Wood Burner Testing Christchurch 2009:

Diurnal variation in emissions, wood use, indoor temperature and factors influencing start-up

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Executive summary

The objective of this study is to utilise the data collected in the Christchurch 2009 real life study to provide further improvement to emission inventories by:

- Determining a diurnal profile for PM_{10} emissions from domestic home heating.
- Measuring the weight of wood used by householders to heat their homes
- Assessing the impacts of wood burner use on indoor temperature, relative humidity, CO and PM_{10}
- Investigating factors that influence the start-up of domestic woodburners

This report summarises data relating to emissions from wood burners, operational aspects such as daily burner operation and fuel consumption and influences of burner operation on variables such as temperature and indoor air quality that was collected as part of the real-life emissions monitoring programme undertaken in Christchurch in 2009.

Data were collected from six households with 1.5 and 1.0 g/kg compliant wood burners over a week during winter 2009 in Christchurch. Measurements of flue particulate, flue temperature, indoor temperature, indoor carbon monoxide, indoor relative humidity and wood use were collected at one minute intervals throughout the day. In addition indoor particulate concentrations were measured at two households.

Flue particulate data were collated to give an average temporal profile of emissions from domestic home heating. This is a major advancement in our understanding of daily variations in emissions from wood burners and will be of value to those requiring details of hourly emissions from this source for atmospheric dispersion modelling. One limitation in this profile however, is the small sample size and it is recommended that the profile be refined with the addition of further sampling.

The average amount of fuel used per day was collected via electronic scales located under the wood basket. The average daily fuel consumption for all households was 15.4 kilograms per day. This is consistent with values estimated for Christchurch in the early 2000s (as reported in Wilton, 2004) but lower than the 23 kilograms per day assumed in the Environment Canterbury projections modelling (Angie Scott, pers comm. 2005). Further sampling of wood use in households in Christchurch is recommended to provide a more robust estimate of daily fuel consumption.

In previous studies the moisture content of the wood had an impact on particulate emissions. In this study the average moisture content of the wood for each household was estimated based on measurements of three wood samples per household. The average wood moisture contents per household ranged from 15% to 23%. Wood fuel moisture did not appear to be a major determinant of particulate emissions in the six households in this study. However detailed analysis similar to that carried out for the 2007 study was not undertaken owning to the relatively small number of households.

Start-up times were evaluated to determine if variables such as ambient temperature or room temperature were key determinants of use of the wood burners. In the absence of any relationships between these variables it is assumed that individual lifestyle factors, such as work schedules, have the greatest influence on start time.

A key concern highlighted in the 2007 testing is the variability in average emissions from NES compliant burners from different locations in New Zealand. It is uncertain whether some location specific factors are influencing emissions from different urban areas or whether the differences are a function of the small sample sizes. To date, 24 households with NES compliant burners have been tested. Further tests are required and additional investigations into location specific factors are recommended.

An evaluation of particulate emissions from the testing programme was reported in Bluett & Meyer (2011). They found an average emission rate from this study of 7 g/kg and that combining the results of this testing with previous studies raised the average emission rate from NES compliant burners from 3.3 g/kg to 4.3 g/kg (wet weight).

The impact of variability in the emission factor and the operational aspects examined in this report on current emission inventories is minimal as few areas have a high proportion of NES compliant burners (the main exception being Christchurch). The potential impact on management options assessments is much greater, however, as such assessments are very sensitive to changes in emission factors for NES compliant burners. Because of the potential variability in inter-household emission rates and inter-region variability, a multi tool approach to evaluating the effectiveness of management options is recommended. Investigations into regional emission rates, evaluation of trends in both concentrations and emissions and consideration of the inclusion of management options to minimise the impact of gross emitters in Regional Plans is recommended.

1 Introduction

1.1 Background

In New Zealand, concentrations of particulate matter (PM_{10}) regularly exceed the National Environmental Standard (NES) of 50 µg/m^3 (24 hour average) in urban areas. The main source of PM_{10} is solid fuel burning for domestic home heating. Wood burning is the major contributor in most areas, although on the West Coast and in Southland domestic coal burning is the key concern in many towns.

To address the ambient PM_{10} problem at a national level, the NES also contains a design standard for new woodburner installations in urban areas. From September 2005, all woodburners installed on properties less than 2 ha in size have been required to have a thermal efficiency greater than 65% and emission rate less than 1.5 g/kg, when tested to AS/NZS4012 and AS/NZS4013 respectively. It is essential to identify the real life emissions from these low emission woodburners, because in many urban areas further management measures are necessary to achieve air quality objectives.

The main tool for determining sources of emissions and subsequently assessing the effectiveness of management options are emission inventories.

When constructing emission inventories, fuel use data are usually obtained and emissions are then estimated via the application of emission factors that specify grams of particulate emitted for every kilogram of fuel burnt (g/kg). Emission inventories are essential for local authorities to identify the dominant sources that contribute to exceedances of the air quality guidelines and standards. Projections models are also commonly used tools and provide local authorities with predictions of future emissions under various management scenarios. The decisions that Councils make to address air quality issues will often be based on emissions inventories and projections models.

The quality of both emission inventories and projections models depend on emission factors and fuel use data. Representative emissions estimates and accurate fuel use data are therefore essential for local authorities to effectively manage air quality issues. Using inaccurate emission factors and fuel use data will lead to poor and potentially ineffective estimation of the reductions in PM_{10} emissions required to meet NES and regional plan air quality targets.

To enhance the quality of emission inventories and projections models a number of studies have been undertaken to measure the real life emissions from wood burners.

1.2 Real life emissions testing of domestic wood burners

A number of studies have been carried out in New Zealand on emissions from older wood burners (Wilton et. al, 2006) and from NES compliant wood burners (Smith et. al. 2008, Wilton & Bluett, 2010, Kelly, et. al., 2007).

In 2007, real life emission testing was carried out in 18 households spread across Nelson, Taumarunui and Rotorua. The method for the former work is detailed in Smith, et. al., 2008. The objective of that study was to identify an appropriate PM_{10} emission factor for representing low emission woodburners in dispersion modelling applications and emission inventories. Average dry weight and average wet weight emission factors were calculated for each woodburner in the study. The mean emission factor for dry weight was 4.6 g/kg and the mean emission factor for wet wood was 3.3g/kg

The report found that the in situ wet-weight emission factor of 3.3 g/kg is around three times smaller than the emission factor of 11 g/kg identified for pre-1994 woodburners (Wilton et al. 2006). The 2006 testing was aligned with the Ministry for the Environment (MfE) “warm homes” pilot project for Tokoroa for 2005 which replaced 19 existing older burners and open fires (in separate households) with NES compliant burners, wood pellet fires and non-solid fuel alternatives.

The main factors influencing emissions from the 2006 testing of older wood burners were average flue temperature and flue oxygen. Operational aspects that influenced these variables were kilograms of fuel burnt, sample duration, fuel moisture content, operational setting, and number of pieces and weight of wood used throughout the sample period.

A further study of operational factors influencing particulate emissions was carried out based on the 2007 testing of NES compliant burners (Wilton & Bluett, 2010). The key determinants influencing emissions from that study were found to be wood moisture, flue temperature, and oxygen, which explained 67% of the variability. Of these wood moisture had the greatest influence resulting in 43% of the variability. The majority (72%) of households in the survey did not appear to increase their fuel consumption when the daily temperature decreased.

In 2009, real life emission testing was carried out in 6 households in Christchurch The approach used differed to that undertaken in 2007 and particulate emission data were collected with a one minute resolutions. The method for this work is detailed in Meyer, et. al., 2008. The objective of that study was to identify an appropriate PM_{10} emission factor for representing low emission woodburners in dispersion modelling applications and emission inventories. The results of this investigation are presented in Bluett and Meyer (2011). Average mean wet weight emission factors were calculated for the woodburners monitored in the study as 7.3g/kg .

1.3 Current study objectives

The objective of this study is to utilise the data collected in the Christchurch 2009 real life study to provide further improvement to emission inventories by:

- Determining a diurnal profile for PM_{10} emissions from domestic home heating.
- Measuring the weight of wood used by householders to heat their homes
- Assessing the impacts of wood burner use on indoor temperature, relative humidity, CO and PM_{10}
- Investigating factors that influence the start-up of domestic woodburners

2 Method

2.1 Sampling programme

The monitoring took place in Christchurch between 26 May and the 19 August 2009. Two emission test units were deployed to sample the emissions of six houses (each test unit monitored three houses). The test houses were randomly chosen from Christchurch City Council records which showed which homes had installed what type of wood burner over the last five years. A total of 20 houses were invited to participate in the test programme. As an incentive the householders were offered a small gratuity for agreeing to host the test kit. Approximately 12 householders accepted the invitation, of which six houses proved to be practical test sites. Four of these houses had installed wood burners that meet the Environment Canterbury 1.0 g/kg laboratory emission test standard and two houses had wood burners that meet the National Environmental Standard 1.5 g/kg laboratory emission test standard. The householders were instructed to operate their wood burners as they would under normal circumstances.

2.2 Data collected

The domestic wood burner emission monitoring system used in this study is described in detail in Meyer et al., (2008). The following section provides a brief overview of the major system components. The wood-heater emissions monitoring system comprises three units: a smoke sampling unit, an analysis unit, and a power supply. The smoke sampler consists of a 1.2 m flue extension, 150 mm in diameter with a 100 mm orifice plate fitted 100 mm from one end. The orifice plate provides the means of measuring the flue gas volumetric flow rate. Flue temperature is measured using paired 1/16” stainless steel sheathed type K thermocouples. Flue gas flow rate is determined by the pressure differential across the orifice plate. Midway along the flue extension a smoke sample is drawn via inlet driven by a venturi. Clean air at a dewpoint of approximately 4^{o}C powers the venturi jet and also dilutes the smoke sample to reduce its dewpoint.

The smoke sample is not drawn from the flue under iso-kinetic conditions. If the particles being sampled were large and had relatively high momentum, this could potentially lead to a distortion of both the mass concentration and particle size distribution of samples. However the particles being sampled are less than 2.5 µm in diameter and therefore any potential distortion created by non-iso-kinetic sampling is considered to be minimal.

Two airstreams are drawn from the primary diluter to the analysis unit. The sample air stream for particle analysis is drawn through ¼" copper tubing where it is further diluted in the analysis unit to bring the particle concentration into the measurement range of the particle analyser (DustTrak, TSI, USA). The diluter is a loop injector which pulses 5 ml of sample gas into a stream of clean air. The loop volume, the injection valve duty cycle, and the flow rate of the dilution air were selected to produce a dilution ratio of approximately 1: 80. The sample airstream for CO and CO_2 analysis is drawn through ¼" PFA Teflon to the analysis unit where it is filtered and further diluted before passing to the CO_2 and CO sensors. CO_2 concentration is measured by NDIR (Gascard II, 10,000 ppm range, Edinburgh Instruments, UK) and CO is measured with Polytron-2 electrochemical sensor (0-1000 ppm range, DrägerSensor CO – 68 09 605, Draeger, PA, USA).

All critical air flow rates, temperature and humidity are measured. The particle, chemical, flow and temperature sensor signals are monitored using appropriate industrial data acquisition interface devices (ADAM model 4017, 4017+,4018, and 4069, Advantech, OH, USA). The analysis unit is located at ground level; external to the house but as close to the flue as practicable. This unit houses all the air supplies, pumps, filters, zero scrubbers, analytical sensors, data acquisition system and controller, and telemetry. Power to the system is supplied by a high capacity battery charger, supplying a series of DC to-DC converters which in turn provide regulated power to the system components. A 12V 80Ah low maintenance lead/acid battery connected in parallel to the power supply provides limited backup power in the event of a power failure.

A dual tracer method was developed for calculating PM_{10} emission factors from CO and CO_2 data collected by the real-world sampling method. This method used for calculating PM10 emission factors is detailed in Meyer et al., (2008).

Indoor PM_{10} measurements were made using a TSI AM510 'Sidepak' aerosol monitor set to log at one minute intervals. The method is an integrating nephelometer, which measures light scattering and is not directly comparable to reference methods. In the absence of a source specific adjustment factor to relate light scattering to mass (for wood burning) the default setting was used. As this is based on Arizona road dust and is unlikely to be appropriate for wood combustion, in this study the measurements made are treated as relative rather than absolute.

2.3 Data Analysis

The main analysis methods used were examination of temporal profiles either on a daily basis or averaged hourly (typically for each household) across the study period. These included evaluations of parameters for hours when the wood burner was and wasn't operating. The variable used as an indicator of this was flue temperature and a value of 50 degrees was selected as an indicator. This value was selected after examining start up and background flue temperature profiles in conjunction with other data such as fuel loading, PM_{10} emissions and room temperature.

3 Results

3.1 Temporal and house to house variations in PM_{10} emissions

3.1.1 Diurnal variation of PM_{10} emissions from wood burners

The diurnal variation in particulate emissions was assessed by averaging particulate data (g/hr) for each household by hour of the day. These were then averaged to give an overall average for households across the study (Figure 3.1). The above distribution is weighted more towards the diurnal profiles for the higher emitting households. This method of averaging is appropriate to derive an average profile for emission inventory or modelling purposes because higher emitting households will have greater influence on diurnal variations in PM_{10} concentrations. An alternative averaging method is shown in Figure 3.2. This shows the average household emissions profile, assuming they all have the same emission rate. The latter method provides a better indication of the average household emissions profile.

Figure 3.1 and 3.2 demonstrate that the results provide good resolution of emission rates at the 1-hour averaging period and that there is considerable variation in hourly PM emissions throughout the day. The hours 00:00 to 14:00 have relatively low emission rates, the emission rates increase rapidly from about 15;00 to 18:00, then on weekdays drop off quickly and constantly to a low level at midnight.

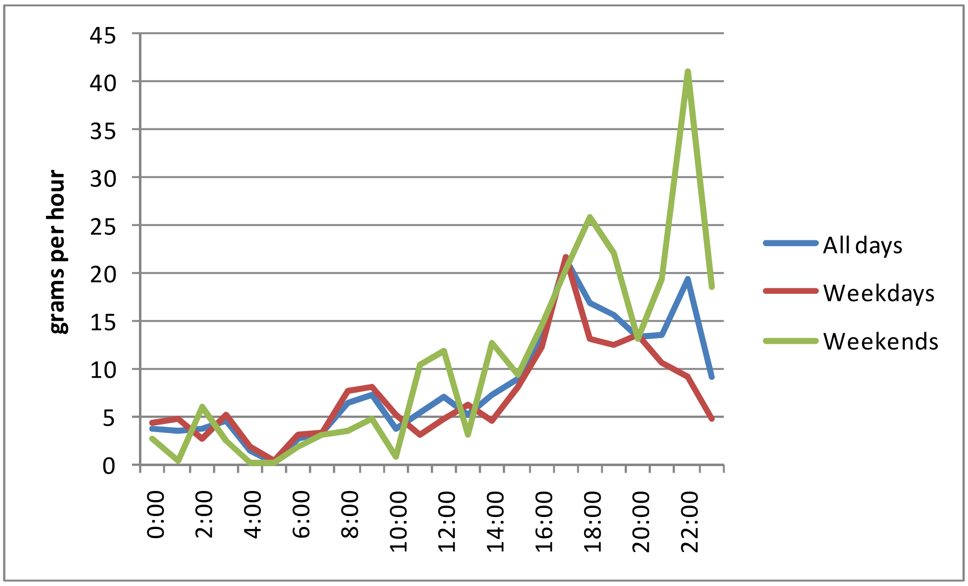

Figure 3-1: Daily variations in particulate emissions from wood burners.

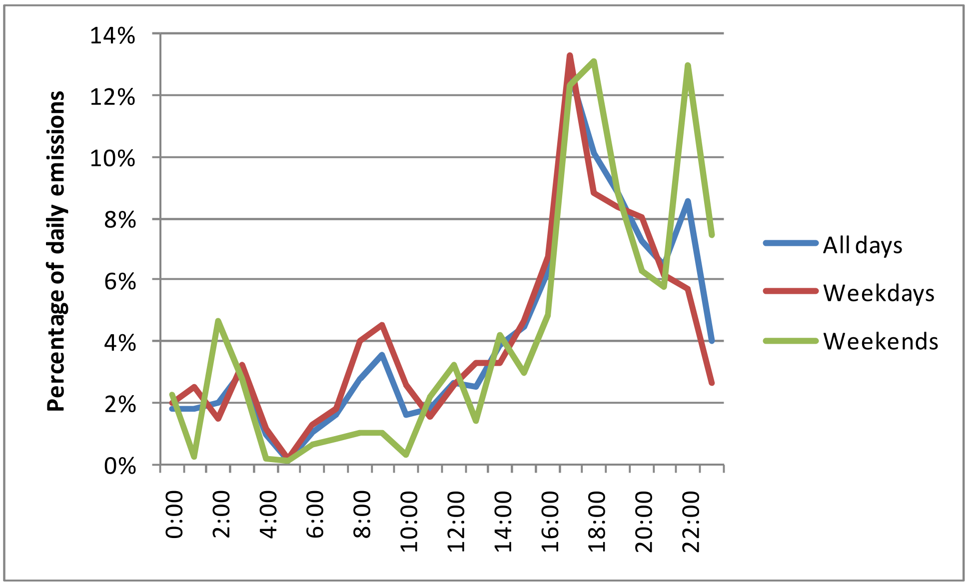

Figure 3-2: Average daily emissions profile for households.

Differences between weekday and weekend burner use are reflected in Figures 3.1 and 3.2. While generally similar the wood burner start-up appears delayed in the weekend, relative to weekdays and wood burner use appears to be prolonged in the weekend with a second evening peak in emissions occurring around 10pm, most probably associated with an additional late evening loading of the firebox.

Table 3.1 details the hourly average particulate emissions from Figure 3.1 based on grams per hour (g/hr) and as a percentage of total emissions.

	Hour	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00
All days	g/hr	3.8	3.5	3.6	4.5	1.4	0.3	2.8	3.3	6.4	7.3	3.7	5.5	7.1
Weekdays	g/hr	4.4	4.8	2.7	5.2	1.9	0.3	3.2	3.3	7.8	8.2	5.1	3.0	4.8
Weekends	g/hr	2.6	0.3	6.1	2.5	0.2	0.1	1.8	3.0	3.6	4.9	0.7	10.4	11.9
All days	% daily total/hr	1.8%	1.8%	2.0%	3.0%	0.9%	0.1%	1.1%	1.6%	2.8%	3.5%	1.6%	1.8%	2.7%
Weekdays	% daily total/hr	2.0%	2.5%	1.5%	3.2%	1.1%	0.2%	1.3%	1.8%	4.0%	4.6%	2.6%	1.6%	2.6%
Weekends	% daily total/hr	2.3%	0.2%	4.7%	2.8%	0.2%	0.1%	0.7%	0.8%	1.0%	1.0%	0.3%	2.2%	3.3%
	Hour	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**	**00:00**
All days	g/hr	7.1	5.2	7.2	8.9	13.1	21.5	16.8	15.6	13.4	13.5	19.4	9.1	7.1
Weekdays	g/hr	4.8	6.1	4.6	8.2	12.3	21.6	13.1	12.4	13.6	10.5	9.1	4.7	4.8
Weekends	g/hr	11.9	3.2	12.6	9.4	14.5	20.5	25.9	22.1	13.2	19.5	41.0	18.6	11.9
All days	% daily total/hr	2.7%	2.5%	3.9%	4.5%	6.3%	12.7%	10.1%	8.8%	7.2%	6.5%	8.6%	4.0%	2.7%
Weekdays	% daily total/hr	2.6%	3.3%	3.3%	4.6%	6.8%	13.3%	8.8%	8.4%	8.0%	6.2%	5.7%	2.7%	2.6%
Weekends	% daily total/hr	3.3%	1.4%	4.2%	3.0%	4.9%	12.3%	13.1%	8.8%	6.3%	5.8%	13.0%	7.5%	3.3%

Table 3-1: Hourly average PM_{10} emissions (g/hr) and average household diurnal profile in emissions (% daily total per hour).

3.1.2 Household variability in emissions

The average particulate emission rate per household (g/kg) is shown in Table 3.2 with summary burner and fuel data.

House	Burner type	Category g/kg (dry)	Lab test average 4013 g/kg (dry)	Wood moisture content %	Test emissions g/kg (dry)	Test emissions g/kg (wet)
1	Ethos IS100	1.0	0.6	15%	7	6
2	Woodsman Matai	1.0	0.8	17%	6	6
3	Ethos IS100	1.0	0.6	16%	12	9
4	Kent Signature	1.0	0.9	23%	23	18
5	Masport LE 3000 Provincial	1.5	1.2	22%	2	1
6	Hewitson Firenzo Contessa EF - Clean Air	1.5		23%	5	4

Table 3-2: Summary burner and fuel data.

The availability of hourly particulate emissions data allows for a comparison of temporal profiles in a number of variables potentially providing insight into inter-household variability in emissions. Figure 3.3 shows averaged particulate, flue temperature, indoor PM_{10} and wood use data for each household by hour of the day.

Figure 3.3. shows that there is considerable house-to-house variation in the averaged particulate, flue temperature, and wood use data. The cause of the variability in particulate emissions is not characterised by the variables illustrated. Household four which has the highest PM_{10} emissions, uses the burner for the longest amount of time per day (20 hours on average) but has the second lowest wood burning rate (1.2 kg/ hour) which may be indicative of a greater use of a low (more oxygen starved) wood burner setting.

Figure 3.3 also shows that the addition of fuel at start up and during the burn process and the firebox temperature at the time the wood is loaded have the most influence on peaks in emissions. For example for household three, increases in wood use around 2pm result in an increase in flue temperature and PM_{10} emissions, and a decrease in wood use around 8pm is accompanied by a decrease in flue temperature and PM_{10} emissions. In comparison, with household four both flue temperature and PM_{10} emissions increase from 6-7am when wood is loaded on the fire but once the flue temperature reaches around 100 degrees C additional fuel loading does not have as much impact on PM_{10} emissions until around 10pm when a peak in fuel loading results in a spike in PM_{10}.

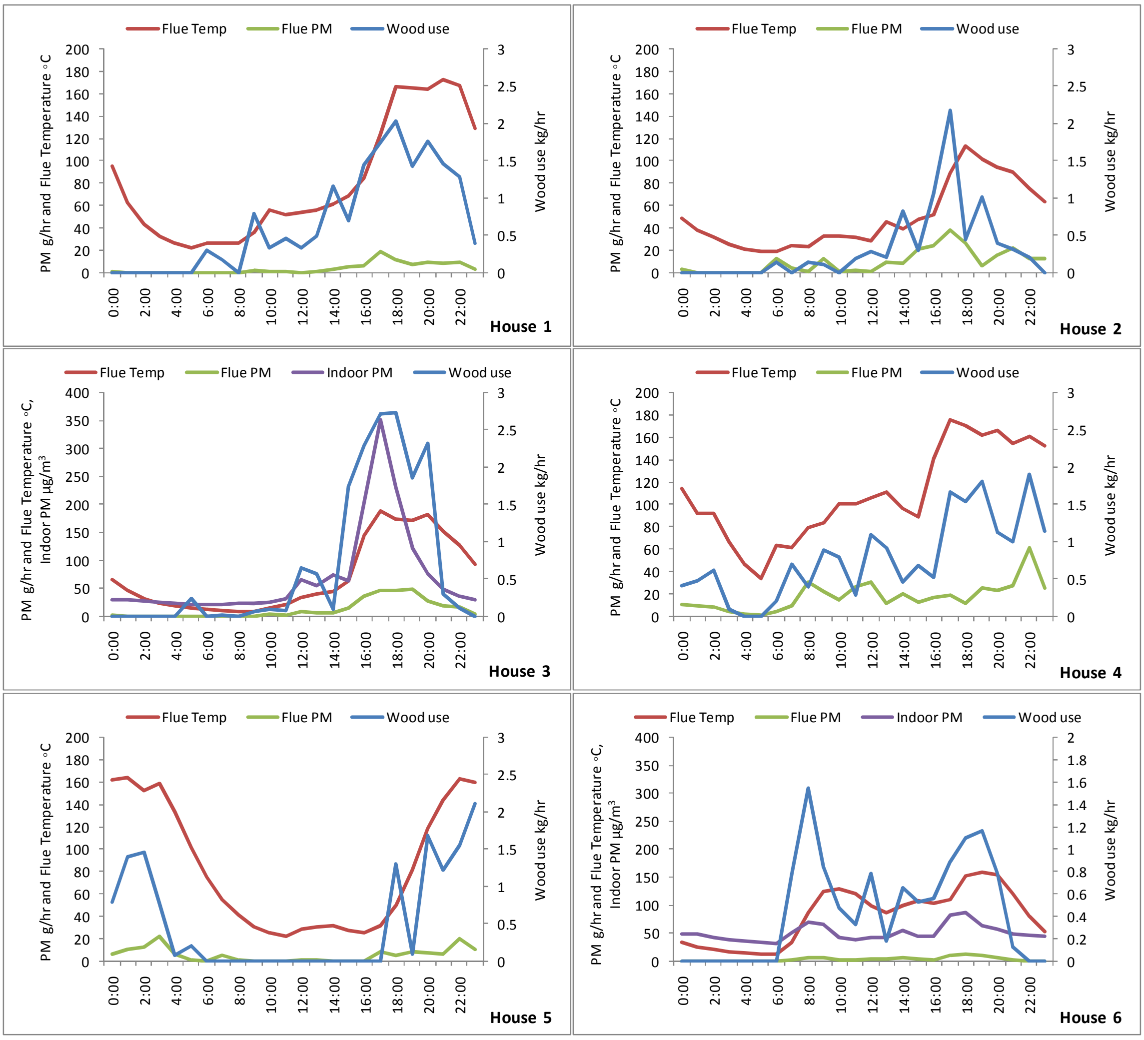

Figure 3-3: Diurnal variation in average flue particulate, flue temperature, indoor PM_{10} and wood use per household.

3.2 Wood fuel use by householders

3.2.1 Weight of wood

The average amount of wood burnt by householders per day in this type of study is of value for validation of fuel use estimates from emission inventory studies. In the inventory surveys households are typically asked about their daily fuel consumption, often in terms of the average number of logs put on a fire per day (e.g., Wilton, 2011). The information is then converted to an estimated daily fuel consumption based on an assumed average log weight. This method is based on average daily use only and does not provide an estimate of the weight of wood burned by domestic wood burners on a specific day. It encompasses a reasonable amount of uncertainty as it relies on households estimates of fuel consumption rather than direct measurement.

In this study the amount of fuel used per day was measured by electronic scales situated in each household under the wood basket. Households were instructed to place all wood used in the in the wood basket prior to loading onto the fire.

The average daily weight of wood burned by the six households included in this study is shown in Table 3.3. This table also shows the average number of hours the fire was operational and the average wood use per hour. The latter information has been used in some inventory studies as an alternative to estimating fuel consumption. However, it is notable from this study that a burner remains operational for many hours after it is no longer being attended. In this study the number of operational hours was derived based on the number of hours the hourly average flue temperature was greater than 50 degrees.

Household	Fuel consumption average all days kg/day	Wood use per hour operational kg/hr	Hours fire going - average hrs/day
1	17	2	11
2	12	1	10
3	16	2	10
4	20	1	16
5	16	2	10
6	13	1	11
Average	15.5	2	11

Table 3-3: Summary wood consumption.

The data in Table 3.3 shows that the average daily fuel use across the six households was 15.5 kg/ day. This compares with around 25 kilograms of wood used per day on average by households in the 2007 NES authorised wood burner emissions study, which included tests in Nelson, Rotorua and Taumarunui (Smith et al 2008). The average fuel use estimated by households in surveys carried out for emission inventory purposes in New Zealand which are typically around 20-25 kilograms (e.g., Wilton, 2006), although previous studies of wood use in Christchurch in the early 2000s supported a value of around 15 kg/day (Wilton, 2004).

3.2.2 Wood moisture

The relationship between wood moisture content and emissions is typically parabolic with lower and higher wood moisture contents resulting in higher particulate emissions.

Figure 3.4 shows the relationship between the average moisture content of the wood for each household and the daily particulate emissions for this study (green triangles), NES burners tested in 2007 (brown dots) and the older burners tested in 2005 ((blue diamonds).

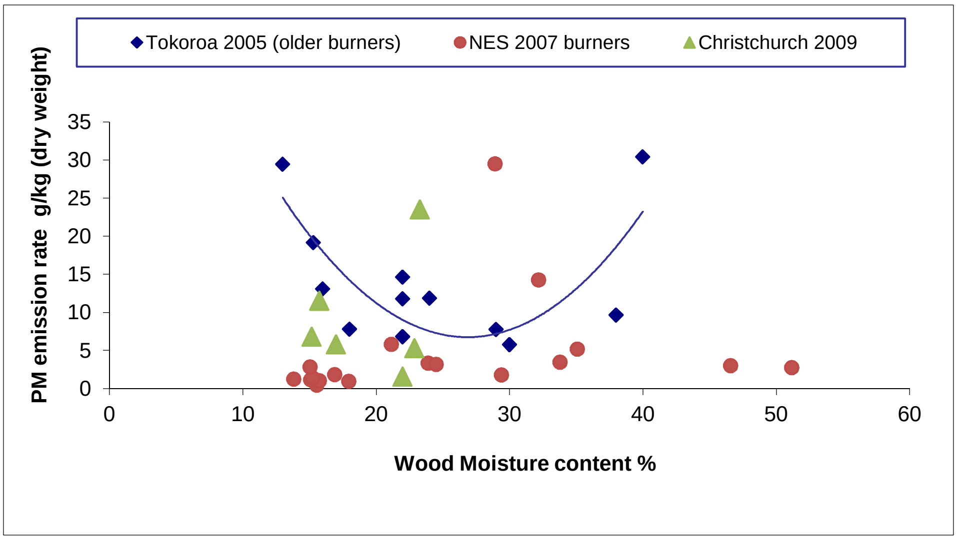

Figure 3-4: Comparison of wood moisture content and emission rate (g/kg dry).

Figure 3.4 shows that in the Tokoroa older burners study (Wilton, et. al., 2005) the typical parabolic curve with lower and higher wood moisture contents resulting in higher particulate emissions occurred. This result was not observed in the 2007 testing of NES compliant wood burners in Nelson, Rotorua and Taumarunui. . The reason for the latter outcome was uncertain. The 2009 data shows that a rather narrow range of wood moisture content was used (15 to 23%) compared to previous studies. The 2009 results suggest that over the moisture content range 15 to 23% emissions are high relative to wood moisture content compared with the earlier 2007 testing of NES compliant burners.

Table 3.4 compares the average wood moisture and the average particulate emissions (dry weight) from the 2007 and 2009 testing of NES compliant burners.

Location	Make	Model	Emission (TSP) g/kg (dry)	Emission (TSP) g/kg (wet)	Wood Moisture %
Nelson	Ethos	FS100	0.9	0.8	18
Nelson	Logaire	Hestia, Bay Door, Clean Air	1.2	1.1	14
Nelson	Firenzo	Lady Kitchener 800, EF Dry	0.4	0.4	16
Nelson	Ethos	FS100	1.0	0.9	16
Nelson	Metro	Eco Pioneer	1.1	1.0	15
Nelson	Ethos	FS100 - bricks removed	5.8	4.6	21
Rotorua	Metro	Eco Pioneer	1.8	1.5	17
Rotorua	Kent	Firenze Max	1.4	1.2	15
Rotorua	Jayline	Classic FS	2.8	2.4	15
Rotorua	Metro	Eco Aspire	3.3	2.5	24
Rotorua	Metro	Eco Pioneer	3.0	1.6	47
Rotorua	Kent	Signature	3.4	2.3	34
Taumaranui	Metro	Eco Rad	2.7	1.3	51
Taumaranui	Woodsman	Matai ECR Mark 2	3.1	2.4	25
Taumaranui	Woodsman	Matai ECR Mark 2	14.3	9.7	32
Taumaranui	Metro	Eco Rad	29.5	21.0	29
Taumaranui	Woodsman	Matai ECR Mark 2	1.8	1.3	29
Taumaranui	Metro	Eco Wee Rad	5.2	3.4	35
Christchurch	Ethos	FS100	11.5	8.8	16
Christchurch	Ethos	FS100	6.8	5.9	15
Christchurch	Firenzo	Contessa EF - Clean Air	5.3	4.5	23
Christchurch	Woodsman	Matai	5.8	5.5	17
Christchurch	Kent	Signature	23.5	17.7	23
Christchurch	Masport	LE 3000 Provincial	1.5	1.5	22
Average	2007		4.6	3.3	
Average all	2007+ 2009		5.7	4.3	

Table 3-4: Wood moisture and emissions data 2007 and 2009 testing.

The data in Table 3.4 shows a greater proportion (66%) of households with average emissions less than 5 g/kg (dry) in the 2007 study compared with the 2009 study (17%). This indicates that while the results for Christchurch are within the range measured previously the data have a very different distribution. It also shows lower average wood moisture contents from households in Christchurch and Nelson compared with Rotorua and Taumarunui.

3.3 Impacts of wood burner use on indoor temperature, CO, PM_{10} and RH

Consideration of the wider impacts of domestic home heating is important in the management of overall health impacts. Wider impacts include warm/ cold homes, indoor air quality, climate changes impacts, energy efficiency and socio economic effects. Use of wood burners for home heating provides a cost effective heating option for households but also has impacts on indoor temperature, CO, PM_{10} and RH.

Figure 3.5 shows daily variations in fuel loading and indoor air parameters averaged for each household. As expected, wood loading corresponds with an increase in indoor temperature, a decrease in indoor relative humidity and an increase in indoor CO concentrations. The decrease in relative humidity (air dampness) occurs as a result of the increased temperature. Concentrations of CO increase as products of combustion escape the firebox and enter the room. A warmer, less damp room means fewer temperature related health impacts. However, increases in indoor CO and PM_{10} may increase health impacts.

For households three and six indoor particulate measurements were also taken at one minute intervals. The average of these for each hour of the day during the sampling period is also shown in Figure 3.5. For both households the trends in indoor PM_{10} were similar to trends in fuel loading. Longley & Gadd (2011) compare indoor and ambient PM_{10} concentrations and show some similarities in variations in concentrations between hourly average indoor and ambient PM_{10} for household three when the burning peaks are removed.

One difference between the two households noted in this study was the difference in PM_{10} concentrations at times when the burners were not operating. For household three the average indoor PM_{10} concentration when the fire was not operating was around 20% of the concentration occurring when the fire was operating compared with 60% for household six. The extent to which this relates to higher ambient contributions, as a result of the different average use patterns[1] of the burners (6am – 9pm versus 3pm to 12pm) or different ambient concentrations or other factors such as other indoor sources is unknown.

More detail on PM_{10} concentrations, in particular minute averages, comparison to ambient concentrations and the decay curves following loading of the firebox is given in Longley & Gadd (2011). Daily average data for households three and six showing the variability in indoor and flue particulate as well as wood use, indoor CO and temperature are shown in Appendix A.

[1] The average ambient PM_{10} concentrations when the fire was operating was 39 $\mu g\ m^{-3}$ for household three and 22 $\mu g\ m^{-3}$ for household six.

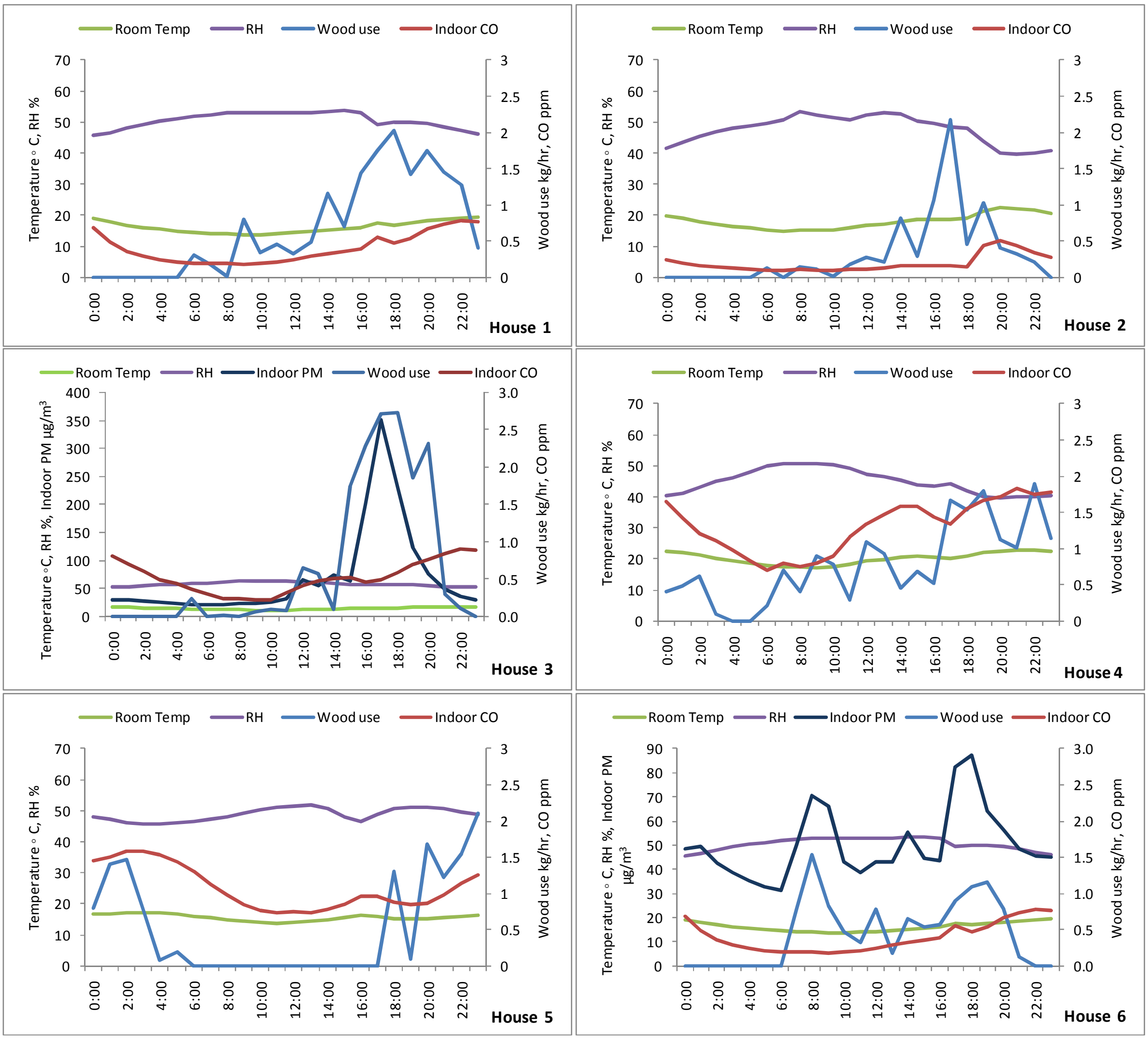

Figure 3-5: Daily variations in wood use and impacts on room temperature, indoor relative humidity and indoor CO concentrations.

3.4 Factors influencing start up

3.4.1 Ambient temperature

To investigate whether ambient temperature has an influence on when people light their fires, the relationship between ambient temperature and fire light up time was evaluated by comparing ambient temperature variables relative to fire light up time. Ambient temperature variables considered included; hourly average temperature, time at light up, minimum hourly average temperature for the day, and daily average temperature.

Figure 3.6 shows the start-up times for each household as dots. The first, second and third panel in Figure 3.6 show start up times against the average daily ambient temperature, the ambient temperature at start up and the minimum hour average temperature during the day respectively.

The data in Figure 3.6 shows that average daily temperature was a poor predictor of start-up time with the best correlation being for household six ($r^2 = 0.13$). Ambient temperature at start up time may have had some influence on start-up time for household five ($r^2 = 0.35$, linear trend shown in Figure 3.6) and possibly household six ($r^2 = 0.2$) but does not appear to be an influencing factor for other households. Minimum daily temperature appeared unrelated to start up time.

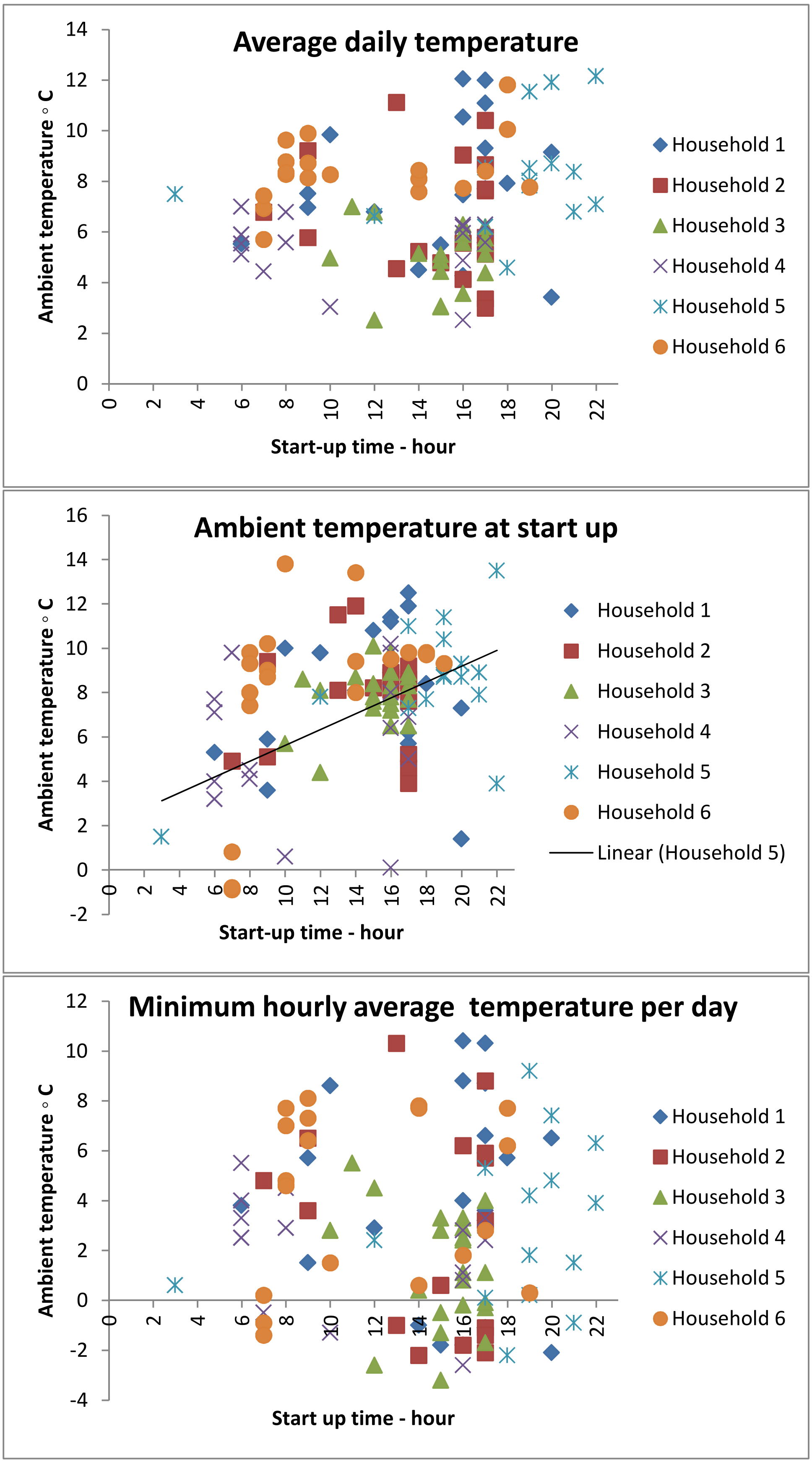

Figure 3-6: Influence of ambient temperature variables on fire start up time.

3.4.2 Room temperature

Figure 3.7 shows the influence of room temperature on the start times of the fires for each household. Figure 3.7 shows the start-up times for each household as dots. The first, second and third panel in Figure 3.7 show start up times against the room temperature at the time of start-up, minimum room temperature for the day, and the average room temperature for hours when the fire was not lit respectively.

For households one and six there is a reasonable correlation between the time the fire was started and the room temperature at that time (trend lines shown in Figure 3.7). However, this may just reflect normal daily changes in indoor temperatures, with colder temperatures in the morning. No other room temperature variables were found to be good predictors of start-up time. Poor correlations were observed for other households with any variables. Generally these variables do not appear to be reliable predictors of fire start time.

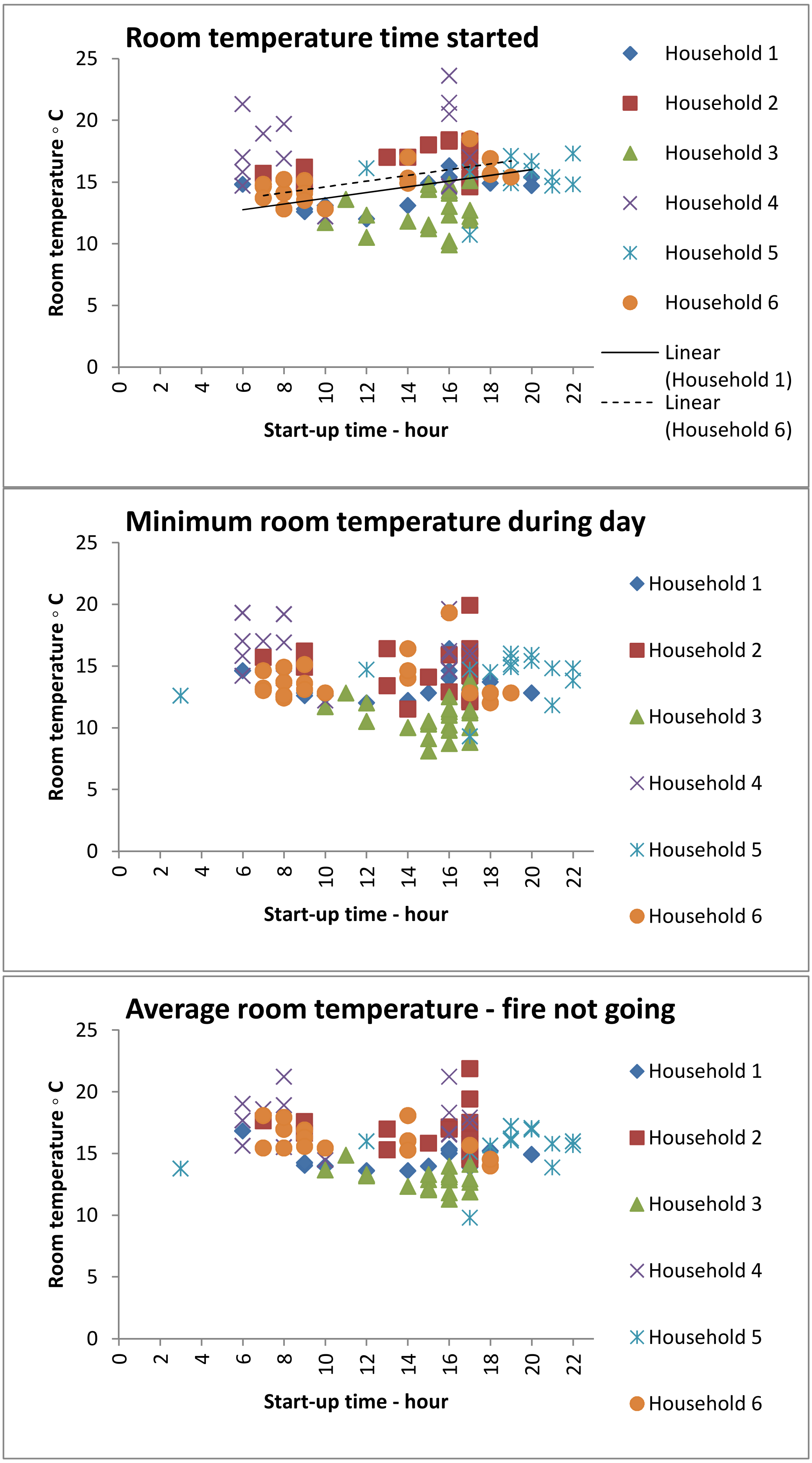

Figure 3-7: Influence of room temperature on start time.

3.4.3 Time of day

The time of day the fire was started up for each household for each day of the week (Sunday = 1) is shown in Figure 3.8. Most households were reasonably consistent with start-up time suggesting that perhaps lifestyle is a key determinant of start-up time. Household one shows variability in start time with the majority of days having the fire lit around 5pm and the remainder anytime during the day with no apparent weekend/ weekday patterns. Households two and three typically start their fires between 2pm and 5pm on weekdays and earlier in the weekends. Households four and six had the greatest frequency of early start ups (6-9am) and the greatest variability in start times (with household one), while household five typically started the fire between 7pm and 9pm.

Lifestyle factors appear to play a role in the time of day a fire is started. However, the lifestyle factors that influence start time clearly vary between households limiting the ability to make more general predictions about fire start times based on these data.

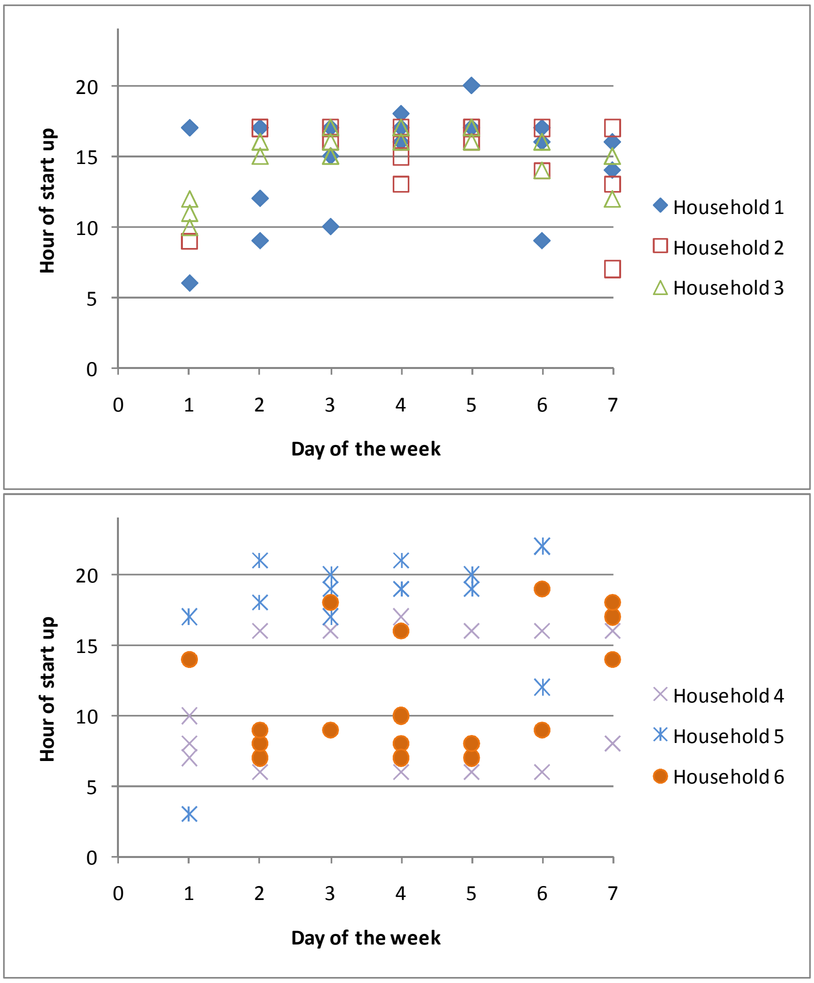

Figure 3-8: Start times by day of the week.

3.5 Factors influencing burn duration and fuel consumption

Data were evaluated to determine if a colder day meant a fire was used for longer or more fuel was burnt. Variables considered included minimum hourly average temperature and daily average temperature. Figure 3.9 shows the influence of ambient temperature on burn duration. Figure 3.10 shows influence of ambient temperature on fuel consumption.

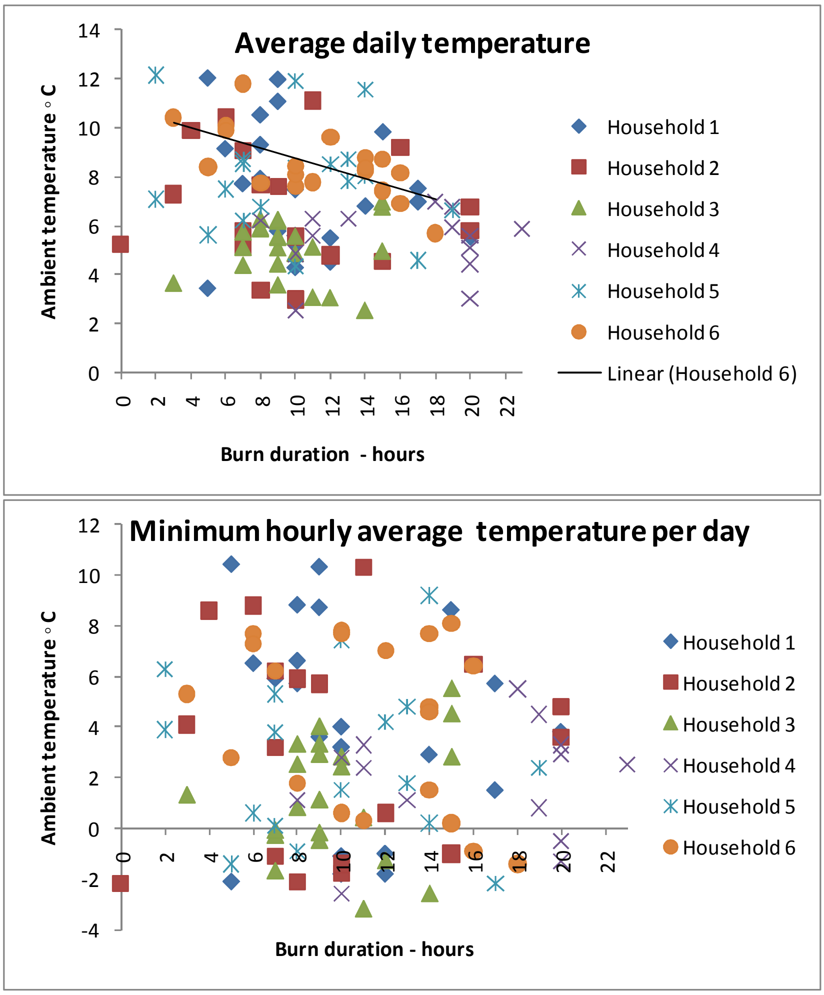

Figure 3-9: Influence of ambient temperature on burn duration.

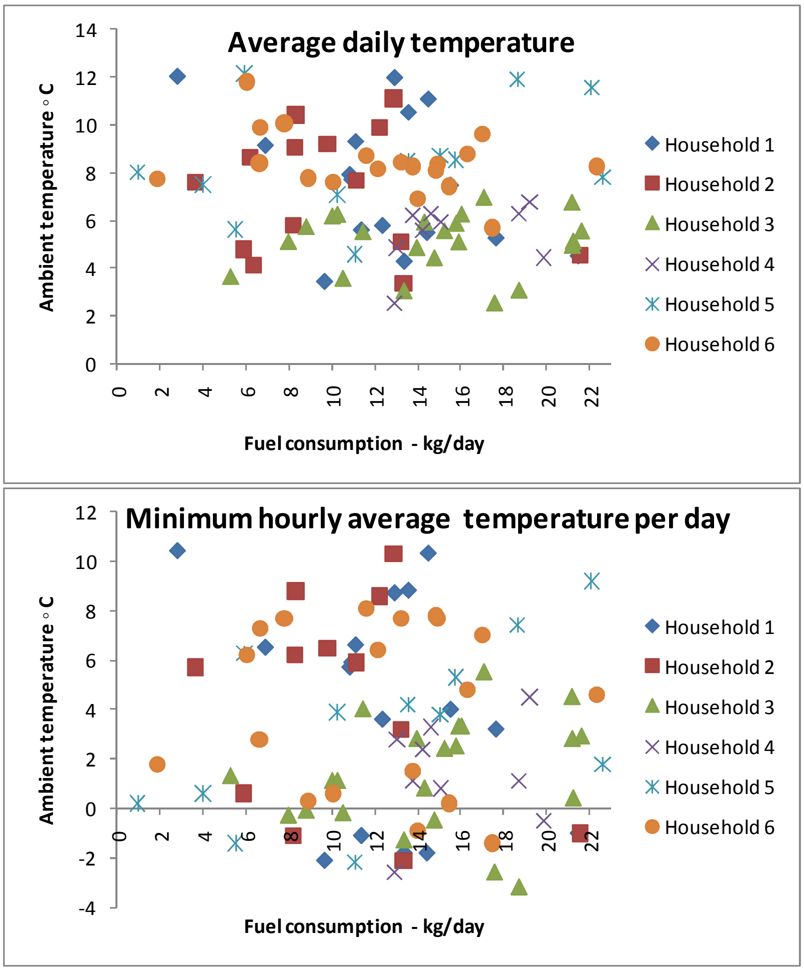

Figure 3-10: Influence of ambient temperature on fuel consumption.

Figures 3.9 and 3.10 show that average daily temperature may have had some influence on the burn duration for household six (r^2 = 0.4, linear trend shown in Figure 3.9) and fuel consumption (r^2 = 0.1) but was not consistently an influencing factor for other households. Minimum hourly average temperature per day did not appear to be an influencing factor on burn duration or fuel consumption for any households.

4 Conclusion

- This study evaluates operational, emissions and indoor data collected from six Christchurch households during the “real life” emissions testing of NES authorised wood burners during 2009. The main objective of the wider programme was to evaluate emissions from the burners to assist with the science of emission factors from NES compliant and 1.0 g/kg wood burners (Bluett, et. al., 2010). The objective of this study is to utilise the data collected in the Christchurch 2009 real life study to provide further improvement to emission inventories by:

- Determining a diurnal profile for PM_{10} emissions from domestic home heating.
- Measuring the weight of wood used by householders to heat their homes
- Assessing the impacts of wood burner use on indoor temperature, relative humidity, CO and PM_{10}
- Investigating factors that influence the start-up of domestic woodburners

A daily particulate profile was established and will be of value in determining emissions profiles for inventories or modelling. This hour-by-hour profile is more detailed than the 24-hour average period used in many inventories to date. It is noted, however, that the profile relies on emissions from just six households and more testing is required to refine the profile derived.

The average fuel consumption per household for this study was 15.5 kg/day. Use of this value is limited by the small sample size. However, results are consistent with studies done in the early 2000s (as reported in Wilton, 2004). The value of 15.5 is lower than the 23 kilograms per day assumed in the Environment Canterbury projections modelling (Angie Scott, pers comm. 2005). Further measurements of the average daily fuel consumption are recommended for Christchurch.

Previous studies have identified wood moisture content, flue temperature and flue oxygen to be the key determinants of PM_{10} emissions from solid fuel burners. In this study behavioural factors such as burner start up time, burner duration and fuel consumption were evaluated along with temporal relationships between emissions and other variables.

For most households start up time, burn duration or fuel consumption did not appear to be consistently influenced by temperature (indoor or ambient) and start times appeared to be mostly related to lifestyle factors. The exceptions were household five for which start up time may have been influenced by the temperature at start up and household six for which burn duration was influenced by average ambient temperature.

A key concern highlighted in the 2007 testing was the variability in average emissions from NES compliant burners from different locations in New Zealand. While results from this study are within the ranges of those observed previously they are much higher than the average for the Nelson testing. It is uncertain whether some location specific factors are influencing emissions from different urban areas or whether the differences are a function of the small sample sizes. To date, 24 households with NES compliant burners have been tested. Further tests are required and additional investigations into location specific factors are recommended.

5 Recommendations

- Further studies of daily average fuel consumption in Christchurch and other places be carried out.

- Data on indoor PM_{10} concentrations be further analysed to better characterise the relationship between ambient PM_{10} concentrations and indoor concentrations and to examine potential influences of non-solid fuel burning indoor sources.

- Councils give consideration to measures to improve the quality of wood burnt, specifically the moisture content (e.g., good wood scheme for Nelson), and options for ensuring appropriately sized wood burners are installed and operated well.

- Further emission testing be carried out to:

    - assist in the development of more robust emission factor for NES compliant burners

    - determine potential inter Region variability in PM_{10} emissions

    - further characterise the temporal profile of emissions from wood burners

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7 References

Bluett, J. and Meyer, M., 2011. Measurement of Real-world particulate emissions from domestic wood burners – Christchurch 2009. 20th International Clean Air and Environment Conference. Auckland 31 July to 2 August 2011. ISBN 978-0-9806045-1-1.

Kelly C., Mues S. and Webley W. (2007) Real life emissions testing of wood burners in Tokoroa. *Ministry for the Environment Warm Homes technical report no. ME814*

McCauley M., and Scott A. (2006) Inventory of emissions to air in Waimate, Ashburton, Kaiapoi and Rangiora, 2004. *Environment Canterbury report no. R06/24*.

Metcalfe J.L., Fisher G.W., Sherman M.W. and Kuschel G.I. (2006) Auckland air emissions inventory: 2004. *Auckland Regional Council technical publication 292*.

Meyer, M.; Luhar, A.; Gillett, R,; Keywood, M. 2008. Measurements of real world PM_{10} emission factors and emission profiles from wood-heaters by in situ source monitoring and atmospheric verification methods. http://www.environment.gov.au/atmosphere/airquality/research/carp.html

Scott A. (2005) Real life emissions from residential wood burning appliances in New Zealand. *Ministry for the Environment Sustainable Management Fund report, ID number 2205*.

Scott A. and Gunatilaka M. (2004) 2002 Christchurch inventory of emissions to air. *Environment Canterbury report no. R04/03*.

Smith J., Bluett J., Wilton E., Mallett T., (2008) In home testing of particulate emissions from NES compliant woodburners: Nelson, Rotorua and Taumarunui2007. NIWA report number CHC2008-092.

Wilton E. (2003) Emission inventories for PM_{10} in New Zealand. *Air quality technical report no. 38 prepared for the Ministry for the Environment*.

Wilton, E., 2004, Summary of 2001 Air plan projections. Unpublished paper prepared for Environment Canterbury.

Wilton E. (2005a) Hamilton emission inventory 2005. *Environment Waikato technical report no. TR05/52R*.

Wilton E. (2005b) Air emission inventory – Hawkes Bay 2005. *Hawkes Bay Regional Council*.

Wilton E. (2005c) Warm Homes Technical Report: Home Heating Methods and Fuels in New Zealand. *Air quality technical report prepared for the Ministry for the Environment*.

Wilton E., Smith J., Dey K. and Webley W. (2006) Real life testing of woodburner emissions. *Clean Air and Environmental Quality* 40(4), 43-47.

Wilton E., (2006) Air emission inventory Nelson 2006. *Nelson City Council.*

Wilton E., and Baynes, M., (2008) Air Emission Inventory – Masterton 2008. *Greater Wellington Regional Council.*

Wilton, E., & Bluett, J., 2010, Factors influencing particulate emissions from low emission woodburners in Nelson, Rotorua and Taumarunui- 2007. NIWA report number AKL2012-013

Wilton, E., 2011, Emission inventory for Invercargill and Gore. Environment Southland Technical Report.

Appendix A Daily household data for households three and six

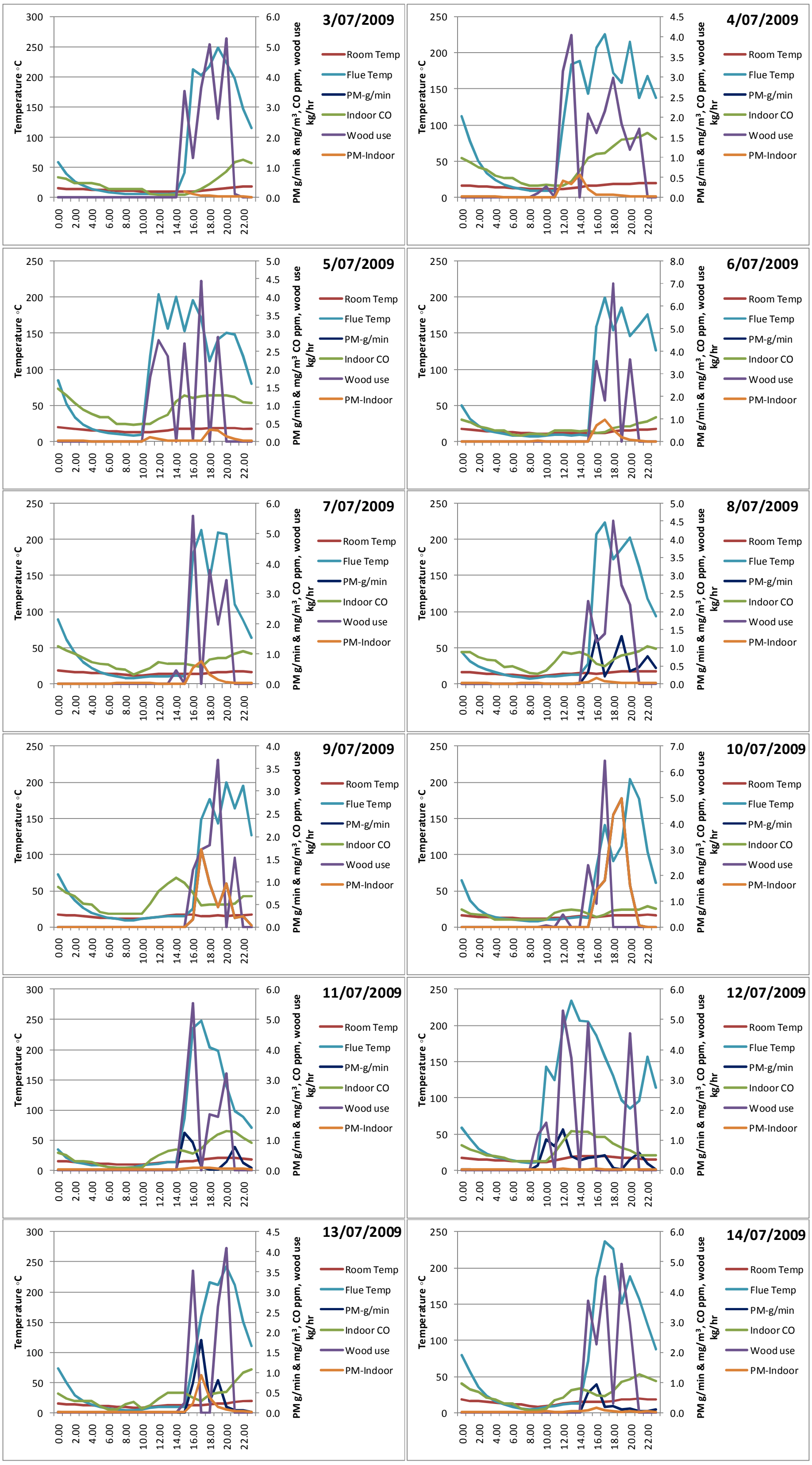

Figure A-1: Daily household data for household three.

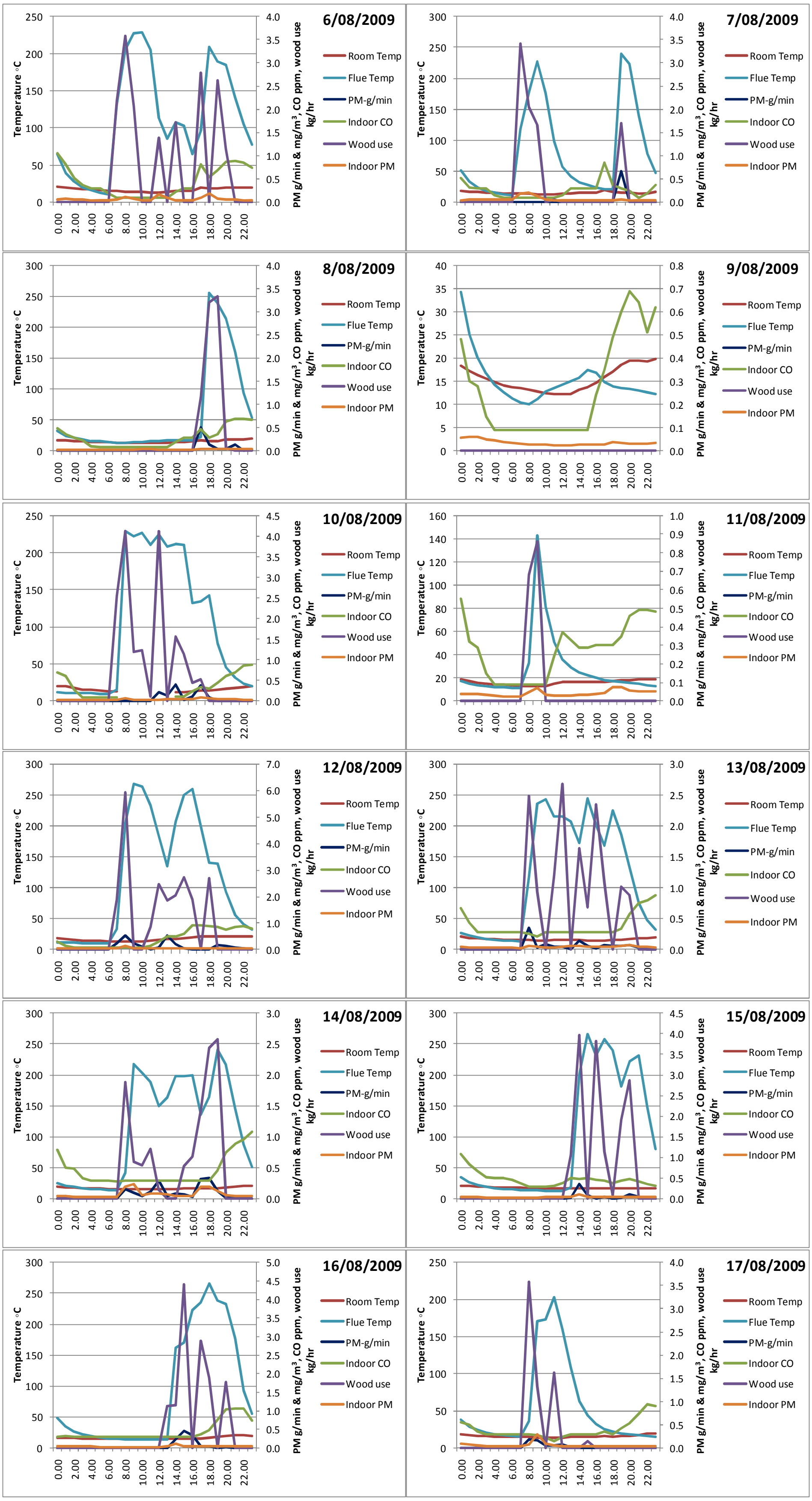

Figure A-2: Daily household data for household six.