991 (1/15$^{th}$ of post 1991 woodburner numbers at 2006). The number of post 1991 woodburners retired and replaced is also accounted for based on the proportion of woodburners replaced at less than 15 years old (from 2007 home heating survey results).
- The oldest woodburners are retired first. In areas with relatively slow retirement, this effectively means that the oldest woodburners are approximately 30 years old.

[1] From the Nelson City Council website, August 2010. (www.nelsoncitycouncil.co.nz/air-monitoring/

In areas with fast retirement rates, the oldest woodburners are approximately 20 years old. The 2007 survey (ARC 2010b) found that 4 per cent of woodburners are older than 30 years old, so these results appear to be realistic.

- The pellet burner installation rate is based on the average installation rate between 2001 and 2006 assuming that all existing burners were installed during this period. The 2007 survey (ARC 2010b) found that 13% of pellet burners are less than 2 years old, with the remainder being 2-15 years old.
- No new multifuel burners or open fires are installed. Multifuel burners and open fires are not allowed in urban areas under the rules of the PARP:ALW. There may be some installations in rural areas, however these are unlikely to have a significant effect on overall burner numbers or emissions and will not be significant in the urban airshed.
- In some areas, estimated burner numbers do not follow expected trends. Specific assumuptions for there areas are discussed in Appendix: 2.

# 7 Results

Estimated solid fuel burning appliances and $PM_{10}$ emissions for 2006 are described in this section. The results of the BAU scenario prediction of likely future burner numbers and $PM_{10}$ emissions from DFEPM are also described.

## 7.1 2006 results

$PM_{10}$ emissions from domestic fires are estimated based on the methodology described in Section 2 by the following equation:

*Emission (g) = number of appliances x emission factor (g/kg fuel used) x fuel use (kg)*

Based on the appliance data in Section 3, emission factors in Section 4.6 and fuel use information in Section 5, it is estimated that there were approximately 78,000 old woodburners (pre-2005), 26,000 open fires, 4500 NES woodburners (post-2005) and 900 pellet burners in the Auckland region in 2006 (Figure 3-1a). Emissions of $PM_{10}$ from these burners are estimated at approximately 13 tonnes per winter day (Figure 7-1a), or appproximately 1300 tonnes per annum. In the Auckland urban airshed it is estimated that there are approximately 61,000 old woodburners, 23,000 open fires, 3,800 NES woodburners, and 700 pellet burners with $PM_{10}$ emissions of approximately 10 tonnes per winter day (Figure 7-1b).

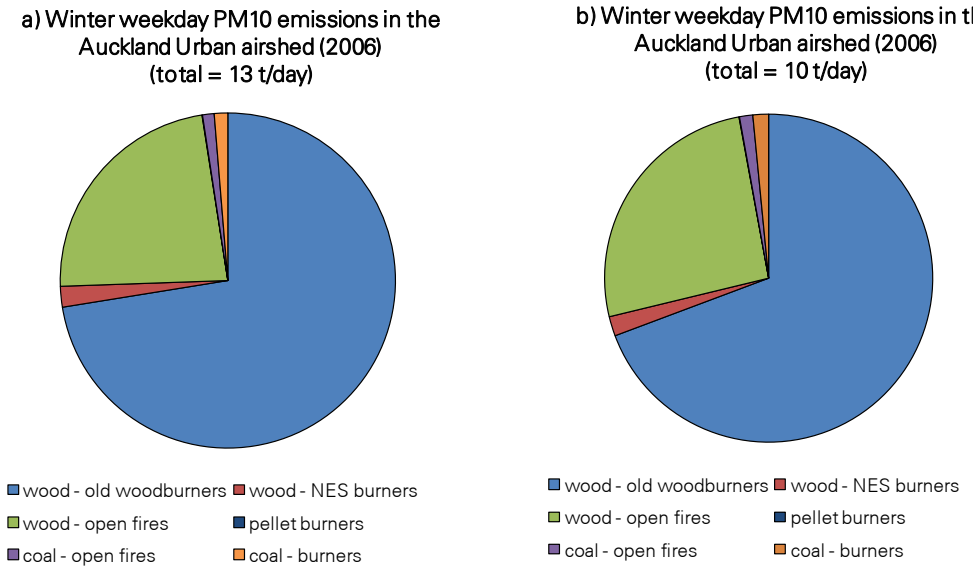



Figure 7-1a): estimated $PM_{10}$ emissions in the Auckland region, and b): estimated $PM_{10}$ emissions in the Auckland urban airshed

## 7.2 Business as usual projection

The BAU projection to 2031 for the Auckland urban area is illustrated in Figure 7-2. This shows that under the BAU projection, $PM_{10}$ emissions gradually reduce as old woodburners are retired, and new lower emission NES burners are installed. Under BAU it is estimated that:

- There are approximately 3900 burner retirements/annum in the Auckland Urban airshed. This comprises of approximately 2500 woodburners, 600 multifuel burners and 800 open fires.
- There are approximately 3000 woodburner installations/annum in the Auckland Urban airshed. This comprises of approximately 1300 replacements of existing (retired) open fires or woodburners, 600 woodburners into existing houses without woodburners and 1100 into new houses.
- There are approximately 9,000 – 10,000 new houses per annum in the Auckland region, so the installation rate in new houses is around 10 per cent on average.
- The number of households burning wood drops to around 85% of 2006 numbers and then remains stable. This is broadly consistent with the home heating survey results, which suggest that 83% of households are not considering changing from solid fuel burning.

It is important to note that current trends may not continue. The rate of reduction in emissions will be much slower if there is a reduction of the rate of conversion from wood to other fuels, or in the rate of replacement of older woodburners. It should also be noted that:

- Emissions could potentially increase in some high growth areas because there are no restrictions on the number of installations of new woodburners.
- The rate of reduction in emissions is sensitive to the emission factor assumed for NES woodburners. Evidence suggests that emissions from NES woodburners are probably lower than old ones, but there is considerable uncertainty.
- To have greater certainty in the emissions reductions we should move to technology with better emission control, such as pellet burners.
- The degradation of NES woodburners over time has not been considered. This could become an important factor if significant numbers of NES woodburners are installed without any "in-service" requirements or age limits.

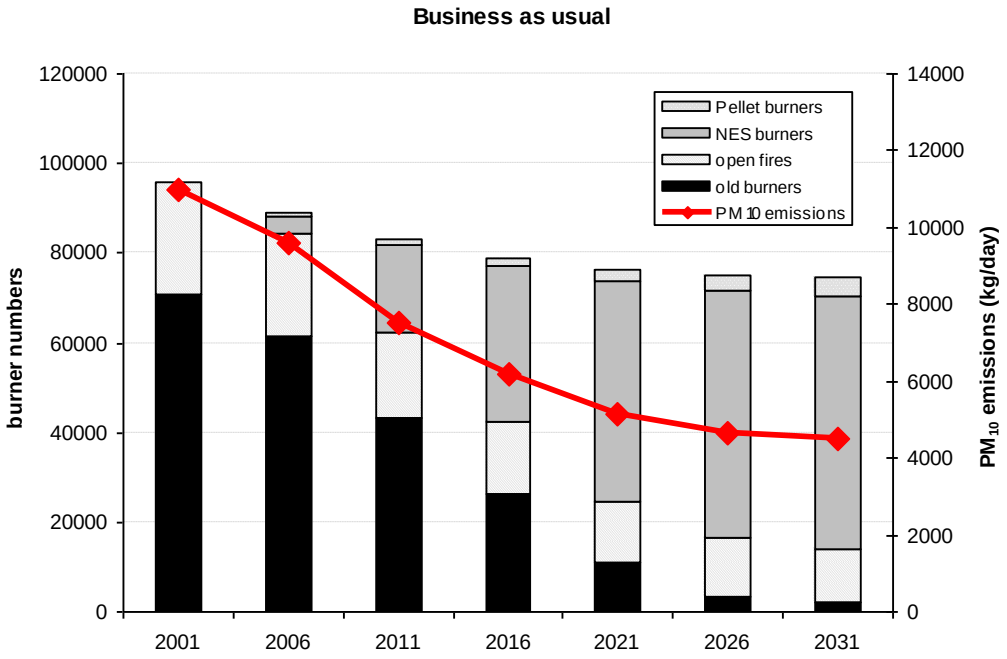



Figure 7-2: Business as usual emission prediction assuming that current trends continue

## 7.3 Sensitivity analysis

Sensitivity analysis has been undertaken for the BAU projection (see Appendix: 3). Key assumptions for the BAU scenario are unchanged for the sensitivity analysis scenarios. So, for the sensitivity analysis it is assumed that current trends continue, and old woodburners are gradually replaced with newer burners. Within this BAU scenario there is uncertainty associated with the rate of change of emissions due to uncertainty in:

- The rate of change of open fire and woodburner numbers.
- The difference of emission factors between old and new woodburners.

The analysis has demonstrated that the extent of $PM_{10}$ emission reduction in the long term is most sensitive to the emission factor that is assumed for NES woodburners. The analysis also shows that the shorter term rate of emission reduction reduction is sensitive to the rate of woodburner retirement. It is important that any policy analysis takes these conclusions into consideration, particularly if the policy is intended to meet an emission reduction target by a certain date.

- A realistic range of assumptions has been developed for sensitivity analysis of these assumptions. These will need to be considered in the development of any policy to achieve emission reduction targets.

# 8 Comparison with previous inventory and projections

Some of the assumptions and methodology for the 2006 emission estimate and predictions are different to previous reports. This means that the results in this report are not directly comparable with previous inventories. However, this section provides a comparison with the previous inventory (ARC 2006a) and previous projections (Wilton, 2004). The key reasons for differences in the estimates are identified.

## 8.1 Comparison with 2004 Inventory

Table 8-1 compares the 2004 domestic fire emissions in the 2004 inventory (ARC, 2006a) and those recalculated by using the methodology outlined in this report.

Table 8-1: Comparison of 2004 $PM_{10}$ emission estimates for the Auckland region (tonnes/winter weekday).

| | 2004 inventory | 2004 emissions recalculated |
|---|---|---|
| Emissions from wood burning | 15.4 | 13.5 |
| Emissions from coal burning | 2.7 | 0.3 |
| Total domestic fire emissions | 18.1 | 13.8 |

Wood consumption estimates and emission factors are similar for the two estimates. Table 8-2 compares the $PM_{10}$ emission factors used in this report and the 2004 inventory (ARC 2006a).

The key difference between the two estimates of 2004 emissions is the number of householders using wood and coal for heating. The 2004 inventory estimated the number of householders burning wood or coal as 160,000 based on survey results. However, the number of householders burning wood or coal is now estimated at approximately 114,000 in 2004 based on interpolation of 2001 and 2006 Census data.

Table 8-2. Emission factors (g/kg, wet weight) used in this report and the 2004 inventory.

| Appliance | This report | 2004 inventory |
|---|---|---|
| Open fire (wood) | 12.0 | 15 |
| Open fire (coal) | 21.0 | 33 |
| Pre-1991 woodburner | 10.7 | 13 |
| 1991-1996 woodburner | 7.2 | 7 |
| 1997-2004 woodburner | 7.2 | 6 |
| NES woodburner | 3.7 | 3 |
| Multifuel-wood | 10.7 | 13 |
| Multifuel-coal | 19.0 | 28 |
| Pellet fire | 1.4 | Not available |

## 8.2 Comparison with previous projections

Domestic heating projections were carried out in a previous study for a range of scenarios based on the 2001 survey results (Wilton, 2004). The key difference for current projections is that these are based on observed trends between two surveys and census data. The previous projections (Wilton, 2004) were based on a number of assumptions about the expected rate of retirement and installation of woodburners based on census data and the 2001 survey only.

The previous projections included a scenario similar to the current business as usual, where all new woodburners were to meet 1.5g/kg emission factor from 2005. The projections of this scenario is compared to the current business as usual projections. For the purpose of comparison, business as usual emissions are also recalculated by using the emission factors in the previous projections. The difference between the current and previous emission factors are shown in Table 8-3. Current projections are based on a constant emission factor for all woodburners from 1991 – 2004, so an average of 6.5g/kg has been assumed for this comparison.

Table 8-3. Emission factors for current projections which are different for previous projections.

| Appliance | Current projections | Previous projections |
|---|---|---|
| Open fire (wood) | 12.0 | 10 |
| Pre-1991 woodburner | 10.7 | 13 |
| 91-96 woodburner | 7.2 | 7 |
| 1997-2004 woodburner | 7.2 | 6 |
| NES woodburner | 3.7 | 3 |
| Multifuel-wood | 10.7 | 8 |

The reduction in $PM_{10}$ emissions as a percentage of 2001 emissions is shown in Table 8-4 for current and previous projections. The previous projections predicted a 65 per cent reduction in $PM_{10}$ emissions by 2021. This compares with the current BAU prediction of 44 per cent by 2021. This difference is partly due to the different emission factors assumed. The current BAU projection predicts an emission reduction of 51 per cent by 2021 using the emission factors from the previous projection. However, this predicted rate of reduction is still significantly slower than predicted by Wilton (2004), because the observed rate of retirement of older woodburners and open fires (based on survey results) is lower than previously assumed.

Table 8-4. Comparison of current projections with previous projections.

| | Predicted $PM_{10}$ tonnes/winter weekday (% reduction compared to 2001) | | | |
|---|---|---|---|---|
| | 2001 | 2007 | 2013 | 2021 |
| Previous projections[1] | 19.9 | 13.3 (33%) | 9.6 (52%) | 7.0 (65%) |
| Current projections (BAU, entire region) with the same emission factors as in previous projections | 13.8 | 12.2 (12%) | 9.0 (35%) | 6.8 (51%) |
| Current projections (BAU, entire region) | 14.1 | 12.7 (10%) | 10.2 (28%) | 8.0 (44%) |

[1] These results are for the scenario assuming all new burners have an emission factor of 3g/kg from 2005 (the 1.5g/kg burners scenario) (Wilton, 2004), which is similar to BAU in the current projections.

# 9 Discussion and Recommendations

There is a significant improvement in domestic fire emission estimates for 2006 in comparison to those for the previous inventory. Key improvements are summarised as follows:

- The total number of householders burning wood or coal is based on the Census, which is a survey of all households. Previous inventories were based on home heating survey results, which includes a relatively small sample size.
- The type of solid fuel burning appliances has been estimated based on the results of the 2007 home heating survey (ARC 2010b). This survey had a significantly larger sample size compared to previous surveys resulting in smaller margins of error.
- The home heating survey (ARC 2010b) estimates the amount of fuel burnt per winter weekday by two different methods. Daily wood use is estimated at 1745 tonnes per day based on the estimated number of pieces of wood burnt per day (from the diary survey) and as 1730 tonnes per day based on the estimated number of hours of burning per day (from the phone survey). These estimates are in very good agreement, providing confidance in the methodology. The first method relies on the assumption that the weight of an average piece of wood is 1.45 kg, which is estimated from the results of the diary survey. The second method relies on the assumption that a woodburner consumes 3.4kg of wood per hour on average. The hourly fuel consumption rate is based on the results of ARC woodburner emission testing (ARC 2010a), as well as the home heating diary survey (which estimated a similar average fuel consumtption rate of 3.5kg/hour.
- Emission factors are based on the wood burner testing undertaken by the ARC. This study has quantified emissions from woodburners under a range of conditions. This study, along with a number of other "real life" emission testing studies undertaken in New Zealand, provide increased confidence that the emission factors selected are representative of real world woodburner emissions.
- Emission projections are based on analysis of trends between the 2001 and 2007 home heating surveys. This provides a real measure of the rate of installation and retirement of solid fuel burning appliances. Previous projections were based on assumptions about the rate of appliance turnover.

### Recommendations

To improve certainty in emission estimates and projections, recommendations include:

- Repeat the home heating survey and update projections at least for every census year. The survey should have similar sample size and methodology to the 2007 survey, to ensure continuity and comparability of results. Additional questions

should be considered to improve our understanding of unused open fires or woodburners (why aren't they used, and what type of appliance are they).

- Track woodburner and open fire installations and removals through the building consent process. This will improve certainty in the number and types of new appliances being installed.
- Implement a regular and comprehensive real-life emission testing programme for NES compliant wood burners. This programme should test the performance of older NES woodburners to check how their performance changes over time as well as new models being introduced into the market.
- Undertake sensitivity analysis for quantitative evaluation of any policy to reduce emissions from domestic fires. The variables considered in Appendix: 3 provide a basis for this analysis.

# 10 Conclusions

Based on the findings of this report, the following overall conclusions can be made about the current state of domestic fire emissions in the Auckland region:

- It is estimated that there are approximately 61,000 old woodburners (pre-2005), 23,000 open fires, 3,800 NES woodburners (post-2005), and 700 pellet burners. In most areas survey results indicate that the number of open fires, multifuel burners, and older (pre-1991) woodburners has reduced while the number of newer woodburners has increased between 2001 and 2006. In addition to the reduced woodburner numbers was the introduction of NES woodburner standards, which together saw emissions reduced by approximately 13 per cent over this period.
- Based on appliance data, emission factors, and fuel use information, emissions of $PM_{10}$ from woodburners in the Auckland region in 2006 are estimated to be approximately 13 tonnes per winter day. In the Auckland urban airshed, $PM_{10}$ emissions are estimated to be approximately 10 tonnes per winter day.
- Under the BAU projection model, emissions of $PM_{10}$ gradually reduce as old woodburners are retired. However, emissions could potentially increase in high growth areas because there are no restrictions on the number of installations of new woodburners.
- There is some uncertainty associated with emission estimates. Sensitivity analysis has demonstrated that the the extent of $PM_{10}$ emission reduction is sensitive to the emission factor that is assumed for NES woodburners. The analysis also shows that the short term rate of emission reduction is sensitive to the rate of woodburner retirement.
- The assumptions used for sensitivity analysis also need to be considered in the development of any policy to achieve emission reduction targets, in particular the rate of wood burner retirement.

# 11 References


ARC, (1998). Auckland Air Emissions Inventory. 1996. Prepared by the Environment Protection Authority (Victoria) for the Auckland Regional Council. July 1997. Auckland Regional Council Technical Publication No.91

ARC, (2006a). *Auckland Air Emissions Inventory: 2004*. Prepared by J. Metcalfe, G. Fisher, M. Sherman, and G. Kuschel for the Auckland Regional Council, February 2006. Technical Report 292.

ARC, (2006b). *Review of Home Heating Surveys and Trends in Fuel Use*. Prepared by M.J. Stewart, July 2006.

ARC, (2006c). *Home Heating Survey Recommendations*. Prepared by M.J. Stewart, July 2006.

ARC, (2009). *Auckland Sustainable Homes Assessment: Part 1 Insulation and Clean Heat Appliances*, Prepared by B Parfitt, G Kuschel and S Sridhar for the Auckland Regional Council. Technical Report 2009/052

ARC, (2010a). *Effects of fuel and operation on particulate emissions from woodburners*, Prepared by S Xie for the Auckland Regional Council. REPORT IN DRAFT.

ARC, (2010b). *Auckland Home Heating Survey 2007,* Prepared by R. Arsilan, K. Webster and J. Petersen for the Auckland Regional Council. Technical Report 2010/007.

ECAN, (2001). *Christchurch inventory of emissions 1999*. Prepared by Emily Wilton for Environment Canterbury. Environment Canterbury Report R01/28.

ECAN, (2007). *Christchurch home panel diary 2006*. Prepared by Charles Lamb for Environment Canterbury. Environment Canterbury Report U07/17

ECAN, (2008). *Inventory of Emissions to Air in Christchurch, 2006*. Prepared by John Smithson for Environment Canterbury. Environment Canterbury Report R08/70.

EW, (2006). *Real Life Emissions Testing of Pre 1994 Woodburners in New Zealand*, Prepared by Emily Wilton, and Jeff Smith for Environment Waikato. Environment Waikato Technical Report 2006/05.

Houck and Eagle, (2006). *Control Analysis and Documentation for Residential Wood Combustion in the MANE-VU Region, Technical Memorandum 4 (Final Report)*, Prepared by J. E. Houck and B. N. Eagle for Mid-Atlantic Regional Air Management Association, Inc.

MfE, (2007a). *Real-Life Emissions Testing of Woodburners in Tokoroa*. Prepared by Colleen Kelly, Suri Mues and Wayne Webley for Ministry for the Environment. Warm Homes Technical Report.

MfE, (2007b). *Real-Life Emissions Testing of Pellet Burners in Tokoroa*. Prepared by Colleen Kelly, Suri Mues and Wayne Webley for Ministry for the Environment. Warm Homes Technical Report.

NIWA, (2007). *Using air quality to track progress toward $PM_{10}$ standards: Case study – Christchurch: 1991-2006*, Report prepared for Foundation for Research Science and Technology, November 2007.

USEPA AP 42 (1995), Fifth Edition, *Volume I Chapter 1: External Combustion Sources*. *Section 1.9, Residential Fireplaces and Section 1.10 Residential WoodStoves*, Supplement B, October 1996

Wilton, (2002). *Auckland Domestic Heating Inventory 2001*. Unpublished report prepared by E. Wilton for Auckland Regional Council.

Wilton, (2004). *Domestic Heating projections in Auckland 2001-2021*, Unpublished report Prepared by E. Wilton for Auckland Regional Council.

# 12 Glossary

| Terms | Description |
|---|---|
| Airshed | A geographic area established to manage air pollution within the area as defined by the AQNES |
| AQNES | National Environmental Standards for Air Quality |
| BAU | Business as usual |
| CO | Carbon monoxide, a type of air pollutant |
| $CO_2$ | Carbon dioxide, a type of greenhouse gas |
| DFEPM | Domestic fire emission prediction model |
| Multifuel burner | A fully enclosed domestic heating device that is designed for burning coal as well as wood |
| NES woodburner | A woodburner that complies with the Design Standard for New Woodburners specified by the AQNES |
| $NO_2$ | Nitrogen dioxide, a type of air pollutant |
| Open fire | An indoor heating device capable of burning wood or coal, including fireplaces, open hearths and visors. Excludes enclosed heating devices such as woodburners, pot belly stoves and the like. |
| PARP:ALW | Proposed Auckland Regional Plan: Air Land and Water |
| Pellet burner | An indoor heating device that burns pellets of compressed wood sawdust, and where the pellets and air are mechanically delivered to an enclosed combustion chamber at a controlled rate. |
| $PM_{10}$ | Fine particles less than 10 microns in diameter, a type of air pollutant |
| RMA | Resource Management Act |
| VOC | Volatile Organic Compounds, a type of air pollutant |
| Woodburner | A fully enclosed domestic heating device designed for burning wood as defined in the AQNES |

# Appendix: 1 Uncertainty in fuel consumption and emission factors

The previous inventory (ARC 2006a) identified that there was significant uncertainty in fuel usage estimates, and emission factors for domestic heating emissions. Uncertainty in wood usage and emission factors for the 2006 inventory is discussed in the following sections.

Coal consumption only accounts for an estimated 2% of $PM_{10}$ emissions and is not considered further in this section. Wood usage is discussed for woodburners and open fires. Multifuel burners are assumed to be essentially the same as woodburners and are not specifically considered in this section.

## A.1.1. Uncertainty in woodburner wood consumption estimates

Daily wood consumption is estimated for 2006 based on the formula described in Section 5.1.

Daily wood consumption was estimated in previous inventories based on the following formula (Wilton, 2002):

*Fuel use (kg/appliance/day) = L * W * DW/7*

*Where:*

*L= average number of logs burnt per day (based on phone survey results)*

*W= average log weight*

*DW=average number of days per week appliance used in winter*

To estimate wood consumption in the 2004 inventory, households were asked to estimate their daily fuel use in number of split logs put on the fire. This was converted to weight based on an assumed log weight of 1.4kg, which was based on the results of Christcurch studies (ARC 2006b). Average log weights for inventories around New Zealand have included 1.4kg, 1.6kg or 1.9kg (ARC 2006b).

A pilot home heating and wood merchant study in Auckland surveyed 67 households and four wood merchants, providing weight data on 487 logs (ARC, 2006). This provided an estimated average log weight of 1.48kg (±0.05kg[1]). A more comprehensive

[1] All errors have been calculated based on a 95% confidence interval for a normal distribution.

dairy survey of 347 householders provided an average log weight of 1.45kg (±0.1kg[1]) from 1734 pieces of wood measured (ARC 2010a).

To improve certainty, daily wood consumption is estimated for the 2006 inventory from phone and diary survey results based on the estimated number of hours per day that the fire is used. The hourly wood burning rate for woodburners is estimated at 3.4kg/hour based on the results of ARC woodburner emissions testing (ARC, 2009b). This compares well to the hourly burn rate estimated from the results of the diary survey of 3.5kg/hour.

The average fuel use across all areas (for woodburners) is estimated at 13.8kg/day based on number of logs (log weight 1.45kg), and 14.4kg/day based on hourly burn rate (burn rate 3.4kg/hour). The 2004 inventory[2] estimated average fuel use for woodburners across all areas to be 13 to 14.6kg/day based on an average log weight of 1.4kg. These results are in very good agreement and provide confidence in the estimate of daily fuel consumption.

We have confidence in the estimated days per week and hours per day of burning. The average number of days per week was cross checked by asking survey respondents whether they used their woodburner last night. It is estimated that woodburners are used on 68 per cent of days based on the average number of days per week, and 64 per cent of days based on whether the woodburner was used last night. Statistical analysis of the phone survey results for the average hours per day of burning indicate an error of less than 10 per cent in most areas with a 95 per cent confidence interval.

The hourly fuel consumption rate estimated by the diary, the phone survey, and the ARC emission testing (ARC 2009b) does not agree well with similar estimates from Environment Canterbury. A diary survey in Canterbury (ECAN, 2007) estimated hourly wood consumption of 1.77kg/hour compared with 3.5kg for the Auckland survey. However, the average hourly burn rates are likely to be affected by much longer burn times in Christchurch. The average burn time in Auckland based on phone survey results was 5.5 hours per day. This compares to the average in Christchurch of around 10 hours per day. On this basis it seems likely that woodburners in Christchurch are more likely be running on a low setting for longer periods of time.Overall, we have reasonable confidence in the wood consumption rates for woodburners.

[1] All errors have been calculated based on a 95% confidence interval for a normal distribution.

[2] Average fuel use by appliance is reported in *TP292 Auckland Air Emissions Inventory* as 17-19kg/day. This is equivalent to 13-14.6kg/day when adjusted for the number of days per week that burners were used.

### A.1.2. Uncertainty in open fire wood consumption estimates

The open fire wood consumption rate is estimated at 4.2kg/hour based on the results of the Christchurch diary survey (ECAN, 2007). This compares reasonably well to the wood consumption rate for open fires estimated from the Auckland diary survey of 3.6kg/hour. Both the Christchurch and Auckland diary survey results are based on a small sample size (a total of 63 burn cycles in Christchurch from four individual households and a total of 75 fires in Auckland). The Auckland diary survey questions were similar to the Christhchurch survey. However, the Christchurch diary panel was provided with scales to weigh the wood as well as personal instruction, while the Auckland diary relied on householders to interpret the questions with no help and to use their own scales to weigh wood. Given that the Christchurch survey also had a slightly larger sample size, the Christchurch results are used in preference to Auckland results for open fire burn rate.

### A.1.3. Uncertainty in emission factors

As discussed in Section 4 there has been considerable work to reduce the uncertainty in domestic fire emission factors since the previous inventory. We now have reasonable confidence that the emission factors selected are representative of real-life emissions from woodburners. However, emissions from woodburners can be affected by factors such as wet (unseasoned) wood and operator behaviour, and there is uncertainty about whether NES woodburner emissions will increase over time. The ARC *Effects of fuel and operation on particulate emissions from woodburners* study (ARC 2010a) found that wet (unseasoned) wood can increase woodburner emission factors by a factor of two. Emissions from woodburners are inherently uncertain because fuel quality and operator behaviour are variable, and cannot be predicted or controlled. The only realistic way to improve certainty in emissions estimates would be to replace existing woodburners with home heating appliances that have consistent fuel quality and minimum room for operator error such as pellet burners. Estimated emissions are directly proportional to the emission factor assumed, and could realistically be a factor of two higher than the current estimates.

To address the uncertainty in woodburner emission factors, sensitivity analysis has been undertaken for the BAU projection based on a high NES woodburner emission factor of 5.7g/kg. This is discussed in Appendix 3.

# Appendix: 2 Assumptions in the BAU projection

The key assumptions for the BAU projection are described in Section 7Error! Reference source not found.. However, in some areas, and for some burner types, survey results do not follow generally expected trends and specific assumptions have been made. These assumptions fall within the margin of error for estimated burner numbers in every case and are described in the following sections.

## Areas 4 (Manukau North) and 9 (North Shore)

In areas where there is an apparent increase in multifuel burner numbers (areas 4 and 9), the multifuel retirement rate is set as zero and the woodburner retirement rate is decreased to compensate (so that the overall rate of change in the number of households burning wood is not affected by the assumption). Estimated multifuel burner numbers are low and this assumption is well within the margin of error. New multifuel burners are not allowed in urban areas under the rules of the PARP: ALW. There may be some installations in rural areas, however these are unlikely to have a significant effect on overall burner numbers.

## Area 6 (Auckland West)

Survey results suggest a significant decrease in woodburner numbers, and a significant increase in open fire numbers in area 6. These results have been considered in the context that:

- The Census indicates a 15 per cent reduction in the number of households using wood in this area.
- New open fires are effectively banned under the requirements of the regional plan.
- Open fire numbers could potentially increase because a high proportion of households have an unused fire in this area (27 per cent). It is likely that the majority of these are open fires. However, it seems unlikely that there would be a significant increase in the use of open fires, while there has been an overall decrease in the use of wood for home heating in this area.
- Survey results indicate that 52 per cent of woodburners installed over the past 15 years have been installed to replace an open fire in area 6.
- The margin of error for 2001 burner numbers is high due to the small sample size.

Overall, it seems unlikely that the increase in open fire numbers is realistic. However, the survey results do not support an assumption that open fire numbers are likely to significantly decrease in the near future. For business as usual it is assumed that open fire retirement is zero in area 6. This assumption is within the margin of error for the estimated burner numbers. The woodburner retirement rate is decreased to compensate (so that the overall rate of change in the number of households burning wood, which is based on census data, is not affected by the assumption).

### Area 7 (Waitakere East)

Survey results suggest a significant decrease in the number of new (post 1991) woodburners, and a significant increase in the number of open fires in these areas. These results have been considered in the context that:

- The Census indicates a 4 per cent reduction in the number of households using wood in this area.
- New open fires are effectively banned under the requirements of the regional plan.
- Open fire numbers could potentially increase because a significant proportion of households have an unused fireplaces in this area (16 per cent). It is likely that the majority of these are open fires. However, it seems unlikely that there would be a significant increase in the use of open fires, while there has been an overall decrease in the use of wood for home heating in this area.
- Survey results indicate that 33 per cent of woodburners installed over the past 15 years have been installed to replace an open fire in area 7.
- The margin of error for 2001 burner numbers is high due to the relatively small sample size.

As for area 6, it seems unlikely that the increase in open fire numbers is realistic. For business as usual it is assumed that open fire retirement is zero in area 7 (so that the overall rate of change in the number of households burning wood, which is based on census data, is not affected by the assumption).

The results suggest very little retirement of older woodburners, but a significant reduction in new woodburner numbers. This seems unrealistic. The difference between old (pre-1991) and new (post 1991) woodburner numbers is well within the margin of error, so woodburner retirement rates have been calculated based on the overall reduction in woodburner numbers in this area.

### Area 8 (Waitakere West)

In area 8, survey results suggest an increase in the number of open fires between 2001 and 2006. The increase is small and is well within the margin of error. In area 8, the open fire retirement rate is assumed to be zero.

### Area 10 (Rodney)

In area 10, the survey results suggest an increase in the number of pre-1991 woodburners between 2001 and 2006. This is not realistic. For area 10 the woodburner retirement has been set at 2.3 per cent of overall woodburner numbers. This is based on the retirement rate in area 1, which is the lowest of all 10 survey areas.

# Appendix: 3 Sensitivity analysis for the BAU projection

The following sensitivity analysis is based on the BAU projection. It is assumed that current trends continue, and old woodburners are gradually replaced with newer burners. Within this BAU scenario there is uncertainty associated with the rate of change of emissions due to uncertainty in:

- The rate of change of open fire and woodburner numbers.
- The difference of emission factors between old and new woodburners.

The following scenarios have been modelled to evaluate the sensitivity of the BAU scenario to these variables:

- New woodburner installation rates and old woodburner retirement rates are 50 per cent of BAU rates. This is an estimate of the the "worst case" rate of turnover as discussed in Section 0 below.
- Retirement of open fires ceases if open fire numbers drop to 45 per cent of current numbers. This is based on the survey result that 45 per cent of respondents with open fires would not or would only remove their open if forced by rules. Under BAU open fire retirement continues at current rates indefinitely.
- Retirement of open fires ceases if open fire numbers drop to 76 per cent of current numbers. This is based on the survey result that 24 per cent of respondents with open fires are thinking about changing to another method of heating.
- The NES woodburner emission factor is 5.7g/kg. This compares to the "base case" emission factor of 3.7g/kg, and is intended to make some allowance for NES woodburner emissions being higher than expected, or increasing over time, as discussed in Section 0 below.

## A.3.1. Rate of change of woodburner numbers

The rate of change of open fire and woodburner numbers has been calculated based on the change of estimated applicance numbers between 2001 and 2006.

To better understand the uncertainty in these estimates, the margin of error for appliance types has been calculated as shown in Table A4-1. The margin of error is relatively high because the breakdown of appliances into different appliance types is based on relatively few survey responses. The margin of error is higher for 2001 results because of the smaller sample size than for the 2007 survey.

The margin of error accounts for the error associated with sample size, so this can be thought of as a measure of the variation one would see in reported percentages if the same survey were taken multiple times. It is important to note that variance due to sample size is not likely to be the only source of error. Other possible contributions to error include:

- Sampling bias,
- Inappropriate phrasing of question,
- Response error,
- Deliberate distortion (fear of consequences, etc),
- Not understanding the question,
- Lack of knowledge.

These errors are difficult to quantify, however they may be significant. For the 2007 home heating survey, comparison of telephone survey responses with diary survey responses provides some indication of response error. Some of the diary participants who were referred from the phone survey answered some of the same questions for a second time. It was found that 19 per cent of those who answered the appliance type question twice provided two different answers. This indicates that there is likely to be a high level of error in the responses to this question, possibly due to confusion over what is an "open fire" vs a "woodburner" etc.

There is significant uncertainty in the rate of retirement of old burners and the rate of installation of new burners. It is important that this is recognised in the development of any policy. To illustrate the effect of this uncertainty, a scenario with installation and retirement rates at 50 per cent of business as usual rates has been modelled. This scenario is considered to represent the "worst case" rate of woodburner turnover based on historical trends. The effect of this assumption is illustrated by

Figure A3-1. This shows a similar long term result to the BAU projection, because the underlying assumptions are the same and eventually older woodburners are replaced with new lower emission woodburners. However, the short term rate of $PM_{10}$ emission reduction is significantly different. This effect may be important in the evaluation of any policy to achieve emission reduction targets. For example, under BAU, $PM_{10}$ emissions fall to 6 tonnes per day by 2017. Under the sensitivity analysis scenario, $PM_{10}$ emissions fall to 6 tonnes per day by 2023, which is a six year delay.

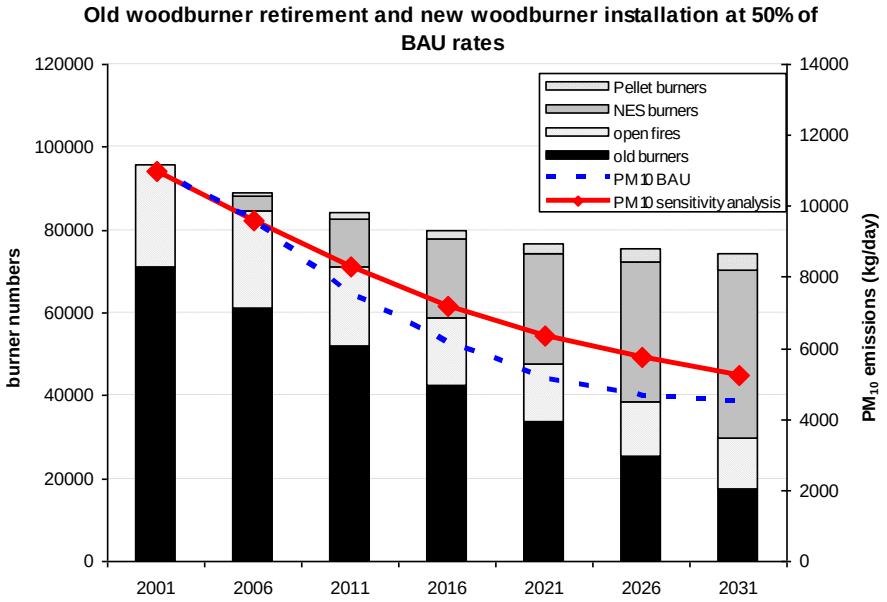



Figure A3-1: Sensitivity to old woodburner retirement and new woodburner installation rates.

## A.3.2. Sensitivity to open fire retirement

- In most survey areas, the number of open fires is declining. It may not be realistic to assume that this continues indefinitely, so sensitivity analysis has been undertaken for two scenarios:
- Open fire numbers remain static if open fire numbers drop to 45 per cent of current numbers (based on survey result that 45 per cent of respondents with open fires would not or would only remove their open fires if forced by rules.
- Open fire numbers remain static if open fire numbers drop to 76 per cent of current numbers (based on survey result that 24 per cent of respondents with open fires are thinking about changing to another method of heating).
- Under the first scenario $PM_{10}$ emissions reduce to approximately 5.2 tonnes per winter weekday by 2031 , compared to approximately 4.4 tonnes per winter weekday with BAU assumptions. Open fires are inefficient and produce relatively high emissions. Open fires currently account for approximately 25 per cent of $PM_{10}$ emissions in the Auckland Urban Airshed. Under business as usual, this proportion increases to 30 per cent by 2031. Under the second scenario where open fire numbers do not fall below 76 per cent of current numbers, open fires account for 40 per cent of $PM_{10}$ emissions by 2031. The results are illustrated in Figure A3-2.

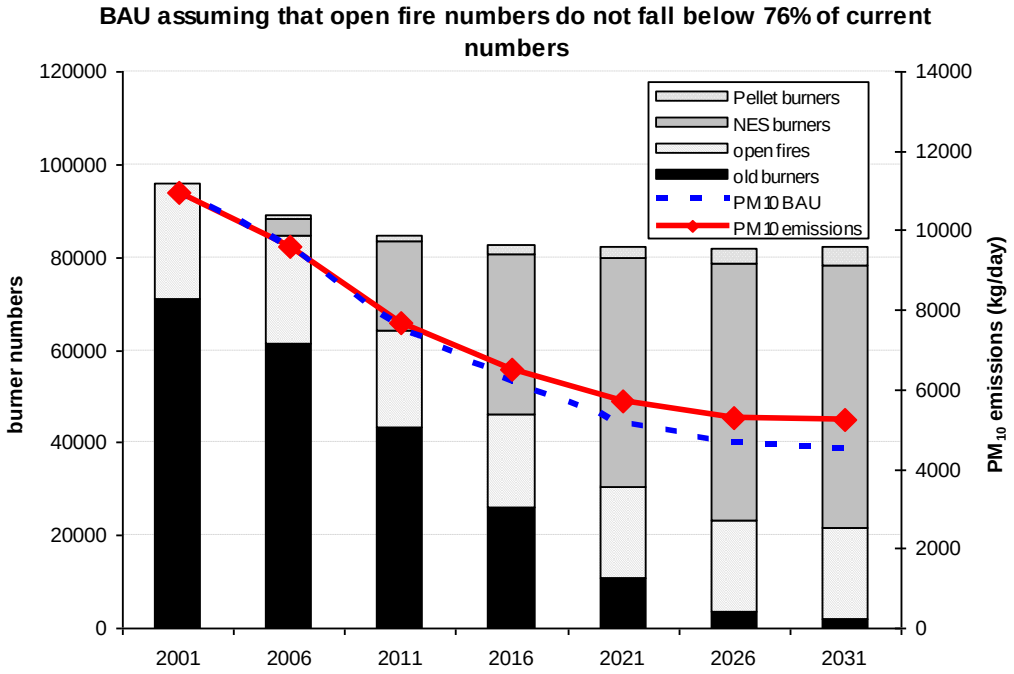



Figure A3-2: business as usual assuming that open fire numbers do not fall below 76 per cent of current numbers

### A.3.3. Sensitivity to NES woodburner emission factors

Under the business as usual projection, the reduction in emissions over time is primarily due to the reduction in average emissions from a woodburner. It is assumed that emissions from a modern "NES" burner are significantly lower than emissions from an older burner. However, we do not know whether the lower (on average) emissions from NES woodburners will remain constant over time. All current emission projections assume that a NES woodburner with emissions of 3.7g/kg will always have emissions of 3.7g/kg. This is may be unrealistic, as emissions are likely to increase over time due to malfunction, poor maintenance or tampering of woodburners. The worst case scenario is that NES woodburners in 10 years time will have a similar emission factor to a current ten year old woodburner, so that effectively the average emission factor of woodburners does not improve with the introduction of NES woodburners.

The results of emission testing undertaken to date suggest that NES woodburners have lower emissions than older (pre-1994) woodburners on average. However, the results also clearly show that older woodburners can have relatively low emissions (similar to a NES woodburner), and a NES woodburner can have high emissions (similar to a pre-1994 woodburner).

There is uncertainty about whether NES woodburner emissions will increase over time. The ARC *Effects of fuel and operation on particulate emissions from woodburners*

study (ARC 2010a) also found that emissions from woodburners can be affected by factors such as wet wood and operator behaviour. The study found that wet (unseasoned) wood can increase woodburner emission factors by a factor of two.

The predicted rate of reduction in emissions is sensitive to the difference in emissions factors, so for sensitivity analysis the 95 per cent confidence intervals have been used from the NIWA in-situ woodburner testing (Table 4-1) to derive a high NES woodburner emission factor of 5.7g/kg (3.3 g/kg + 2.4 g/kg = 5.7g/kg). Under this scenario $PM_{10}$ emissions reduce to approximately 6 tonnes per winter weekday by 2033 compared to approximately 4.4 tonnes per winter weekday with BAU assumptions. These results, as illustrated in Figure A3-3. clearly show that the rate of reduction in emissions is sensitive to the emission factor assumed for NES woodburners. This assumption may be important in the evaluation of any policy to achieve emission reduction targets. For example, under BAU, $PM_{10}$ emissions fall to 6 tonnes per day by 2017. Under this scenario, $PM_{10}$ emissions fall to 6 tonnes per day by 2031, which is a 14 year delay.

An average emission factor of 5.7g/kg for NES woodburners is considered to be realistic, especially for these long term projections which need to allow for degradation of woodburners over time. This emission factor is still lower than the emission factors assumed for pre-NES woodburners of 7.2g/kg (1991-2004) and 10.7g/kg (pre-1991 woodburners).

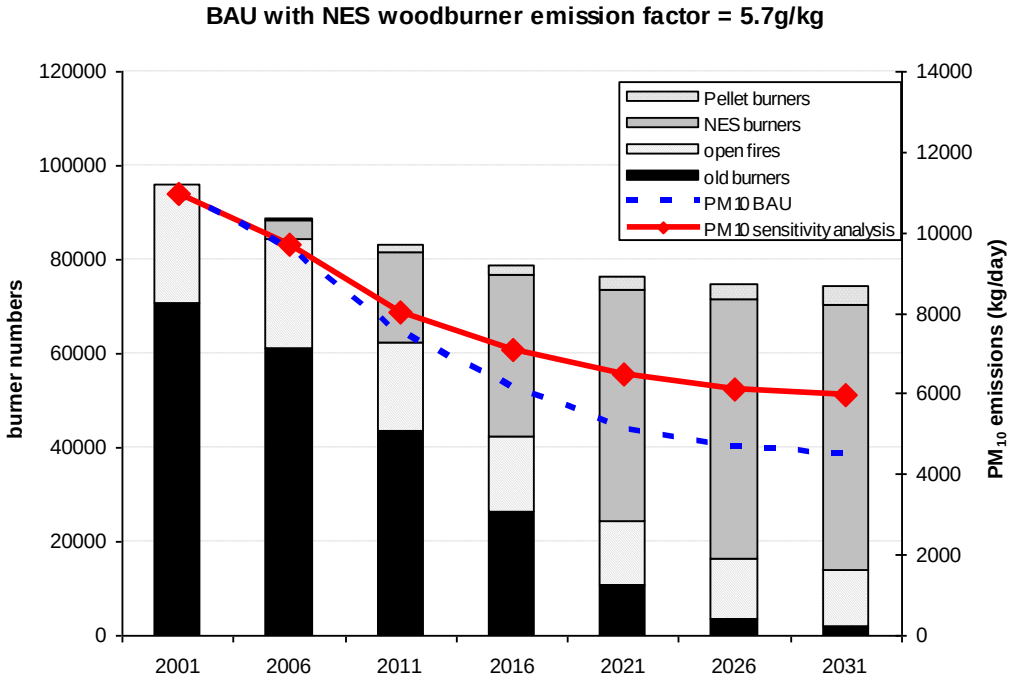



Figure A3-3: Business as usual with a NES woodburner emission factor of 5.7g/kg

## A.3.4. Summary of sensitivity analysis

Sensitivity analysis for the BAU projection is summarised in Table A3.1 below. The analysis has demonstrated that the extent of $PM_{10}$ emission reduction in the long term is most sensitive to the emission factor that is assumed for NES woodburners. The analysis illustrated by Figure A3-1 also shows that the shorter term rate of emission reduction reduction is sensitive to the rate of woodburner retirement. It is important that any policy analysis takes these conclusions into consideration, particularly if the policy is intended to meet an emission reduction target by a certain date.

Table A3-1: Sensitivity analysis for business as usual projection

| | Number of domestic fires in the Auckland urban airshed at 2031 | | | Emissions (tonnes/winter weekday) | | |
|---|---|---|---|---|---|---|
| | NES woodburners | Pre-NES woodburners | Open fires | 2006 | 2031 | Per cent reduction |
| Business as usual | 57,000 | 150 | 11,800 | 9.6 | 4.4 | 54 |
| Old woodburner retirement and new woodburner installation at 50 per cent of business as usual rates | 43,000 | 14,000 | 11,800 | 9.6 | 5.1 | 47 |
| Open fire numbers do not fall below 45 per cent of current numbers | 57,000 | 150 | 15,700 | 9.6 | 4.8 | 50 |
| Open fire numbers do not fall below 76 per cent of current numbers | 57,000 | 150 | 20,000 | 9.6 | 5.2 | 46 |
| Higher NES woodburner emission factor of 5.7g/kg for future years | 57,000 | 150 | 11,800 | 9.6 | 5.9 | 38 |

# Appendix: 4 Estimated appliance numbers

Table A4-1. Estimated appliance numbers in the Auckland region for 2001 and 2006

| | Survey area | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Area 1 | Area 2 | Area 3 | Area 4 | Area 5 | Area 6 | Area 7 | Area 8 | Area 9 | Area 10 | Total | Percentage of total | Margin of error |
| **Census:** | | | | | | | | | | | | | |
| Total households | 27,300 | 26,400 | 29,300 | 33,500 | 64,000 | 60,500 | 46,200 | 4400 | 60,500 | 37,500 | 389,600 | | |
| Total households burning wood | 8400 | 10,300 | 7000 | 8900 | 12,900 | 16,200 | 16,600 | 2400 | 17,800 | 15,100 | 115,800 | | |
| **Estimated appliances:** | | | | | | | | | | | | | |
| wood burner - pre 1991 | 2300 | 3700 | 2000 | 3200 | 3200 | 4100 | 4400 | 800 | 6800 | 2200 | 32,600 | 29% | ±3% |
| wood burner post 1991 | 3400 | 4300 | 2400 | 2200 | 2800 | 5200 | 10,500 | 1100 | 5900 | 8600 | 46,300 | 42% | ±4% |
| Multifuel | 1400 | 500 | 800 | 400 | 350 | 1300 | 1100 | 200 | 700 | 1800 | 8700 | 9% | ±2% |
| Open fire | 1300 | 1700 | 1800 | 3100 | 6600 | 5600 | 700 | 300 | 4500 | 2500 | 28,100 | 20% | ±3% |
| | Survey area | | | | | | | | | | | | |
| 2006 | Area 1 | Area 2 | Area 3 | Area 4 | Area 5 | Area 6 | Area 7 | Area 8 | Area 9 | Area 10 | Total | Percentage of total | Margin of error |
| **Census:** | | | | | | | | | | | | | |
| Total households | 30,200 | 34,300 | 31,400 | 35,400 | 73,400 | 63,600 | 50,900 | 5600 | 64,000 | 45,100 | 434,000 | | |
| Total households burning wood | 7700 | 10,860 | 6200 | 8200 | 11,500 | 14,200 | 15,900 | 2500 | 16,500 | 16,100 | 109,800 | | |
| **Estimated appliances:** | | | | | | | | | | | | | |
| wood burner - pre 1991 | 1400 | 1900 | 1300 | 1400 | 2300 | 1600 | 4100 | 400 | 3300 | 4100 | 21,300 | 19% | ±2% |
| wood burner 1991-2005 | 4100 | 6400 | 2700 | 4300 | 3800 | 4700 | 8300 | 300 | 7800 | 8400 | 51,000 | 51% | ±2% |
| NES woodburners | 400 | 350 | 150 | 400 | 200 | 400 | 1100 | 1500 | 650 | 1000 | 4500 | | |
| Multifuel | 600 | 500 | 500 | 500 | 200 | 300 | 700 | 100 | 800 | 800 | 5500 | 5% | ±1% |
| Open fire | 1200 | 1700 | 1700 | 1600 | 5000 | 7200 | 1700 | 400 | 3900 | 1900 | 26,000 | 24% | ±2% |
| Pellet fire | 80 | 50 | 50 | 120 | 0 | 140 | 200 | 10 | 0 | 80 | 900 | 1% | ±0.4% |