The use of biomass fuels in the UK, and the potential human health and environmental impacts

In partnership with the Gas Safety Trust and Milton Keynes Council

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Abstract

Biomass is used as domestic fuel for cooking and heating in many developing countries. The recent adoption of biomass for this purpose in developed countries, such as the UK, is associated with its sustainability, energy security and potential to mitigate the emissions of greenhouse gases and global warming, when compared to conventional fuels. However, not much is known about the health and environmental impacts of emissions from biomass burning.

This study examined the health and environmental effects of emissions from domestic biomass burning devices in the Milton Keynes area, United Kingdom. Questionnaire-based survey was conducted to understand the public perception of biomass. Trial measurements of indoor air quality were conducted in six houses near Cranfield University. CO and PM were measured in order to assess the impact of domestic biomass burning devices. Laboratory analysis of metal content and particulate matter of bottom ash from such combustion was carried out using Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) and Dynamic Light Scattering (DLS) methods.

It was found that the public awareness of risks associated with the use of biomass is low and that the views are divided concerning biomass benefits. The indoor air quality contained more pollutants in homes with biomass burning devices than in homes without. The ash showed little content of heavy metals, but the particulate matter sizes were very large compared to the sizes which are known to be toxic (PM 0.1, 2.5 and 10) after characterisation. Bottom ash from biomass combustion contains large-sized particulates which are not toxic to the alveolar epithelium because they do not penetrate these cells.

There is need for further study to examine the effects of fly ash particulates on these cells as they are finer than bottom ash; more houses, especially with modern biomass boilers, should be sampled for measurement of indoor air quality.

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List of Abbreviations

%db	Percentage of dry basis
%LEL	Percentage of lower explosive limit
AQG	Air Quality Guidelines
BEC	Biomass Energy Centre
BM	Biomass (Houses numbered 1, 2 and 3)
C	Carbon
Ca	Calcium
CBC	Central Bedfordshire Council
Cd	Cadmium
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
Conc.	Concentration
Cr	Chromium
CSE	Centre for Sustainable Energy
Cu	Copper
db	Dry basis
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
DLS	Dynamic Light Scattering
EST	Energy Saving Trust
ES&T	Environmental Science and Technology, Department of Cranfield
Fe^{2+}	Ferric iron
Fe^{3+}	Ferrous iron
FIT	Feed In Tariffs
H	Hydrogen
HCl	Hydrochloric acid
H_2SO_4	Sulfuric acid
HAPs	Hazardous air pollutants
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy

kg	Kilogram
kW	Kilowatt
MJ	Mega Joules
MK	Milton Keynes
MKB	Milton Keynes borough
MKC	Milton Keynes Council
MREC	Multi-Centre Research Ethics Committee
MW	Megawatt
MWh	Megawatt hour
n	nano
N	Nitrogen
NH_3	Ammonia
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
N_2O	Nitrous oxide
NOBM	No Biomass (Houses numbered 1, 2 and 3)
O	Oxygen
O_3	Ozone
Ofgem	Office of Gas and Electricity Markets
ONS	Office for National Statistics
P	Phosphorous
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead
PdI	Polydispersity Index
PID	Photoionization detector
PM	Particulate Matter
$PM_{0.1}$	Particulate Matter smaller than 0.1 micrometres in diameter
$PM_{2.5}$	Particulate Matter smaller than 2.5 micrometres in diameter
PM_{10}	Particulate Matter smaller than 10 micrometres in diameter
RHI	Renewable Heat Incentive

ROCs	Renewable Obligation Certificates
S	Sulphur
SO_2	Sulphur dioxide
SO_x	Sulphur oxides
SEREC	Science and Environment Research Ethics Committee
SPSS	Statistic Package of Social Sciences
SRC	Short Rotation Coppice
TSP	Total Suspended Particulates
TPM	Total Particulate Matter
t/ha	Ton per hectare
UK	United Kingdom
UPC	Ultrafine Particle Counter
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
WHO	World Health Organisation
wt	weight
µ	micro
Zn	Zinc

1. Introduction

Worldwide energy production currently relies on fossil fuels as a source of electricity and heat generation, as over 80% of the world's energy comes from fossil fuels (City of Whitehorse, 2007). This dependence is not sustainable, since fossil fuel reserves will eventually run out if the energy consumption trends continue as they are at present (Eco-info). For instance the UK is no longer self sufficient in natural gas production as the North Sea resources are depleting (Skea *et al*., 2011).

On the other hand, these sources of energy are major contributors to climate change due to the greenhouse gases emitted (mainly CO_2) during their combustion for energy generation. Again its market is likely to suffer great price fluctuations which may endanger the energy security of consumers. The previous issues are also true for the UK. As shown in Figure 1, the UK domestic energy mix is clearly dominated by natural gas with a 63% share, which almost replaced coal completely over time.

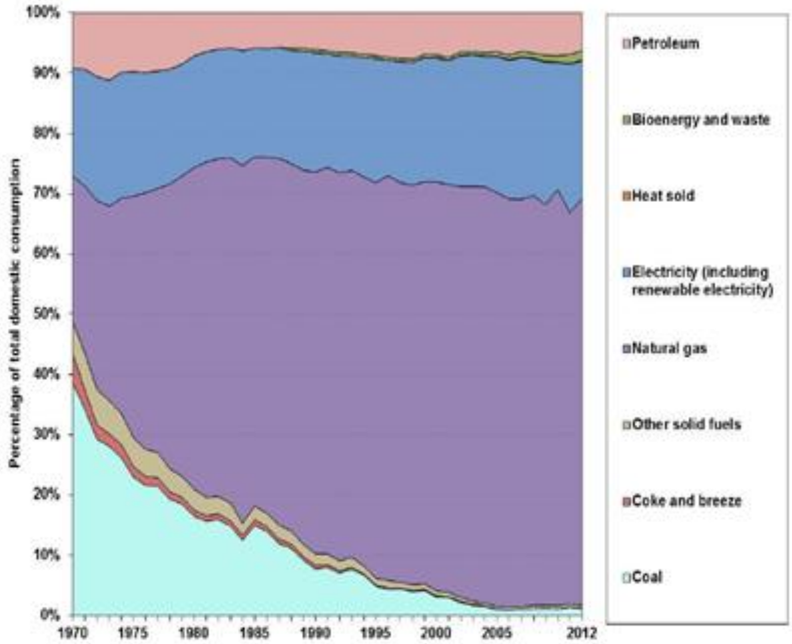


Figure 1: Domestic energy consumption by fuel, UK (1970 to 2012) (DECC, 2013)

However, renewable energies will play a key role in climate change curbing due to their possibility of helping the decarbonisation of the energy sector (DECC, 2011). As a result of this, the European Union set precise objectives in terms of energy: by the year 2020, a 20% of the energy production should come from renewable sources e g. biomass.

There is a growing recognition of the importance of biomass burning as an energy source with regards to domestic and small commercial scale biomass boiler in developing and developed countries (Hall *et al.,* 1991). As reported by Hammond, *et al.* (2008), biomass is a key tool that helps to reduce carbon emissions, effects of climate change and energy prices, thereby ensuring energy security, compared to fossil fuels.

The term 'Biomass' is a biological material derived from living or recently living organisms. With respect to energy, biomass is often regarded as plant based materials, however it can include animal and vegetable derived materials. It is carbon based and is composed of organic molecules containing hydrogen, oxygen, often nitrogen and minute amount of heavy metals present in functional molecule such as chlorophyll which contains magnesium (BEC, 2011). Example of biomass includes: wood, straw, poultry litter or energy crops, and all of which can be burnt to produce energy. Such includes a thermochemical conversion of biomass resources to produce heat (Figure 2) using small scale-devices.

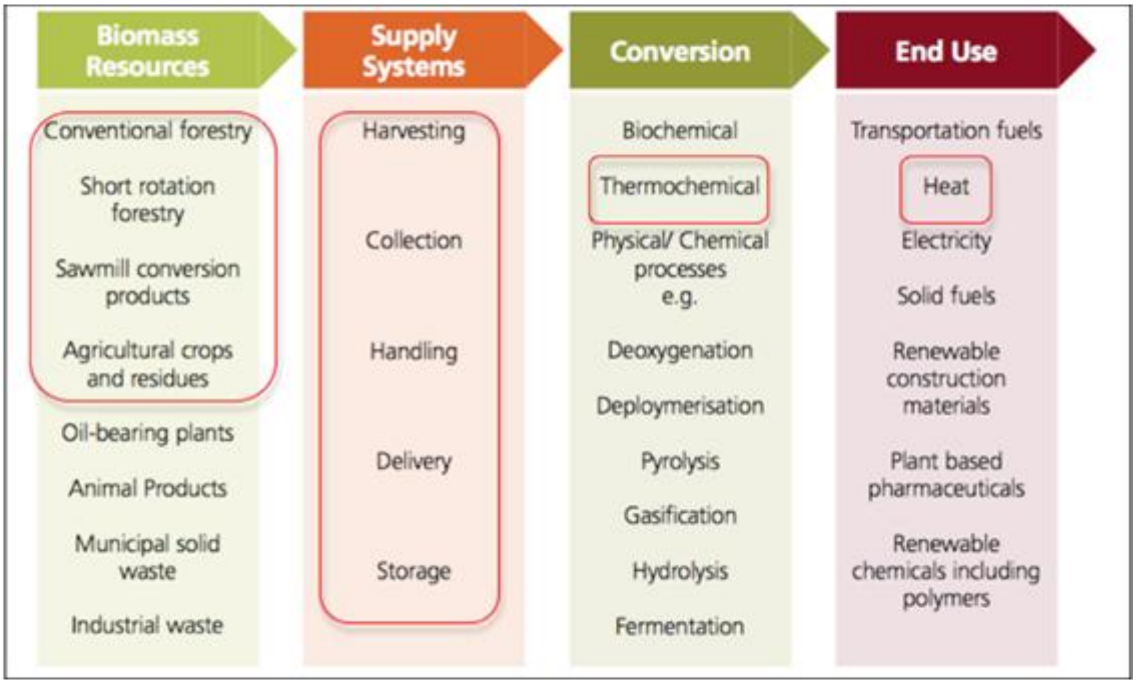


Figure 2: Biomass supply chain (DEFRA, 2007)

The size of the facilities spans from a few kilowatts (kW) for a stove to heat a room to several megawatts (MW) for a large power plant and the type of feedstock used is mainly wood from forestry or sawmill, energy crops and agricultural residues that are solid. Hence to match domestic stoves and boilers feedstock requirement, the biomass is commercialised in three main forms: chips, pellets and logs, which are displayed (Figure 3)

Figure 3: Type of biomass fuel- from left to right: chips, pellets, logs (Ashwell Biomass, 2012)

In domestic setting, the two main types of biomass system used to provide heat are stoves which are installed in rooms, and boilers which serve as central heating systems. The typical heat capacity is around 10kW. Figure 4 shows the combustion process in a burner which produces ash and many emissions including CO and PM. After the combustion, these flue gases are conveyed through a heat exchanger and then led into the chimney (Obernberger and Thek, 2010).

Figure 4: Diagram of the system at study (author)

In the UK, biomass burning is envisaged to be a key part of the strategy for heat supply. A switch from conventional fuels, such as natural gas to biomass could help the country hit renewable and CO_2 emissions targets. However, biomass burning could have some impact on air quality and consequently on human health.

The Gas Safety Trust focuses on reduction in CO emissions from the use of conventional fuels since central heating appliances relate to over 66% of reportable CO incidents (Gas Safety Trust, 2010).

The Milton Keynes Council awaits a study of fine PM emissions from biomass combustion as it could have significant health impacts. Figure 5 shows potential for biomass burning to make a significant contribution to particulate emissions as is the case in Austria where residential heating produces almost as much fine particulates as traffic and wood is the main contributor to these emissions.

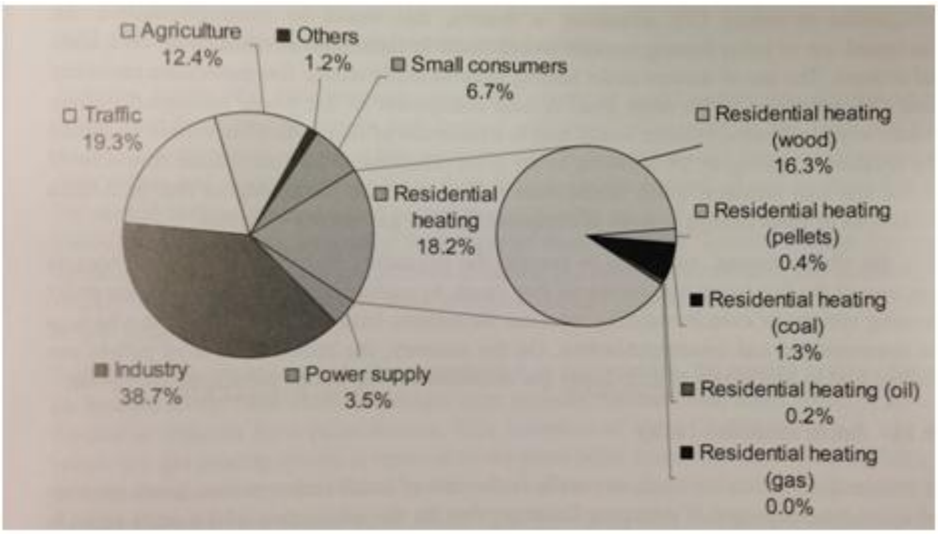


Figure 5: Fine particulate emissions in Austria (Obernberger and Thek, 2010)

1.1. Aim and objectives

1.1.1. Project objectives

This project aims to identify the environmental and health impacts associated with indoor biomass burning emissions in the UK – Milton Keynes area.

The objectives of this project are:

1. To critically review the emissions from biomass burning, compare to conventional fuels and discuss future scenarios of biomass use.
2. To conduct surveys to understand the public awareness and perception of biomass burning for domestic use.
3. To conduct trial measurements of indoor air quality in homes using biomass burners.
4. To conduct laboratory analysis on bottom ash to determine the presence of heavy metals and size of particulate matter ($PM_{0.1,2.5,10}$).

The study involves reviewing existing literatures, designing and implementing questionnaire-based survey, assessing indoor air quality based on trial measurements, and laboratory analysis of particulates from biomass burning. Results obtained would be used to evaluate the impacts of emissions from biomass burning associated with environment and health. Finally a focus on all these impacts is analysed regarding Milton Keynes (MK).

1.1.2. Table of responsibilities

There are four main tasks in the project: literature review, laboratory analysis of metals and PM from biomass ash, trial measurements of indoor air quality and a survey. These tasks are divided between the group members, one task for two or three persons. The task delegation is detailed in the Appendix A.1. should any question arise regarding one of these parts.

A detailed Gant chart with the project planning is included in Appendix A.2. It shows the project timeline followed according to the different tasks.

2. Literature review

2.1. Methodology

A literature review structure was outlined covering basic areas relevant to the project topic. Peer review was used to gather information and literature review was desk based. Journal articles, books, theses, dissertations, library catalogues, government reports from newspapers and information on websites from 1980-2014 were used. The Appendix B provides more detail.

2.2. Use of biomass for domestic heating

2.2.1. Definitions within the scope of the research

2.2.1.1. Biomass & its general issues

Biomass could be sourced from wood, straw, agricultural residues and energy crops. All of which can be combusted to produce energy. Solid biomass is made up of cellulose, hemi-cellulose and lignin; carbon (C), oxygen (O) and hydrogen (H) which are its constituent elements; but it can also contain nitrogen (N), sulphur (S) or various minerals such as calcium (Ca) or phosphorous (P) (Biomass Energy Centre, 2011).

Biomass burning produces little net carbon dioxide (CO_2) emissions to the atmosphere (Singha and Shuckla, 2013). But there are some issues to take into account:

- Environmental and health issues: both due to the gases and particles released to the atmosphere, which can be harmful for environment and health. For example, the 25% of all primary fine particle emissions in Finland came from domestic wood combustion in the year 2000 (Leskinen, *et al.,* 2013).
- Low energy density: more material must be transported to supply a specific amount of energy required for a power plant. Therefore, the source of biomass should be near the combustion plant. A good idea is to increase the density the raw material (Toscano L. A. and Barriga).
- Storage space: as a result of biomass low energy density, the storage space needed is usually really big.
- Odour: stored biomass odour is usually really strong and it can be disgusting. Besides, this odour is increased by the one emitted in the burning process.

2.2.1.2. Technologies for domestic biomass combustion

Biomass use for domestic application includes two main types of devices: stove and boiler, both displayed on Figure 6. A single stove is used to heat one room and a boiler (or furnace) is used to provide heat to a central heating system.

Figure 6: Left to right – stove using logs, boiler using pellets (Biomass Energy Centre, 2011)

Table 1 below presents case studies (Obernberger and Thek, 2010) of the main characteristics of a stove and a boiler using pellets.

Table 1: Main characteristics of a stove and a boiler both using pellets

	Stove (Germany)	Furnace/Boiler (Austria)
Nominal heat output (kW)	8	10
Fuel consumption (kg/h) at nominal load	1.8 at nominal load	2.3 at nominal load
Wood consumption (kg/a)	900	4,100
Wood consumption (m3/a) - with a bulk density of 650kg/m3	1.4	6.3
Heat production (MWh/a) - with a pellet net calorific value of 4.7kWh/kg and a boiler efficiency of 90%	3.81	17.3
Storage capacity (kg)	16	6,000 (9.2 m3)
Lifetime (a)	20	20

2.2.2. Domestic energy and biomass in the UK

2.2.2.1. Current biomass contribution to heat and projections

Biomass is expected to play a key role in this development to meet the 2020 targets (Petroleum Review, 2010). It is a good option because it is able to get over the two main constraints of fossil fuels; its CO_2 emission level is lower and it goes into energy security by stable prices. Besides, biomass has a huge advantage when it is compared with other more established renewable energy technologies (e.g. wind): its energy production is predictable and non-intermittent.

The current contribution of biomass in the total percentage of fuel used to generate heat is expected to grow significantly by the year 2020 (Panoutsou and Castillo, 2011). Figure 7 shows the amount of biomass dedicated to heating in 2010 and the projections for 2020, differentiating the various kinds of biomass used for it. The type of biomass that will undergo the greatest growth is solid biomass, excluding biomass produced domestically, which will be placed in the second position.

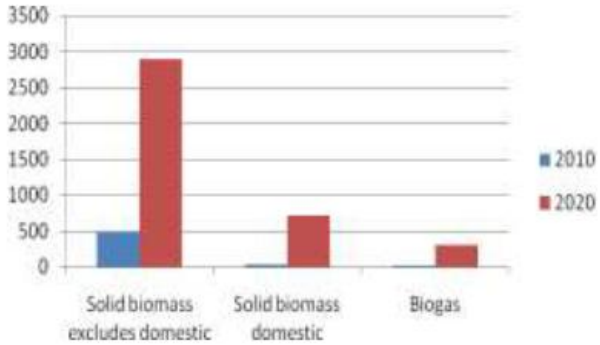


Figure 7: Estimated contribution (ktoe, kilo tonnes of oil equivalent) by biomass to heat, 2010 and 2020 (Panoutsou and Castillo, 2011).

Figure 8 shows how the energy used is distributed in terms of domestic consumption. The biggest share of domestic energy use corresponds to space heating, with a 66% share (DECC, 2013). For this clear reason, the primary objective of this report will be the use of biomass for heating generation and when the situation permits, it will also be used to produce electricity.

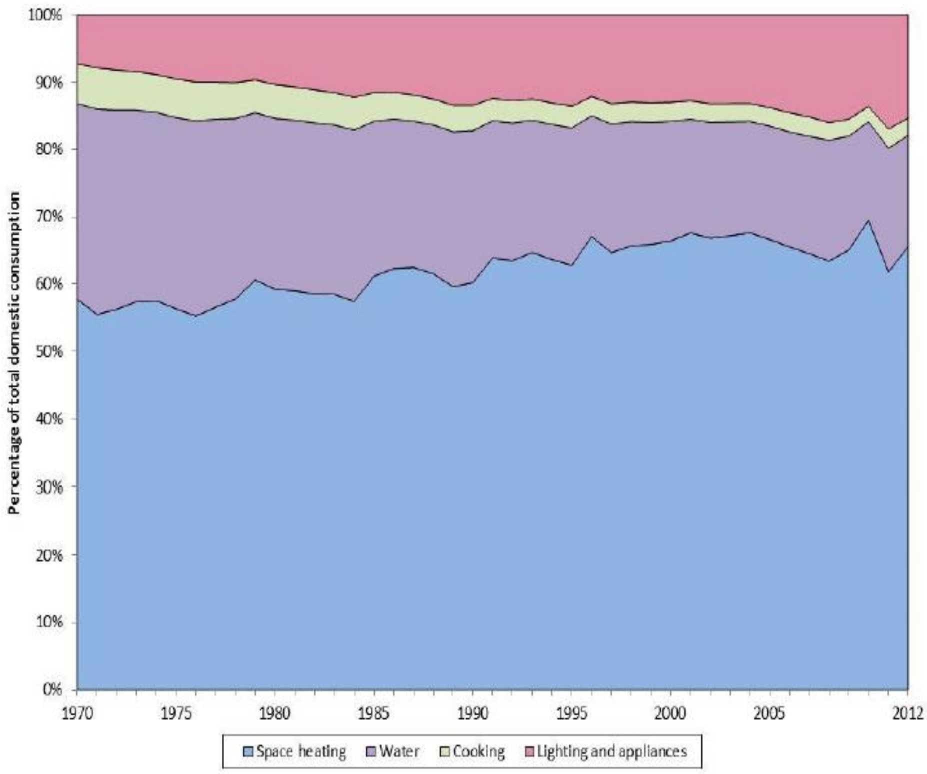


Figure 8: Domestic final energy consumption by end use, UK (1970 to 2012) (DECC, 2013).

2.2.2.2. Policies and incentives

In order to meet the expected growth and projections, the UK government set different policies and incentive for biomass technology development. The key mechanisms with relevance to biomass energy are the following:

- Renewable Obligation Certificates (ROCs): an obligatory system of tradable commodities in the electricity sector (GOV.UK). Their aim is to increase generation of renewable electricity from a range of technologies across all scales to 30%. Started in 2002 with support available to 2037 (Panoutsou and Castillo, 2011).
- Feed in Tariffs (FITs): a government programme of financial incentives designed to promote the uptake of a range of small-scale renewable and low-carbon electricity generation technologies. Introduced in 2010, it will close in 2021.Involves households, communities and small businesses investing in projects up to 5MW (Panoutsou and Castillo, 2011).
- Renewable Heat Incentive (RHI): equivalent to FIT but for renewable heat technologies. Introduced in 2011 with the aim of increasing renewable heat generation from a range of technologies to 12%. Involves individuals, communities and businesses investing in renewable heat at all scales. (Panoutsou and Castillo, 2011).
- Woodfuel Implementation Plan: Forestry Commission led plan to deliver a sustainable biomass industry based on English suppliers of woodfuel. Its aim is an additional two million green tonnes of material per annum by 2020 from under-managed woodlands. Introduced in 2010 (Panoutsou and Castillo, 2011).

Table 2 summarizes the different possibilities of biomass for energy production that could be interesting for this report and their corresponding incentive policies.

Table 2: Summary of policies that foster small scale bio-energy (Panoutsou and Castillo, 2011)

Segment	User type/needs	Support mechanism
Biomass heat - domestic	Stoves and domestic scale boilers. Residents require a range of fuel types, from local chips or logs to pellets.	Renewable Heat Incentive
Biomass heat - Commercial	Boilers in commercial, industrial or public authority buildings and facilities. Operators require range of fuel types, from local chips or logs to pellets.	Renewable Heat Incentive
Biomass heat - community / district heat	Local energy centres with district heat networks providing heat to residential and non-residential users. Operator of energy centre requires pellet or wood chip; end users require reliable, competitively priced heat.	Renewable Heat Incentive

2.3. Emissions

2.3.1. Emissions of domestic heating technologies

2.3.1.1. Emissions of biomass burning

The pollutants of the biomass flue gas stream are in two forms: gas and particulates. According to Toscano and Barriga, the particles present in the atmosphere are divided in two groups:

- Primary: derived directly from combustion sources, including road traffic, power generation, industrial processes etc.
- Secondary: formed by chemical reactions in the atmosphere, and comprise principally of sulphates and nitrates.

The components emitted to the atmosphere can be divided in two groups, those that appear when the combustion is complete and those which appear when it is incomplete (Table 3).

Table 3: Emissions according to the type of combustion carried out (Khorshidi Z., et al., 2013)

Emissions	Complete combustion	Incomplete combustion
Carbon monoxide (CO)	-	✓
Carbon dioxide (CO_2)	✓	-
Nitrogen dioxide (NO_2)	✓	-
Oxides of Nitrogen (NO_x)	✓	-
Methane (CH_4)	-	✓
Ammonia (NH_3)	-	✓
Non-methane volatile organic compounds (NMVOC)	-	✓
Particulate matter (PM)	✓	✓
Sulphur oxides (SO_x)	✓	-
Hydrochloric acid (HCl)	✓	-
Heavy Metals	✓	-
Ozone (O_3)	-	✓
Polycyclic aromatic hydrocarbons (PAH)	-	✓
Polychlorinated dibenzodioxins and Polychlorinated dibenzofurans	-	✓

According to Obernberger and Thek (2010), incomplete combustion in an inefficient wood burner has proved to have more risks for human health than burners that optimise the combustion.

2.3.1.2. Comparison with conventional fuels

Conventional fuels can be divided in two main groups:

- Fossil: coal, oil and natural gas

- Derivative fuels: petroleum coke, synthetic fuel, recovered gaseous butane, coal tar oil and coke oven gas

Principal pollutants that will be reviewed are nitrogen oxides (NO_x), particulate matter ($PM_{10-2.5}$), carbon monoxide (CO), volatile organic compound (VOC), sulphur dioxide (SO_2), and carbon dioxide (CO_2). It is possible to say that CO_2 emissions are generally very high, while NO_x and SO_2 are significantly lower (Partnership for Policy Integration, 2011) for all kind of boilers.

The Table 4 presents the emission from conventional and biomass fuels described by the Biomass Energy Centre as indicated by the Austrian Testing Agency. As shown in it, the kind of fuel used in a boiler influences the level of each type of emission. It appears that the gas-fuelled boilers produce less of each type of emissions than the other ones using coal, oil or biomass. The nitrogen oxides emissions stated in Table 4 are significantly higher for biomass than for gas, but the difference is not significant when considering biomass and oil. The PM emissions are almost at the same level for biomass and oil, whereas coal emissions are significantly higher. Gas is the only conventional fuel whose sulphur dioxide emissions are very low, whereas oil and coal have respectively high and very high emissions compared to biomass.

Table 4: Emissions from conventional fuels and biomass fuel with tested boiler <100 kW (Biomass Energy Centre, 2011)

Emissions	Conventional fuels	Biomass fuel
NO_x	5-20 mg/MJ gas 50-70 mb/MJ oil	60-170 mg/MJ Most below 100 mg/MJ
Particulate Matter (PM)	Less than 1 mg/MJ gas 5-50 mg/MJ oil 120 + mg/MJ coal	10-70 mg/MJ More than half <20
SO_2	Less than 1 mg/MJ gas 140 mg/MJ oil 900 mg/MJ coal	20 mg/MJ

The Table 5 below presents the same kind of data but showing also CO_2, CO and hydrocarbons emissions. The main benefit of biomass is that its CO_2 emissions are considered neutral regarding its lifecycle. The use of oil and natural gas is better in terms of CO, NO_x and especially PM emissions. Looking into different types of biomass, the use of woody pellets seems to be recommended along with new devices.

Table 5: Emission factors (mg/MJ) of different type of fuels from small scale devices (Obernberger and Thek, 2010)

Heating system	CO2	CO	C_xH_y	NO_x	SO_2	Dust (PM)
Woody pellets	0	102	8	100	11	24
Wood chips (before 1998)	0	1,720	88	183	11	54
Wood chips (from 2000 onwards)	0	717	18	132	n/a	35

Heating oil	75,000	18	6	39	45	2
Natural gas	55,000	19	6	15	0	0

Therefore, boilers using conventional fuels like natural gas have significantly lower emission of local air pollutants than those using biomass fuels. The only exception is SO_2 (Table 4) when comparing oil and coal to biomass.

2.3.2. Factors influencing the emissions

Although different emissions from biomass burning that can impact significantly on health and environment have been identified, their overall effect will depend largely on burning conditions (Streets and Waldholf, 1999). The different factors affecting the emission of gaseous species and particle matter are:

- Biomass characteristics and constituents
- Type of combustion technology used (design, age and maintenance)
- Conditions of combustion process: changing load, wind speed, temperature, moisture, etc. Taking into account all the possible factors, Leskinen *et al.* (2013) differentiated three kinds of combustion:
  - Efficient combustion: continuous optimal biomass combustion.
  - Intermediate combustion: non-optimal settings in continuously fired biomass.
  - Smoldering combustion: conditions adjusted to approach batch combustion conditions.
- Emission reduction actions taken in the plant.

The need of taking into account all the above said factors makes the precise measurement of these emissions quite difficult.

2.3.2.1. Feedstock characteristics

Table 6 compares some properties of differently treated biomass with black coal. As it is stated on it, the fuel is better as the treatment increases. For instance, the use of pellets is more recommended than using chips as it is a more homogeneous and dry fuel.

Torrefied pellets are processed pellets. Firstly, biomass is pretreated at a temperature between 200-300 °C. Biomass is completely dried and develops properties as a higher calorific value. Then it can be pressed into pellets, where the density and energy density is increased. The transportation is facilitated and the cost of transport and storage decreases as more energy can be transported at the same time (Happonen, 2011).

Table 6: Comparison between different types of biomass and coal properties (Khorshidi et al., 2013)

Property	Wood Chips	Wood Pellets	Torrefied Pellets	Black Coal
Moisture content (%wt)	40-50	7-10	1-5	10-15
Calorific Value (MJ/kg)	9-12	15-16	20-24	23-28

Volatiles (%db; dry basis)	70-75	70-75	55-65	15-30
Fixed Carbon (%db)	20-25	20-25	28-35	50-55
Volumetric Energy density (GJ/m3)	2.0-3.0	7.5-10.4	15.0-18.7	18.4-23.8
Hydroscopic properties	Hydrophilic	Hydrophilic	Hydrophobic	Hydrophobic
Biological degradation	Yes	Yes	No	No
Handling properties	Special	Easy	Easy	Easy
Product consistency	Limited	High	High	High

Besides, when considering the characteristics of the biomass used as fuel, it is very important to differentiate between wood and waste wood (also urban wood). The reason for this is that waste wood is usually treated or painted. Chromated Copper Arsenate (CCA) is a commonly used water-based wood preservative containing Copper Oxide (CuO), Arsenic Pentoxide (As_2O_5) and Chromic acid (CrO_3), and all of them pose risk to environmental and human health when released to the atmosphere (Wagland and Pollard, 2014). For this reason, wood resource should be used over herbaceous biomass.

Carbon and hydrogen contribute the most to the calorific value as they ignite exothermic reactions. That is the reason why energy crops and agricultural residues have a lower calorific value than woody biomass. Also energy crops and agricultural residues have a disadvantage comparing to wood: their combustion produces more fine particulate matter, NOx, SOx, HCl and ash (Obernberger and Thek, 2010).

2.3.2.2. Focus on particulate matter emissions

In modern small-scale wood boilers, around 90% in weight of total PM emissions are particles smaller than 1 µm. The fine particles are of two kinds: either soot or organic particles resulting from an incomplete combustion; or ash particles due to non-combustible matter, mostly potassium forming elements from ash (Obaidullah, 2012). Under incomplete combustion the toxicity of fine PM increases as more soot and hydrocarbon compounds are produced (Obernberger and Thek, 2010). According to Obernberger and Thek (2010), the concentration of fine PM in the flue gases depends highly on the age of the facility, the type of feedstock and the combustion conditions. The best conditions correspond to a new system working at a nominal load with wood pellets.

2.3.3. Emissions reduction methods

Removal of particulates generally falls into five main categories; gravity, centrifugal, electrostatic precipitator, fabric, and wet scrubbers (Singha and Shuckla, 2013).

There are different methods to clean the flue gas in the industry and consequently reduce the combustion emissions. Each method can use different technologies to accomplish the flue gas cleaning (Table 7). There was not found similar information for domestic appliances.

Table 7: Methods and technologies for flue gas cleaning

Method	Technology
Dry	Cyclones Electrostatic Precipitator Filters
Wet	Scrubbers Wet Electrostatic Precipitator Mop Fan
Hybrid	Electrocyclone Novel Swirl Cyclone
Removal of water solvable gas and mercury	

2.4. Environmental impact of biomass emissions

Biomass burning emits a complex mixture of air pollutants, both as gases and particulate matter (Jenkins, *et al.,* 1998). These gaseous pollutants include CO_2, CO, NO_X, SO_2, PM and other trace gases, which are capable of having an impact on the environment (Andreae and Merlet, 2001).

2.4.1. Airborne Particulates

Burning of biomass is a major source of airborne particulates. A study of 15 cities in United States found that 36% to 95% of airborne particulates during wintertime were produced by wood burning (Rozenberg, 2003). Burning of biomass produces large amount of PM which affects air quality as it increases airborne particulates in the atmosphere. In Quebec and Indonesia smoke from forest fires was found to increase particulates in the air around the incident area and some kilometres away from it (Awang *et al.,* 2000; Sapkota *et al.,* 2005). Airborne particulates could lead to varying effects on human health which depends on the level of exposure and the toxic components associated with the particles (Reisen and Brown, 2006; Naeher *et al.,* 2007). Particulates could be made up of toxic metals like mercury and lead, polycyclic aromatic hydrocarbons (PAH) and persistent organic toxicants such as dioxins (Dickey, 2000; Jaward *et al.,* 2004).

2.4.2. Greenhouse Effect

Biomass burning emissions such as CO_2 has been known to lead to greenhouse effect which contributes to climate change (Jain, 1993 and Najjar, 2011). According to Ma'mum *et al.* (2007), CO_2 contributes about 60% of greenhouse effect, 20% by Methane (CH_4) and 20% by nitrous oxide (N_2O), ozone and other industrial gases. However, the emissions of CO_2 from biomass burning is said to be carbon-neutral (Dermibas, 2005; Abbasi and Abbasi, 2006). This means that the CO_2 released into the atmosphere when biomass is burnt is about the same used during its production (growth and development of biomass). However, this depends on the sustainable use of biomass (Demirbas, 2005).

2.4.3. Smog formation and Acid Rain

Biomass burning also produces NOx which can undergo photochemical reactions in the atmosphere (Pandey and Chandrashekhar, 2014). These reactions produce new pollutants, including ground level ozone, exotic organic compounds and aldehydes. Ground level ozone (O_3) is dangerous to plants, trees, animals and human health. It inhibits the growth of plants, causes serious damage to forest trees and could lead to respiratory and cardiovascular problems in humans. Ground level O_3, CO, PM and VOCs interact to form smog, usually in the presence of sunlight (Westberg, Cohen and Wilson, 1971). Smog hampers visibility and also reduces the quality of air in the environment.

NOx and SO_2 emissions can indirectly cause damage to buildings, forests, soil and water resources due to the formation of acid rain (Flower *et al.* 1998). The reaction of NOx and SO_2 with other chemicals (hydrocarbons, VOCs etc.) in the atmosphere and water, in the presence of sunlight, produces nitric and sulphuric acids. These acids are dissolved in clouds and washed to the ground by rain or snow. This phenomenon is known as acid rain. However, Demirbas (2008) noted that since biomass fuels contain low levels of sulphur, especially from wood sources, the contribution of biomass combustion to acid rain is almost zero and is comparable to zero pollutant emission technologies such as solar, wind and hydro power. Hence, the use of biomass as a renewable energy could help in restoring balance in the environment.

2.4.4. Air Quality Objectives in the UK

In a bid to protect and enhance air quality in the environment, and also to improve public health and wellbeing in the UK, the national air quality objectives were established based on the European guidelines. The objectives were set on the different types of pollutants found in the environment and their toxicity levels. These objectives are shown in Table 8.

Table 8: Air Quality guidelines for both European Union (EU) and the UK (DEFRA, 2012)

Pollutant	UK objectives	EU Objectives	Period	EU permitted exceedences
Fine particles (PM2.5)	25 µg/m^3 Target of 15% reduction in concentration at urban background	25 µg/m3	1 year	n/a
PM10	50 µg/m3 not to be exceeded more than 35 times a year	50 µg/m3	24 hours	35
	40 µg/m3	40 µg/m3	1 year	n/a
Carbon monoxide (CO)	10 µg/m3	10 mg/m3	Maximum daily 8 hour mean	n/a
Nitrogen dioxide (NO_2)	200 µg/m3 not to be exceeded more	200 µg/m3	1 hour	18

	than 18 times a year			
	40 µg/m3	40 µg/m3	1 year	n/a
Sulphur dioxide (SO_2)	350 µg/m3 not to be exceeded more than 24 times in a year	350 µg/m3	1 hour	24
	125 µg/m3 not to be exceeded more than 3 times a year	125 µg/m3	24 hours	3
Lead (Pb)	0.5 µg/m3	0.5 µg/m3	1 year	n/a
Benzene	5 µg/m3	5 µg/m3	1 year	n/a
Ozone	100 µg/m3 not to be exceeded more than 10 times a year	120 µg/m3	Maximum daily 8 hour mean	25 days averaged over 3 years
Polycyclic Aromatic Hydrocarbons	0.25 ng/m3 as annual average	1 ng/m3 (expressed as concentration of Benzo(a)pyrene)	1 year	n/a

2.5. Human health impact of biomass emissions

Biomass burning emits a number of pollutants which contributes largely to indoor and outdoor air pollutions (Torres-Duque *et al.,* 2008). These pollutants, when emitted, are released into the atmosphere thereby compromising the air quality. This fact could result in indoor air pollution in many households (Bruce *et al.,* 2000). High amounts of these emissions can affect the indoor air quality in poorly ventilated homes.

Humans come in contact with these pollutants mainly by inhalation. Breathing in polluted air could have some impacts on human health. Oral uptake of contaminated plants and water, and dermal absorption could occur, with children. Elderly and people with pre-existing diseases are most susceptible (Schwartz, 1994).However, the magnitude of the effect will vary depending on the concentration of the pollutant and the time of exposure.

2.5.1. Particulate matter

The United State Protection Agency (USEPA, 2013) classified PM into:

- Inhalable coarse: particles greater than 2.5 micrometres and less than 10 micrometres in diameter.
- Fine: particles of 2.5 micrometres and lesser in diameter.

The former is found near roadways and dusty industries and the latter, in biomass smoke and haze.

Marilena and Elias (2007) indicated that PM health effect is determined by the particle size (aerodynamics diameter), of which USEPA is concerned with those of aerodynamic diameter 10 micrometres (PM_{10}) and less than 2.5 micrometres ($PM_{2.5}$). This is because they pass through the nose and throat into the lung and exert damaging impacts. However, according to World Health

Organisation (WHO), PM $_{2.5}$ is of major concern as it penetrates into lungs, interfering with gaseous exchange (WHO, 2011). Recently, particles with aerodynamic diameter less than 0.1 in micrometre (ultrafine particles) has been defined and found to have an elevated impact in the pulmonary and cardiovascular sections (Seaton, *et al*., 1995). Figure 9 shows PMs and the different location occupied in the lungs.

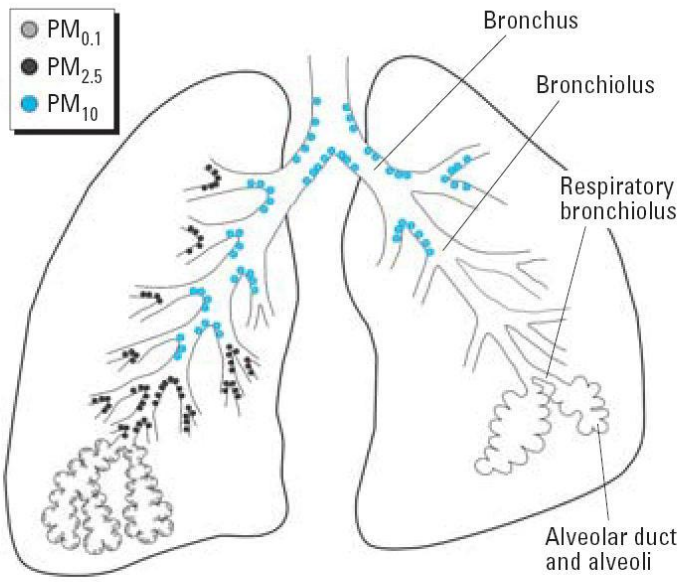


Figure 9 Showing the deposition of the different particulate MATTERS (PM $_{10}$, PM $_{2,5}$, PM $_{0.1}$) in the lungs (Cormier, et al., 2006)

Several studies have shown an association of PM and acute health effect of which infant, elderly and people with pre-existing diseases are most susceptible. One of which is increased risk of death due to cardiopulmonary dysfunction from indoor exposure to wood smoke (Core and Peterson, 2001). Again, PM that penetrates the alveolar epithelium initiates lung inflammation (Ghio and Huang, 2004).

Furthermore, epidemiological studies have documented an association between morbidity and PM exposure. Such includes decrease pulmonary functioning in school children with asthma (Koenig *et al.*, 1993) and $PM_{2.5}$; increase asthma emergency hospital visit in ages under 65 with PM_{10} (Schwartz, *et al*., 1993) and in children (Norris *et al.*, 1999) with $PM_{2.5}$. More so, Low birth weight (Boy *et al*., 2002), increase infant cough, wheezing and bronchitis (Pino *et al*., 2004) have been documented. In addition, in 2 out of 8 studies conducted by Lee *et al*. (2002) the mean level of PM_{10} was below that of USEPA standards, for that PM was suggestive as an asthmatic inducer in children.

According to Cynthia (2003), irritation of the eye (watering, burning), runny nose and sore throat could result from PM exposure and, PM in combination with SO_2 may induce irritating effect (Evan and Campbell, 1983). However, USEPA reported that in some part of USA, $PM_{2.5}$ is responsible for reduced visibility (USEPA, 2013).

Despite the evidences of acute health effect with PM, relatively few numbers of studies have investigated the chronic health effect from long term exposure of PM. There is also a strong evidence of about 34,000 women mortality resulting from chronic obstructive disorder (Smith, 2000) from indoor pollution. In addition Schwartz, (1994) reported an increase pneumonia and chronic obstructive pulmonary disease (COPD) with increase PM_{10} exposures in the elderly. Again, Dockery and Pope (1994), after adjusting for a range of risk factors found that life expectancy decreases with increasing concentration of ambient air $PM_{2.5}$ exposure. However, haven found reasons for the link between premature death and $PM_{2.5,}$ Dockery and Pope suggested that $PM_{2.5}$ is an environmental stressor.

Eeden (2001) documented bone marrow sensitization resulting to increase production of white blood and platelet cell. This promotes systemic inflammation which affects blood coagulation (Reidiker *et al*., 2004), cause diabetes (Pearson *et al*., 2010) and promotes development of heart problem in response to circulatory cytokines (Miller *et al*., 2007). Again it could worsen cardio-metabolic syndromes bought by unhealthy diet and life style (Carol, 2014).

Nevertheless, a little of the association of $PM_{0.1}$ and human health effect is known and has been reported as only implying to people with pre-existing diseases, genetics and age. Such documented health effect includes oxidative stress inducement, elevated pro-inflammatory response, immune problem and heart problems (Li *et al*., 2003; Donaldson *et al*., 2001; Oberdorster *et al*., 2005; Stone and Godleski, 1999) respectively.

2.5.2. Carbon monoxide

CO is known to be a toxic gas that causes hypoxia and asphyxiation because it is capable of causing death by depriving the body of oxygen (Prakash *et al.,* 2010). This is as a result of its affinity for haemoglobin. CO disrupts the transport of oxygen to organs and tissues by binding rapidly with haemoglobin to form carboxyhaemoglobin (COHb). According to Prockop and Chichkova (2007), the most susceptible organs to CO toxicity are the heart and the brain due to their high metabolic rates and requirement for oxygen.

Inhalation of CO results in common symptoms which include headaches, fatigue, dizziness and confusion, and is most times misdiagnosed as flu (Handa, 2005). When exposed for long periods to low concentrations, CO poisoning could decrease motor and cognitive functions as noted by Townsend and Maynard (2002). Further epidemiological studies have shown that in high concentrations, CO damages body tissues and increases cases of coronary heart disease and atherosclerosis, and could result in death in some cases (Therriault, 2001; Evans and Kantrowitz, 2002). People with pre-existing lung disease, chronic heart disease, anemia and respiratory problems (e.g. asthma) are at greater risks of being affected by CO poisoning.

Unborn babies are also at risk as CO inhaled by the mother will be passed onto the foetus. Foetal haemoglobin has greater affinity for CO. This could result to damage of the foetal brain as oxygen supply is interrupted, as well as low birth weight (WHO, 1999; Burg, 1999; WHO, 2008). Based on the acceptable exposure standards in the UK (see Table 8), and following the WHO research study, exposure of humans to CO levels greater than $29.7ug/m^3$ per day is toxic and dangerous to health (Townsend and Maynard*,* 2002). Studies have also shown that CO poisoning could lead to death within few minutes of exposure to high concentrations (Tam, *et al.*, 2012).

2.5.3. Oxides of nitrogen

The most common oxides of nitrogen (NO_x) are nitrogen dioxide (NO_2), nitrogen monoxide (NO), also known as nitric oxide, and nitrous oxide (N_2O). Exposures to small levels of NOx have been shown to result in eye and nose irritation, nausea and shortness of breath, while exposures to high levels can lead to death (Paul et al., 2008).

NO_2 is a toxic gas known to have negative effects on the respiratory system of humans as it causes irritation of the lining of the lungs and air passage (Paul *et al.* 2008). Experimental studies done by Helleday *et al.* (1995) showed that NO_2 reduces the regular beating of cilia lining the bronchial passage. As a result of this, the ability of the cilia to remove tiny particles and other contaminants alongside mucus from the respiratory tract is reduced (Helleday *et al.* 1995). When inhaled, NO_2 worsens cases of respiratory diseases such as bronchitis and asthma and can aggravate heart disease.

This gas is unhealthy for humans especially the elderly, children, people with chronic obstructive pulmonary disease and asthmatics as they are more susceptible (van Strein *et al.* 2004; Belanger, *et al.* 2006). Studies have shown that inhaling NO_2 causes nose, throat and lung irritations and triggers problems for people with pre-existing respiratory problems e.g. asthma attacks in asthmatics (Strand *et al.* 1997). As stated by Paul *et al.* (2008), symptoms associated with NO_2 include cough, eye irritation, headaches, chest pain, fever, dyspnoea and, in extreme cases, NO_2 can result to death. The UK government has recommended NO_2 air quality standard of 104.6ppb/hour mean as studies showed exposures to about 100ppb of this gas having effects on asthmatics (Devalia *et al*. 1994; Bayarm *et al*. 2002).

NO when inhaled in high concentrations forms methemoglobin, which carries iron in the ferric state (Fe^{3+}) instead of the ferrous state (Fe^{2+}), in the red blood cells (Corn, 2012). This reduces the ability of the blood to deliver oxygen to organs and tissues in the body which could result to death.

Nitrous oxide (N_2O) is a secondary product of the combustion of NO_2. It is often used as an oxidizer, anaesthetic or food additive (Rowland *et al.*, 1992). However, in high concentration, N_2O is seen to cause spontaneous abortion and reduced fertility in females (Rowland *et al.*, 1992). It is known to be capable of causing respiratory damage in patients with asthma at a concentration of 650 over 3 hours due to its acidic nature (Beckett *et al.* 1995; Belanger *et al.* 2006).

2.5.4. Others

2.5.4.1. Sulphur dioxide

Sulphur dioxide (SO_2) is known to affect human health by causing increased pulmonary resistance, bronchitis and bronchoconstriction (Komarnisky *et al.,* 2003). SO_2 forms sulphuric acid (H_2SO_4) when in contact with moist membranes such as in the eye, nose, respiratory tract and the skin (Komarnisky *et al.,* 2003). Studies have shown that long term exposure to SO_2 could lead to breathing problems especially in people with pre-existing lung and heart diseases (Dennison *et al.,* 2002). Children and the elderly are also susceptible to SO_2 respiratory illness.

2.5.4.2. Polycyclic Aromatic Hydrocarbons

Exposures to polycyclic aromatic hydrocarbons (PAHs) are known to have significant effects on human health. PAHs increase the risk of skin and lung cancers occurrence and have other non-carcinogenic effects on the gastrointestinal, pulmonary and renal systems (Nielsen *et al.,* 1996; Boström *et al.,* 2002). Studies have shown exposures to high concentrations of PAHs to be associated with childhood asthma, behavioural problems and reduced learning and memory (Schroeder, 2011).

In their experiments (Perera *et al.,* 2006), exposure to PAHs during pregnancy was discovered to cause premature births, heart malformations and low birth weights. Long term exposures result in liver and kidney damage, cataract and jaundice.

2.5.4.3. Volatile Organic Compounds

Volatile organic compounds (VOCs) have been associated with sensory irritations in the eyes, nose, throat and respiratory system, headaches, nausea and damage to the central nervous system, kidney and liver (Mendell, 2007; Dales *et al.* 2008). Some VOCs are known to be carcinogenic in humans (Knox, 2005). Symptoms of VOCs include headache, nose, throat and skin irritation, fatigue, dizziness, nausea and memory impairment. An experimental study carried out by Rumchev *et al.* (2004) shows that exposure to VOCs could increase the likelihood of asthma occurring in children. Long term exposures can cause cancer and exacerbate asthma and other respiratory illness (Rumchev, *et al.,* 2004).

2.5.4.4. Hazardous air pollutant

The USEPA classified two hazardous air pollutants (HAPs) as human carcinogenic (arsenic and the hexavalent form of chromium) and three HAPs (cadmium, lead and nickel) as probable human carcinogens. All of which are emitted in significant amount by biomass energy facilities which burn ‘‘urban wood’’ (Mary, 2012). The respiratory tract is the main organ of acute and chronic chromium toxicity exposure with recorded dyspnoea, coughing and wheezing for acute and, bronchitis, decreased pulmonary function, pneumonia and other respiratory effect for chronic (USEPA, 2013).

According to Ratnaike (2003), mercury, lead and arsenic play vital role in neurotoxicity with Lead responsible for amnesia and mercury neurological cancer (Marinela and Elias, 2007). Studies have also reported association of HAP exposure and pregnancy. Bellinger (2005) reported that heavy metals, especially Lead, can pose high risk of spontaneous abortion, stunted foetal growth and in-utero malformation. Also an impaired newborn cognitive ability could also result (Garza *et al*., 2006).

2.5.5. Factors affecting the degree of health impact

With the rising concern over the impacts of climate change on the environment, the demand for energy efficient buildings is increasing rapidly (Parliament, 2010). The structures are constructed in such a way that they are air tight and conserve energy. These buildings have been seen to positively impact mental and physical health of the occupants especially during the winter periods as they improve the indoor temperatures (Howden-Chapman *et al.,* 2007; Barton *et al.,* 2007).

However, there are concerns about the impact of increased air tightness as they are less ventilated. This inadequate ventilation makes them prone to air pollutants accumulation (Parliament, 2010). Gases from stoves, heaters and boilers would continue to accumulate in the building till it reaches concentrations higher than the indoor air quality standards. Insufficient ventilation causes the levels of indoor pollutants to increase (Bone *et. al,* 2010). Pollutants such as CO, NOx, VOCs, amongst others could adversely impact the indoor air quality as well as human health.

Other activities that can affect indoor air quality include most human activities which are capable of releasing pollutants. Activities such as cooking, smoking cigarettes, cleaning and cleaning fluids, and the use of cosmetic emits trace amounts of gases and particulates (Spengler and Sexton, 1983).

Cooking and smoking have been identified in several studies as significant activities which generate indoor particulates such as CO and NO_x (Buonanno *et al.,* 2009; Saade *et al.,* 2010; Wan *et al.,* 2011). Cooking methods such as boiling, frying, broiling, grilling and roasting all contribute to the emission of pollutants and are affected by the type of fuel used, temperature, ventilation and even the ingredients used (Zhang *et al.,* 2010). Smoking cigarette is known to produce unsafe levels of particulates and VOCs over a long period of time (Saade *et al.,* 2010).

Household cleaning fluids and chemicals have also been seen to emit trace amounts of HAPs when used as they can react with other air pollutants to produce secondary pollutants which are potentially harmful (Nazaroff and Weschler, 2004).

Building components such as paints, new electrical appliances, construction materials, carpets, upholstery, adhesives and furnishings being used in buildings can emit VOCs and heavy metals (Wallace *et al.*, 1987). This is due to the chemicals used during production. A building with new electrical fittings and furnishing should be properly ventilated to prevent accumulation of these pollutants.

2.6. Summary of the literature review

The current energy production worldwide is dependent on fossil fuels, but since fossil fuels are a finite resource, this is not sustainable. Biomass has been proved to be a key tool that will allow the energy production to go a step further in reducing fossil fuels dependency. The UK is not an exception to this, and several policies and incentives have recently set out to encourage energy production from biomass.

Producing energy by burning biomass releases to the atmosphere particulate matter and gases. The amount and nature of the released pollutants would highly depend on the used fuel and the combustion conditions.

After considering emissions from both biomass and conventional fuels, it can be concluded that biomass emits more CO_2, PM and NO_x than oil or gas. There is a need however, to consider the problem on a more global scale to assess whether biomass could be used instead of coal, whose emissions are considered to be the highest of any fuel. There are also factors (cleaning, type of feedstock, combustion optimisation and implementing the standards) to take into account while considering emission from biomass.

This technology of burning biomass emits a number of pollutants which has an effect on the air quality of the environment in different forms and as such causes impact on human health. However, the health impacts of these emissions can be mitigated if the factors responsible for the emission of the pollutants are put into consideration.

3. Questionnaire based survey

The aim of the survey was to investigate the public's perception of biomass burning for domestic heating. This survey was designed as a questionnaire directed towards a specified population target.

The first target considered is the campus of Cranfield University, consisting of the staff, students, and residents. Since a 1MW biomass boiler is being built on the campus, it was interesting to grasp the knowledge of the persons living in the nearby area.

However, after an exchange with the representative of Milton Keynes Council, it appeared that Milton Keynes area was also a good target, since the knowledge of its population will more likely reflect that of UK inhabitants. As a result, the survey covered residents of Milton Keynes district, Cranfield University and Village.

3.1. Methodology

3.1.1. Design of the survey

The design of the questionnaire itself was guided by the aims of the project and advice from the supervisors. The survey spanned a wide range of questions covering health, environmental and socio-economic aspects of the use of biomass for domestic heating. Some questions aimed to explore the knowledge of the local population about the details of biomass burning and its impacts on the environment and health; others targeted the attitudes towards a possible change to biomass fuels to supply one's home.

The survey was split in four main sections: personal background, biomass use for domestic heating, biomass impact on the environment, and on health and wellbeing. The questionnaire form is presented in the Appendix C.1.
The first questions asked were about the individual background and some accommodation characteristics. Then the enquiry followed on the knowledge and attitudes of the person towards biomass burning as an energy source for domestic heating.
Later on, the questionnaire studied the person knowledge on the links between biomass and four environmental issues that are climate change, renewable energy, sustainability, and air quality. Finally, the awareness of the impacts of domestic wood burning on health and wellbeing was investigated. The questions were focused on the emissions of CO, CO_2, NO_x, and PM.

The Appendix C.2. gives more details about the design of the survey.

3.1.2. Implementation

After design completion, the survey was sent for ethical approval to the University Multi-centre Research Ethics Committee (MREC), mandatory for any research project involving more than secondary sources, especially projects involving data collected from the public. The Appendix C.3. details how the ethical approval was granted and all the discussions with the MRE Committee.

This questionnaire-based survey was designed in two ways:

- An online survey with Google Drive form for Cranfield residents & MK Council staff, the link being sent by email or social media;

- A paper questionnaire for giving by hand during the day in public places only. Those places were the MK shopping centre, Kingston shopping centre, and MK train station. The work was split among the group depending on the availability of each member. The implementation was done by groups of two persons minimum.

The survey was to be implemented during two weeks, from the 28th of March to the 11th of April. The number of answers expected was about 100, with 80% coming from Milton Keynes.

3.1.3. Analysis of the results

The Statistic Package of Social Sciences (SPSS) was used to analyse the results. The paper questionnaires were reported in the spreadsheet along with the online ones. The database has been lightly reorganised while keeping the original version. A tab was created in which the people's living areas were grouped as MK, Bedford, Cranfield boroughs and 'others'. The Appendix C.4. specifies the towns included in each of the four areas.

In order to be closer with the main project aim, it is more relevant to look into the results from participants living in Milton Keynes Borough only (this sample is referred to as MKB in the whole discussion). When results from MKB and the general sample were different, results for both samples are exhibited. When they are similar, with less than 10% of difference and the same trend, then the findings from MKB sample were chosen when presenting the results.

The only part where the general results were systematically used is when doing crosstabs. Indeed, crosstabs are weak when there is not enough data (less than 50 answers).

3.2. Results

3.2.1. Sample statistics

The number of questionnaires collected is 295, including 100 from Milton Keynes Borough (MKB) residents. For the general population, people live mainly in Milton Keynes (34%), Cranfield (31%), Bedford (13%) and others from different locations around the UK, mainly in the close area such as Northampton, Aylesbury, or London. The sample called 'MKB' includes Milton Keynes, Newport Pagnell, Woburn Sands, and Olney inhabitants.

The Figure 10 below compares the main characteristic of the sample, depending of the area where participants are living.

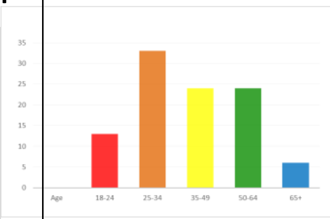
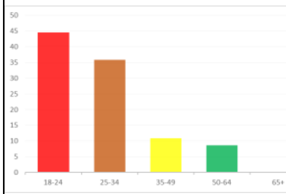
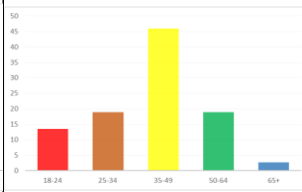
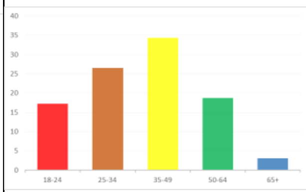
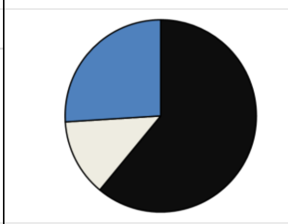
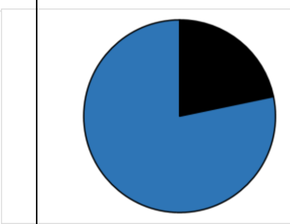
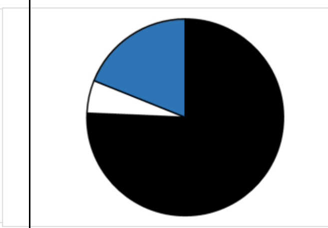
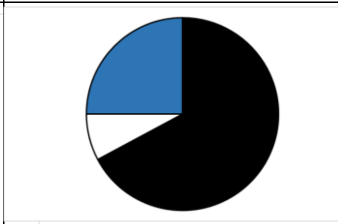
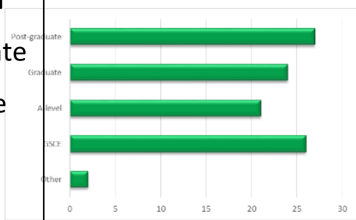
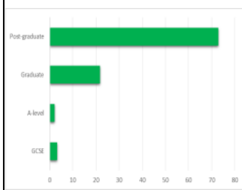
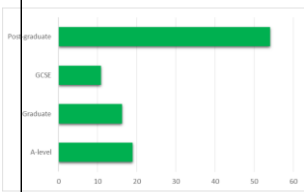
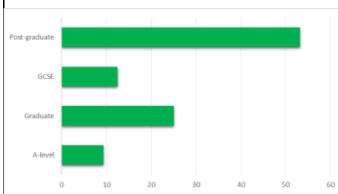
	Milton Keynes Borough	Cranfield borough (Marston Vale)	Bedford borough	Others
Number of responses	100	92	38	65
Male/Female	47/53	52/40	20/18	39/26
Age repartition 18-24 25-34 35-49 50-64 65+				
Occupation Employed Not employed Student				
Level of education -Postgraduate - Graduate -A-level -GCSE -None (MK only)				

Figure 10: Comparison of characteristics between the four main areas taken by the survey

3.2.2. Frequency results

3.2.2.1. Accommodation heating details

Concerning question 6, the proportion of the six different heating supply types is shown in Figure 11 below. More than half of all respondents use natural gas and more than a quarter use electricity. It is worthy to note that around 10% of responses are 'Do not know', which highlights the fact that domestic heating is considered by some as a service and not something you really decide on.

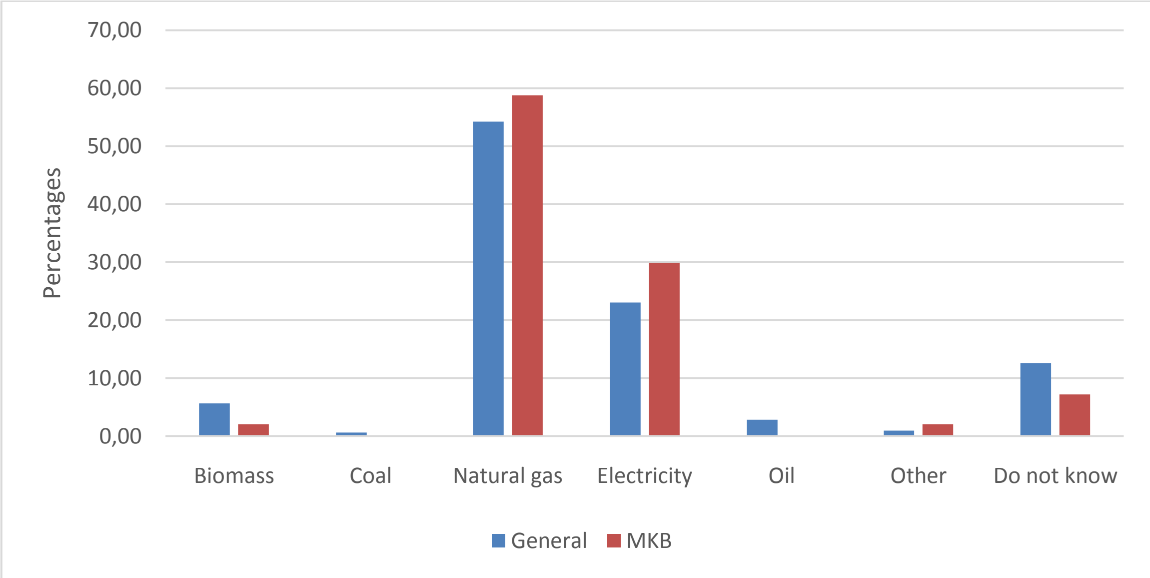


Figure 11: Type of heating supply for the two samples

It has been decided not to consider the results for question 7: 'Do you have domestic or individual heating supply?' as people were generally not aware of what is a district heating system.

The answers for question 8 are quite similar in both samples: around 90% of the sample has a smoke detector and only 35% has a CO monitor. It seems that possessing a smoke detector is more linked to the regulation in place than to a real concern for their safety. However, it was uneasy to establish whether the presence of a CO monitor was linked to awareness of risk from emissions or if it was simply a precaution measure.

3.2.2.2. Biomass use for domestic heating

When asking if people knew about biomass (question 9), about 80% answered 'yes'. Therefore, only 2 out of 10 people have never heard of biomass use for heating. They probably would understand wood but are not aware of the term 'biomass' encompassing a broader fuel. Looking at MKB sample, only 66% had heard of biomass before.

Concerning question 10, the results are very similar between MKB and the general population, so only MKB results will be used. About 43% of people interviewed answered that UK inhabitants should probably switch to biomass for heating their homes. Only 9% of them are definite answers and 36% answered 'Do not know'.

For the next question (question 11), 61% of the total participants said they would like to have a biomass-heating device in their home, whereas for MKB sample less than half of the sample said so.

3.2.2.3. Biomass impact on the environment

The results are very similar for question 12 between MKB and the whole sample; consequently MKB results only will be used. Half of the population think that biomass use would help more to mitigate climate change than fossil fuels use, when 38% do not adopt a position on this matter.

For question 13, out of MKB sample, more than two third of participants consider biomass as a renewable energy source, whereas only 23 % do not have a point of view, and 11% think it is not renewable.

In question 14, less than half of the population thinks that biomass is sustainable, 36% do not know and 23% think it is not sustainable.

For question 15, the Figure 12 below compares the opinion given by people on the indoor and outdoor air qualities in their respective area. The trend corresponds to a quality between average and good (3 and 4). It is noticeable that the outdoor air quality trend is more skewed to the right than the indoor air quality, however their average are essentially the same.

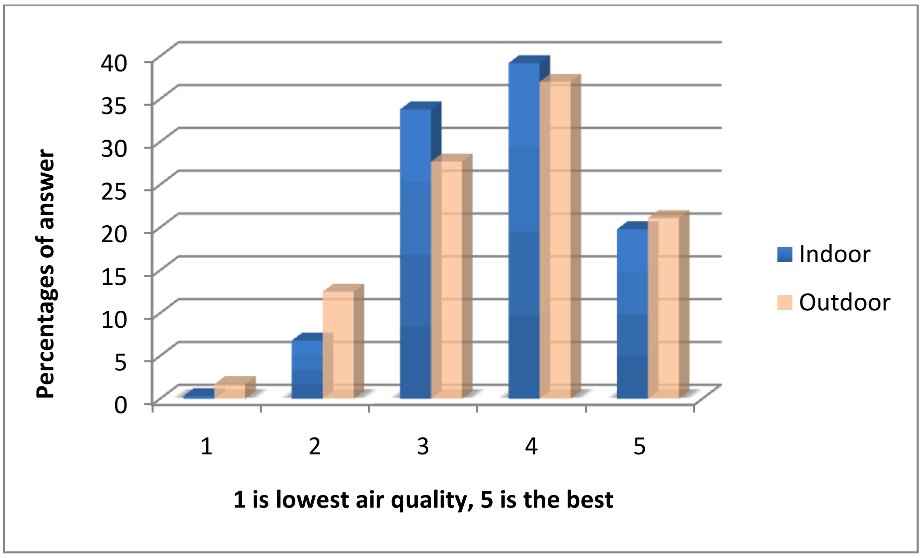


Figure 12: Comparison between indoor and outdoor air qualities for the general sample (question 15)

To discover whether the public thought that biomass use have a negative impact on air quality or not, the question 16 obtained some results which are similar wherever the person comes from. The majority of MKB sample, 39%, has picked that its use will probably have an impact, but it is significant considering that 22% answered 'no' against 8% responding 'yes'.

3.2.2.4. Biomass impact on the health & wellbeing

As in the previous questions, the answers of question 17 from MKB and from the rest are comparative. A majority of the MKB sample answered positively, 64% in a definitive manner and 20% thought it probable that air quality has an impact on the health.

In question 18, people are more aware (in decreasing order) of particulate matter (PM), carbon dioxide (CO_2), carbon monoxide (CO) and nitrogen oxides (NO_x) emissions from biomass burning as shown on Figure 13. The proportion of people responding 'yes', which is the right answer, is respectively for MKB and the general sample: 55% and 71% for PM, 49% and 65% for CO2, 37% and

49% for CO and finally 22% and 34% for NO_x. In both samples, NO_x has the highest rate of 'do not know' answers, and PM the lowest one.

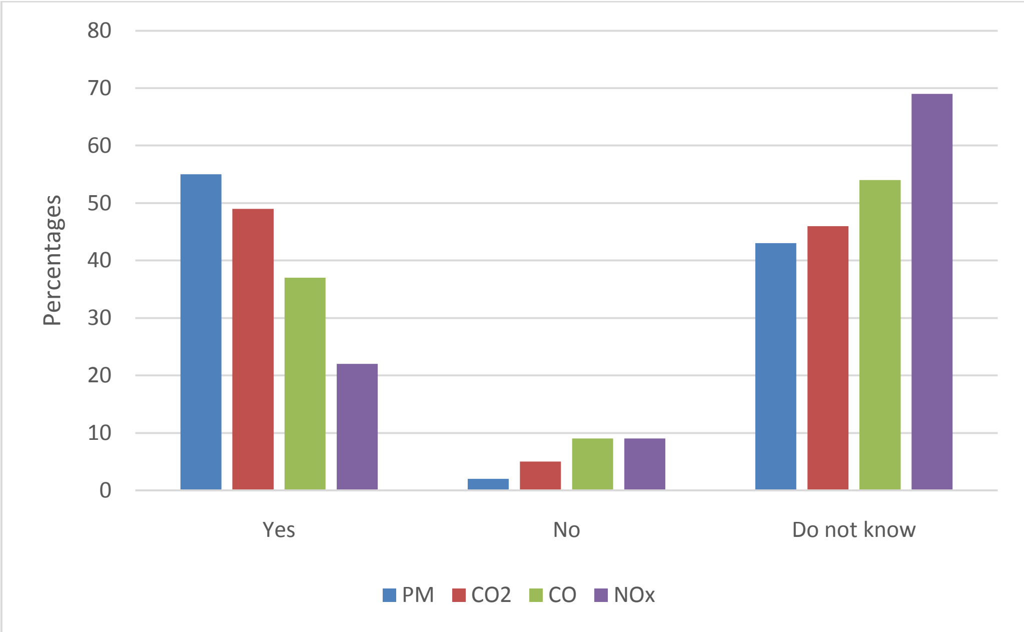


Figure 13: Comparison of the population's knowledge about biomass emissions (question 18)

For the question 19 on Figure 14, the greatest percentage of 58% of 'do not know' answers is associated with NO_x emissions, which is similar to the previous question. CO is considered as the highest risk emission with a mean value of 4.3. The mean value of the risk associated with PM is 3.5 and 3 for CO_2 and NO_x.

The major difference between both samples concerns the number of people answering '5' for a higher risk for CO, which is of 48% for the general sample and only 35% for the MKB one. Similarly, this is counterbalanced by 'do not know' answers in the MKB sample. Also for PM, 26% of the general sample answered '4' and 16% '5' compared to 19% and 11% for the MKB one.

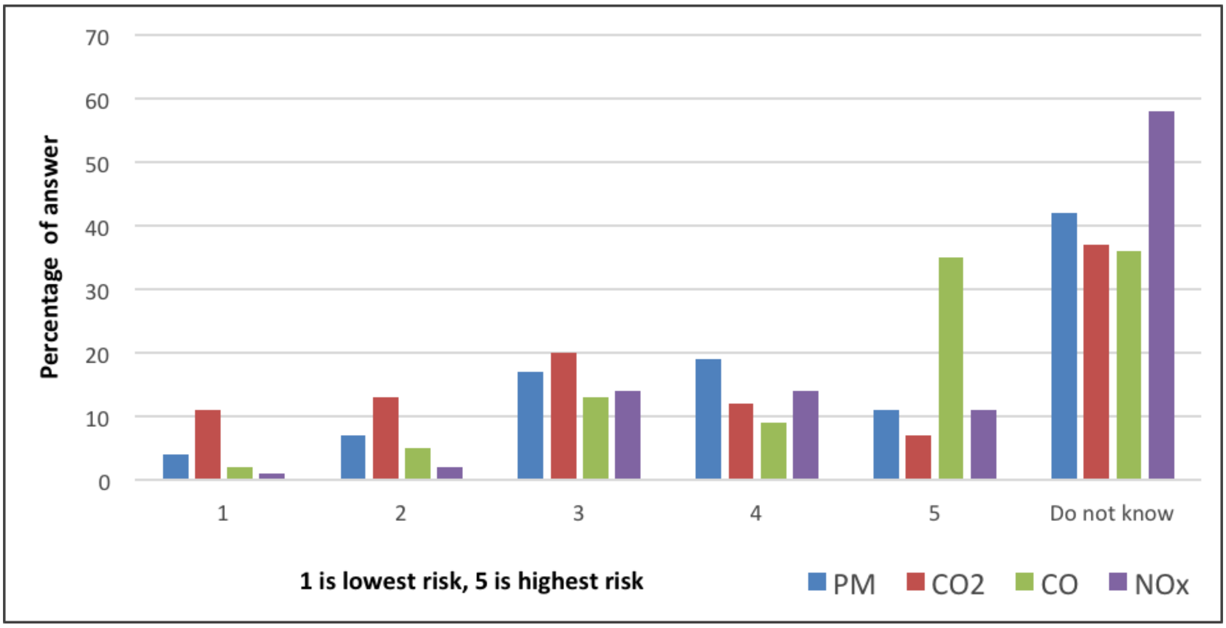


Figure 14: Risk evaluated by the population regarding biomass main emissions (question 19)

In question 20, when asked about the impacts of biomass on some aspects of everyday life, people's answers are very diverse as shown on Figure 15. The impacts on health are particularly perceived as negative, which makes sense when one takes the smoke or particulate matter from ash into account. The same goes for the effects on odour, which are in majority more negative: the trend is the same as the one for health effects, only with a lower kurtosis than the first.

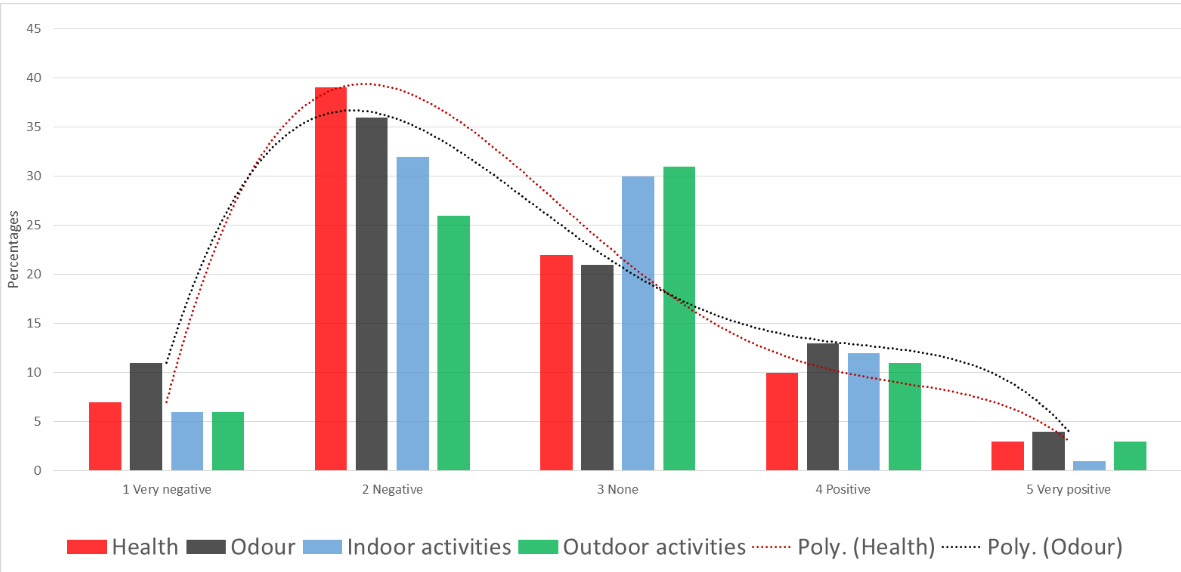


Figure 15: Impacts of biomass on aspects of every day's life as evaluated by the sample (question 20)

Concerning the impact of biomass emissions on indoor and outdoor activities, the average of answers is very much the same for both, considering that the differences are below 10%. It is therefore possible to conclude that the impacts are viewed as less negative on the activities than on health and odour. More people consider that there is no real impact on the activities compare to the ones that think there is no real impact on health.

As a general source of knowledge, it has been concluded that people are aware of the negative impacts of smoke or ash on human health.

3.3. Discussion

3.3.1. Sample statistics

A detail comparison of the samples with national statistics is given in Appendix C.5. To sum up, the whole sample has a higher level of education and is globally younger than the national average, especially the group living in Cranfield University. Meanwhile, the type of heating supply follows the national trend as natural gas and electricity prevail over coal, oil or biomass use.

3.3.2. Analysis of results

3.3.2.1. Biomass use for domestic heating

For question 9, the focus on biomass boilers and stoves was not readily understood. Indeed there should have been more details given as people could include also fireplaces. In addition, the results are different when comparing different towns of origin. For example, Bedford sample knew about biomass for 76%, MKB 66% and Cranfield 95% (Figure 16). This is due to the education level of Cranfield area being higher than the general statistics. The knowledge of biomass is independent from the type of fuel they have in their accommodation (with the exception of biomass heating, which is quite low).

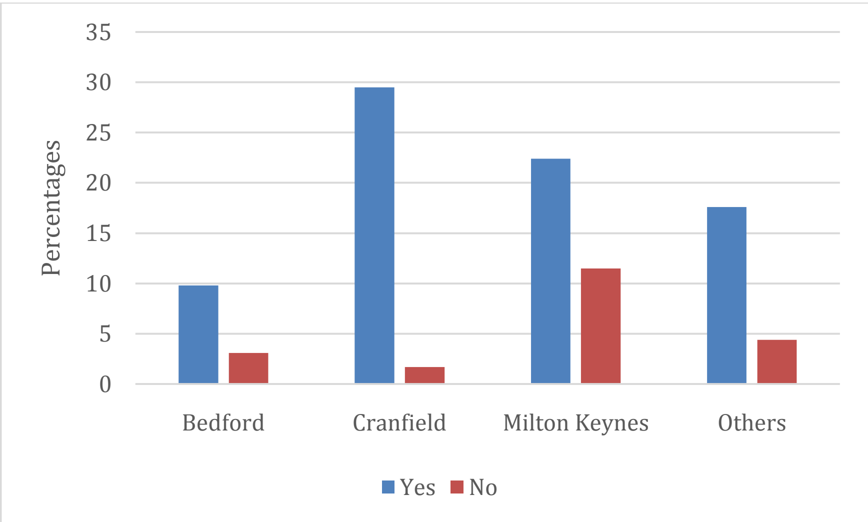


Figure 16: Result of crosstab of area with knowledge of biomass

Correlating answers from question 10 to the previous question for the general sample, it seems that in the 80% that knew about biomass, only 30% are either against or unsure about the generalized use of biomass in the UK. Probably some people need more information before giving a definitive answer.

For question 11, two thirds would not mind using biomass to heat their homes but about ten people during the hand-to-hand survey answered that they needed more data to take an informed decision. It did not constitute a significant change of percentage, but up to about ten of 'I do not know' were counted down as 'no'. Furthermore, as the results are quite different between the two samples, the reason for this change is studied.

Considering the education level, people who are educated at graduate and post-graduate level are generally more eager to have a biomass heating device in their homes, whereas about half of people with only A-level or GCSE were against it (Figure 17).

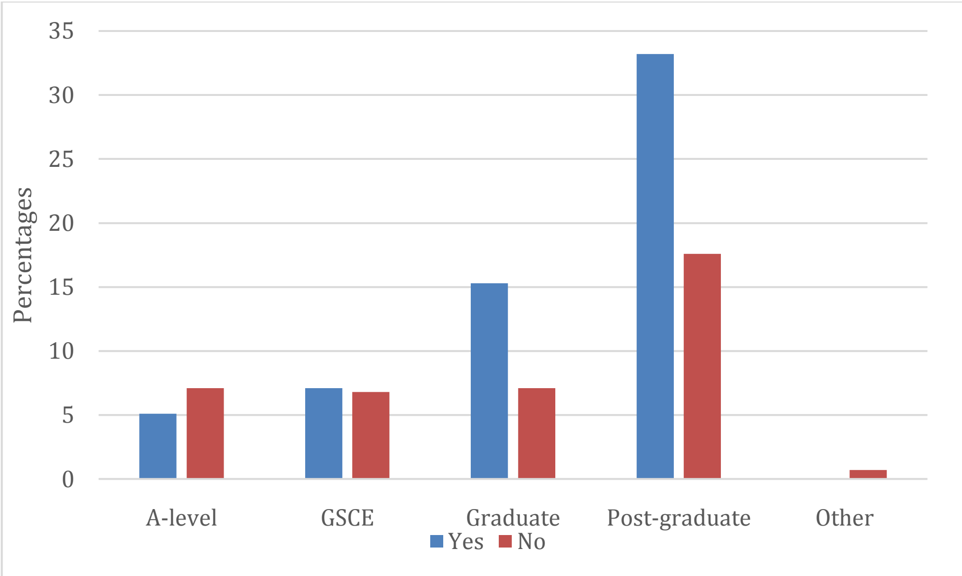


Figure 17: Result of crosstab of highest level of study with approval of biomass in people's home

Regarding the age, all age categories present similar results except for the elderly (65+): more than half of them are against installing a new biomass device in their home. This could have two interpretations: they are more aware of issues linked with wood burning, or they are less inclined to change their heating device. As there are only 9 answers for 65+ whereas there were more than 50 answers for every other category, it might be a biased finding due to the small number in the sample of this age group.

3.3.2.2. Biomass impact on the environment

For question 12, the number of people that did not understand that question was important, partly because of the long sentence and partly because of the general lack of precise knowledge about the aggravating factors for climate change.

For questions 12 and 13, the expected answer was 'yes', since it is a very popular issue nowadays. However, the sample did not answer as it was expected. It confirms that biomass is very controversial regarding its CO_2 life cycle and the wood feedstock management.

For example, during the hand-to-hand questionnaire, some of them refers to the fact that planting trees can always be done after cutting them down. Others are thinking of the difference between the long time it takes to grow a tree compared to the short time to take it down and burn it. Both opinions are valuable because they provide a view from different perspectives.

For question 14, there is no right answer as sustainability depends on many factors such as forestry management or transport. Since biomass is a renewable source of energy, it is vastly the reason why people think it is sustainable. However, some people do not know what sustainable means, or if they know, they probably do not know about the different economic, social, and environmental aspects of the biomass supply chain and combustion process to take an informed decision about it.

For question 15, a comparison of the outdoor air quality perception is done regarding the participants living area. The air quality is perceived to be better in the Cranfield area compared to the other areas, with an average of 4, whereas MKB is 3.44 and Bedford is 3.30. This result was to be expected, as Cranfield is a rural area with less traffic or industrial activities than MKB or Bedford.

For question 16, an interesting trend shown in the Figure 18 below is that people older than 65 think more certainly that biomass will have a more negative impact on air quality than fossil fuels whereas it is the opposite for younger people aged 18 to 24.

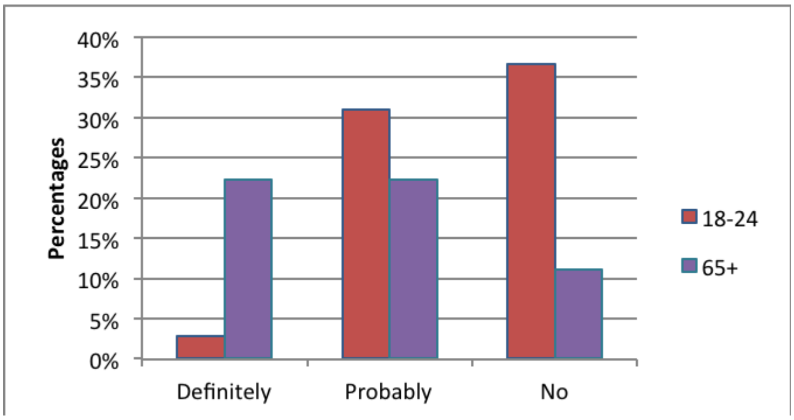


Figure 18: Result of crosstab between the extreme categories of age and the opinion they have on the potential negative impacts on air quality

3.3.2.3. Biomass impact on the health & wellbeing

For question 17, it was quite unexpected that 16% either did not know or think air quality would not affect their health. This might be due to the fact that any pollutant would be too diluted in the air to have any effect on them.

For question 18, the general sample had more correct answers than in MK only as the level of education is higher. There was also the consideration that a significant amount of people working in the School of Applied Sciences heard of biomass. The number of 'do not know' answers was higher in MKB sample and balances the differences highlighted above.

The decreasing rate of good answers for each emission from PM to NO_x may be linked to different reasons: particulate matter can be seen in a fireplace, CO_2 emissions awareness has risen with climate change issues, and CO is directly threatening human health.

3.3.3. Limitations

As a first remark, many people during the hand-to-hand survey did not know what biomass meant. Once told about wood, stoves, boilers and fireplaces, they understood the subject better. Maybe the term biomass should have been replaced with wood to make it easier to understand. Even if it was explained in the text introducing the questionnaire background and shown in pictures, few people paid attention to it and started directly answering the questions. Once pointed in the right direction, they understood the survey objectives (whenever they had time to spare).

Part of the problem is that the questionnaire was addressed to a wide span of people with different levels of education. During the person-to-person implementation, the comprehension of the questions was sometimes difficult and people asked for explanation on some details. This might be due to the vocabulary used or the length of these questions.

A lot of attention was paid to the demanded answers: a yes/no/do not know was more efficient than a simple yes/no, since some people seemed somehow scared to make a decision and were reassured by the third option.

A common issue with the three last questions was when people lacked time to answer, or had little knowledge about the subject; consequently, they tended to tick all the 'do not know' boxes without thinking. This tendency has been noticed in a third of the paper questionnaires.

During the implementation of the survey, the bus stops were chosen as a good place to ask questions to the public. However, the proportion of people living in MKB itself was lower since some persons were leaving Milton Keynes to return to Hertfordshire, Cambridgeshire, Leicestershire, Northamptonshire or London.

Besides, as students and not professionals handed the questionnaires, the sample of population obtained could differ from non-student-recruited samples according to Wheeler et. al. (2013). However, the latter study showed that the conclusions of the results should not be affected.

3.4. Conclusions

Comparing to national statistics, the sample has a higher level of education and is globally younger, especially the part living in Cranfield. Meanwhile, the type of heating supply follows the national trend as natural gas and electricity prevail largely on coal, oil or biomass use.

Almost 80% of people knew about biomass for domestic heating, but only 61% would like to have a biomass heating device in their homes. For MKB sample, the trend is identical but with around 10% less for each question.

The awareness of people on environment issues linked with biomass is moderately good with half the participants thinking it would be beneficial to mitigate climate change compared to fossil fuels. Looking at their perception, less than half of the sample thinks biomass is a sustainable fuel.

The perceived air quality is between average and good in the whole area with a better score for Cranfield borough. Having noted that, almost 40% think biomass will probably have a negative impact on air quality, with a skewness towards no. It should be noticed that people older than 65 think more certainly that biomass would have a negative impact on air quality, whereas young people think the opposite.

In general, the awareness is greater when one is more educated. Results showed that PM and CO_2 were the most known emissions from biomass burning. The highest risk is associated with CO but it is noteworthy that between 40% and 50% of the sample does not have much knowledge on the emissions and the risks associated with them.

The impacts on health and odour are in majority considered as negative regarding smoke, ash or storage from wood burning including fireplace. However, the perception of the impact on indoor and outdoor activities is less negative.

4. Trial measurements of domestic air quality

The use of biomass as an energy source produces pollutants as CO, NO_x or PM. One of the objectives of this project is to know how it affects the indoor air quality in order to understand the possible human health impact due to the long time exposure to these contaminants.

The indoor air quality in 6 houses near the Cranfield University was measured. Three of these houses (BM1, BM2, and BM3) had a biomass burning device, which was in use during the sampling. The other three did not have any biomass device (NOBM1, NOBM2 and NOBM3). The devices used permitted to measure during 90 minutes in these houses the concentration of the PM and the CO. All the measurements were taken in the living room of the house.

The sampling strategy was based on the ISO 16000-1 and limited by the time and availability of the volunteers and equipment.

4.1. Methodology

4.1.1. Ethical approval for indoor air quality measurements

The research was authorized by the Science and Environment Research Ethics Committee (SEREC), from Cranfield University. The first submission of the documents for this work was under the denomination of 'Low Risk'. However, the response of the committee was to request resubmission as 'High Risk'. After including in the documents the feedback from the committee the resubmission was done and the authorization confirmed.

The documents that received the approval are included in the Appendix D.2.

4.1.2. Monitoring devices

When possible, all the available appliances were used to measure carbon monoxide and particulate matter. The appliances used for the sampling are listed and described below.

4.1.2.1. Particulate matter

<u>a. Osiris Particulate monitor</u>

This is manufactured by the Turnkey Instrument Ltd. It is able to detect airborne particles from 0.5 µm to 20 µm (aerodynamic diameter). From then it calculates the mass concentration of TSP (Total Suspended Particulates), PM10, PM2.5 and PM1.0 respectively. Any particle above 20 micrometers is classified as 20 micrometers; however, it is quite difficult to get very large particles into the instrument inlet (Turnkey Instruments Ltd). It can also measure parameters such as wind speed, wind direction, temperature, humidity and rainfall at the same time. The device was given to the researchers with a battery charger, CD software, instructional manual, calibration filter, sample inlet and PC cable connector. To measure said weather parameters it would be needed additional equipment.

The Osiris Particulate Monitor uses a light scattering technique to determine the particle concentration. Air is continuously drawn by a pump into the instrument. The individual particles are sized as they pass through a laser beam in a photometer and then collected on the reference filter. Before particle coincidence in the laser beam, thousands of particles can be analyzed in only one second. The light scattered by individual particles is converted into an electrical pulse which is proportionate to the size of the particle. From this, and assuming that the density of the particles is $1.5g/cm^3$, the microprocessor calculates the mass of the particles. The final results are given in $\mu g/m^3$ with a resolution down to 0.01µg (Turnkey Instruments Ltd).

It is important to highlight that results are expressed in mass concentration, so this device is not able to determine the number of particles analyzed; it only determines the weight of a certain particle size interval. This may be a drawback of Osiris Particulate Monitor. Big size particles are heavier than small size particles, so the TSP result will be more influenced by PM10 than by PM2.5 or PM1, even if the amount of particles of the last two sizes is higher.

Another important fact to keep in mind is that particles above PM10 are detected by Osiris Particulate Monitor. They are not classified in any individual category according to their size, but they are included in the TSP final result. Due to this, the TSP data cannot be obtained by summing the PM10, PM2.5 and PM1 data, the difference shown will correspond to particles which size is bigger than PM10 (Turnkey Instruments Ltd).

b. P-Trak Ultrafine Particle counter

The TSI's P-Trak® Ultrafine Particle Counter (UPC) 8525 is an instrument used in measuring levels of ultrafine particulate. It can detect and count ultrafine particles in the size range from 0.02 to 1micrometer with a concentration range of 0 to 5×10^5 particles/cm^3. P-Trak counts ultrafine particles in particle/cm^3. The use of P-Trak is supported and has been used in previous studies by (Zhua *et al.,* 2006; Matsona *et al.,* 2004) to monitor particle concentrations in an indoor environment.

The operational mechanism involves magnification of the ultrafine particle by a supersaturated alcohol (isopropyl) and detection of the magnified particle by an optical chamber before counting. The alcohol used here is the reagent graded alcohol which ids 95% pure. Particles are drawn in through a suction pump in the device. The particles are mixed with alcohol vapour as it passes through a saturator tube. The mixture is then passed through a condenser tube were the particles are condensed into droplets for it to be easily counted. The droplets are then passed through a focused laser beam which counts and determine the particle concentration.

The P-Trak used for monitoring was logged to measure in intervals of 1 minute.

4.1.2.2. Carbon monoxide

a. EL-USB-CO Carbon Monoxide (CO) Data Logger with USB Interface

EL-USB-CO Carbon Monoxide (CO) Data Logger is an instrument that measures and records CO levels in air over a period of time. Sample readings are set in intervals for monitoring, recording and analysis purposes. It measures CO ranging from 0 to 1000ppm and stores up to 32,510 readings.

The data logger is plugged into a PC's USB port and the software designed for the instrument is run on the computer. The software is used to set up the logging rate (10s, 30s, 1m, 5m), start time, warning threshold and also to download stored data from the instrument after monitoring. The data obtained are stored in a non-volatile memory and would it be available if the battery is empty. If a preset warning level is exceeded a bright red led will flash. The device has an expected sensor life of 4 years (Lascar 2013). It is not appropriate to be used as an industrial or domestic detector or alarm.

b. FirstCheck+ 5000Ex

FirstCheck+ 5000Ex is a photoionization detector (PID) for VOC and toxic gases with sensors for oxygen, hydrogen sulphide, carbon monoxide and explosive gases. It is commercialized by Ion Science.

The device was used to measure CO in mg/m^3. The FirstCheck+ 5000Ex is especially useful as it can be used in the Health and Safety mode for STEL ant TWA. The appliance's resistance to humidity and contamination is provided by the patented Fence Electrode Technology, which incorporates a three-electrode format (Ion Science Advanced Gas Sensing Technologies).

In the Table 9 the gases that can be controlled and their range are provided.

Table 9: Range associated with controlled gases (Ion Advanced Gas Sensing Technologies)

Gas	Range
VOCs	1 ppb -10,000 ppm
O_2	0-28%
CO	1-1,000 ppm
H_2S	0.1-100 ppm
LEL	0-100 % LEL

c. Gas Alert Microclip XT

The product designed by BW Technologies by Honeywell detects H_2S, CO, O_2 and combustibles (%LEL) (BW Technologies). It is a personal monitoring appliance used to double check the CO concentration in the ambient air in this project. The device was designed to do the auto-zero when starting up.

4.1.3. Procedure of measurements

4.1.3.1. Settings

The study was carried out in houses offered by volunteers that lived nearby Cranfield University. The researchers contacted the staff of the School of Applied Sciences in Cranfield University and the staff of Milton Keynes City Council to ask for their collaboration. Moreover, acquaintances were also contacted. Four houses without biomass burning device and seven with were available for the study, but due to the lack of time the air quality of only six of them could be measured. Some characteristics of the houses are presented in Table 10.

Table 10: Characteristics of the studied houses

House code	Biomass device	Central heating energy source	Age of the house (years)	Ventilation/ Sealing	Size of the living room

- BM1	Open fire place	Gas	>20	No/Poor	Medium
BM2	Open fire place	Gas	>20	Yes/Good	Big
BM3	Closed wood stove	Gas	>20	No/Good	Small
NOBM1	N/A	Gas	>20	Yes/Good	Medium
NOBM2	N/A	Gas	10-20	Yes/Good	Small
NOBM3	N/A	Electricity	>20	No/Good	Medium

The houses using biomass burning devices also had gas for heating. The ones without biomass had different energy sources: NOBM1 and NOBM2 used gas and NOBM3 used electricity.

4.1.3.2. Procedure

Biomass burning utilities are considered intermittent sources of contamination that have a variable strength (British Standards Institution, 2006). Therefore, it is a source of pollutants that varies during the day. However, it can show similarities in its trend over longer periods of time. This fact must be taken into account when designing the sampling strategy. When sampling, some of the factors affecting the results are: temperature, distance from source, humidity of the air, ventilation and situation of doors and windows, size of the room, fuel used in the boiler, height of the measurement or habits of people: frequency of using the boiler, number of people who smoke and quantity of cigarettes smoked, etc. (Konstantopoulou, *et al.,* 2014).

The majority of these factors are out of control of the researcher. However, during sampling special attention was paid to those factors that could be controlled: time of sampling, sampling duration and frequency, and sampling location.

Time of Sampling: As the sampling was done over a short time, ventilation was a crucial factor and it was always recorded in the notes taken by the researchers. The ISO 16000-1 says that if a window is opened while measuring or have been opened short time before starting, results can change drastically. The sampling always lasted 90 minutes. The initial plan for the sampling in houses with biomass burning was to measure during 15 minutes the indoor air quality without biomass burning and after that measure during 75 minutes while the wood was burning, so as the difference derived from biomass burning in the indoor air quality could be seen. These 15 minutes of measuring would give the opportunity to the researchers to compare the normal air quality in houses with and without biomass burning. However, in BM2 and BM3 houses by the time the researchers arrived, the fire was set.

The 90 minutes period permitted the researchers to compare the results obtained with the World Health Organization guidelines for carbon monoxide average concentration for 15, 30 and 60 minutes.

These guidelines can be observed in the Table 11.

Table 11: Substances measured, possible sources and Air Quality Guidelines (British Standards Organization, 2006)

POLLUTANT	SOURCE	REMARKS
Carbon monoxide (CO)	Open fires, tobacco smoke, vehicle exhaust gases	100 mg/m^3 (15 min) 60 mg/m^3 (30 min) 30 mg/m^3 (1 h) 10 mg/m^3 (8 h)
Suspended particulate matter $PM_{2.5}$ PM_{10} TPM (total particulate matter)	Fuel combustion, cooking, fungi spores, pollen, animals, humans, bacteria, wind-blown dust	No information available

Sampling Duration and Frequency: The duration and frequency were limited by the availability of the owners and the nature of the experiment. Usually when short term sampling is done the conditions are extreme in order to build a worst case scenario. However, in the measurements carried out in this project, conditions were tried to maintain standard in order to observe the exposure that the owners have in their daily life. All houses were measured once.

Sampling Location: It was impossible to define before knowing the place which could be the best place to leave the devices. In the research, sampling was tried to be done in the middle of the chosen room and about 1-1.5m above the floor since this is the typical breathing zone (British Standards Institution, 2006).

More information about the houses and the sampling can be found in the Appendix D.1.

The activities carried out during and before the sampling time were recorded in order to understand possible peaks in the concentration of the species. These activities included: cooking, water heating, smoking, cleaning, etc.

4.2. Results

PM was measured with two devices. Osiris Particulate Monitor was used for TSP, PM10, PM2.5 and PM1, and P-Trak Ultrafine Particle counter for ultrafine particulates (less than 1µm).

CO was principally measured using FirstCheck+ 5000Ex appliance. However this device was not available for the researchers since the beginning of the sampling. Therefore in BM1 and NOBM1 there are not results available with this device.

The results of the measurements, as obtained from the software, are shown in Appendixes D.3, D.4 and D.5.

4.2.1. Houses with wood heating devices

Three houses with wood heating devices were visited in order to measure their air quality. The first two ones counted with open fire places, the third one with a wood stove. All of them used wood logs and some paper as fuel.

As already explained in the methodology section, the sampling lasted one hour and a half. In BM1 the fire was set after 15 minutes of sampling; in the BM2 and BM3 the fire was already set when the researchers arrived to the house. While the researchers were carrying out the measurements, the normal daily life continued in the house.

4.2.1.1. Particulate matter

<u>a. Total suspended particles</u>

The TSP registered levels in the three houses varied between wide ranges of particle mass concentrations (conc.), especially in the first one. It can be seen in Figure 19. The TSP average data obtained are BM1 = 136.36 μg/m^3, BM2 = 79.94 μg/m^3 and BM3 = 130.40 μg/m^3.

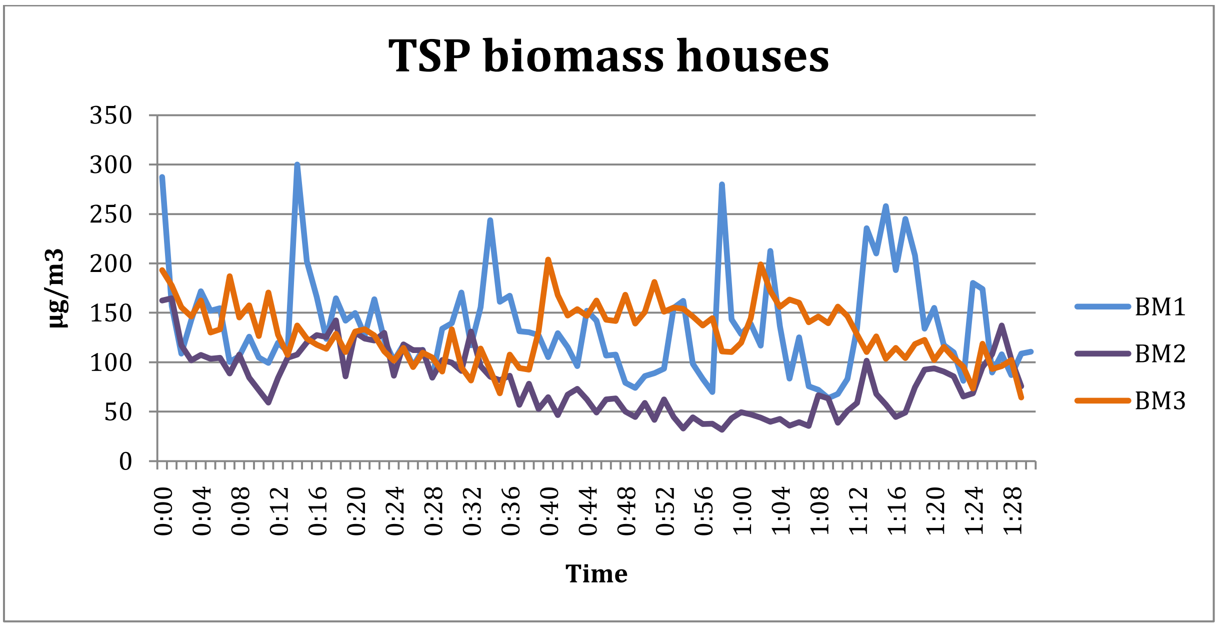


Figure 19: TSP sampling results for biomass houses

BM1 was the only house in which the fire was set after 15 minutes of sampling. In that moment the highest TSP conc. was measured. Other two peaks close to the highest level were reached, one when sampling started and another one after an hour of sampling. Both of them were sudden increases of the particles mass conc. These abrupt changes could be caused by air currents in the house felt by the researchers during the sampling. This location was a living room in an old house with three windows and two doors in which poor sealing around windows and doors frames was noticed. These gaps would possibly be the reason of the existing air currents.

BM2 was a house with a big and well ventilated living room, which is the possible reason why the TSP mass conc. levels were lower. Initially, the Figure 19 shows a decreasing trend in concentration over time for, approximately, one hour and ten minutes. After that it changes and starts increasing slowly, probably due to the fact that all the doors and windows were closed during the sampling, so the wood burning emissions cannot be diluted in outside air.

BM3 could be expected to show the lowest levels of TSP conc., since the heating device was a closed wood stove which expels the combustion gases directly out of the house via a chimney flue. However, the stove door sealing was probably not as good as expected, so some gas escaped into the living room. In addition, it was a small and poorly ventilated living room. Therefore, the gases were not diluted in outside air and the results obtained are higher than in BM2. In spite of this, the average conc. is lower than in BM1. The two peaks registered coincide with the two moments in which the stove was open to add more wood.

b. PM10

The PM10 mass conc. trends shown in Figure 20 are quite similar to those seen in Figure 19. The reason of that is the Osiris Particulate Monitor measures mass conc., not particle counts. PM10 are the heaviest particles, so they will have more influence in the TSP results than the other particle sizes, even if the number of small particles is higher.

The PM10 average results obtained are BM1 = 62.67 μg/m^3, BM2 = 30.66 μg/m^3 and BM3 = 55.15 μg/m^3.

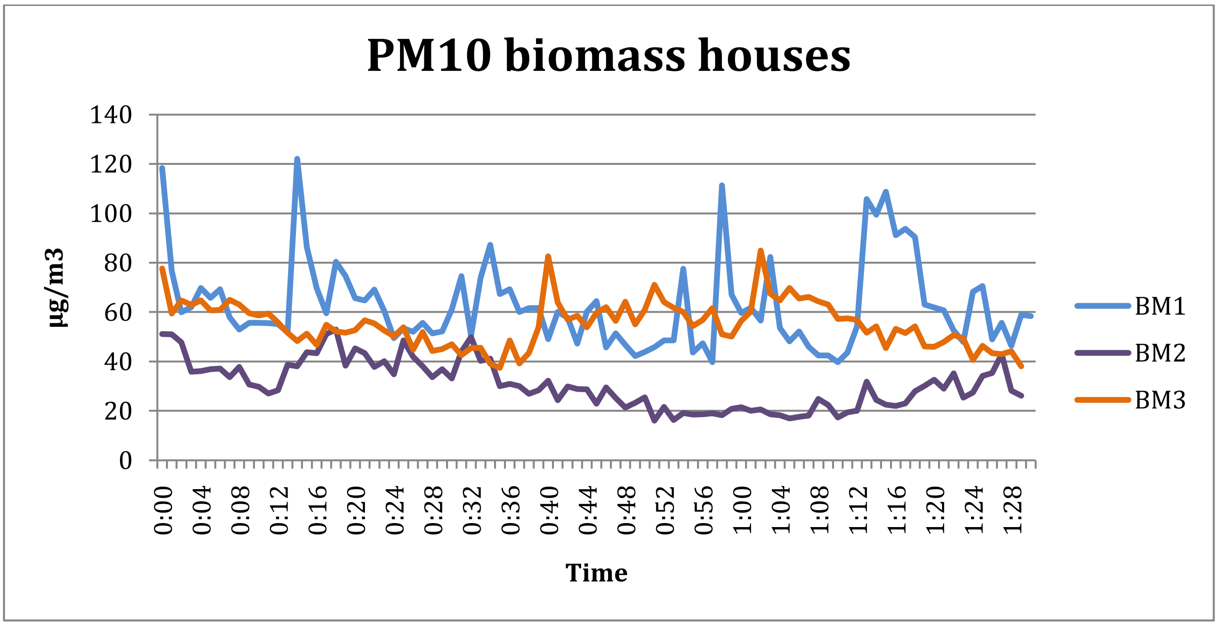


Figure 20: PM10 sampling results for biomass houses

c. PM2.5

Figure 21 shows the PM2.5 mass conc. results for the three houses with wood heating devices studied. The average results obtained from them are BM1 = 12.69 µg/m^3, BM2 = 5.11 µg/m^3 and BM3 = 7.15 µg/m^3.

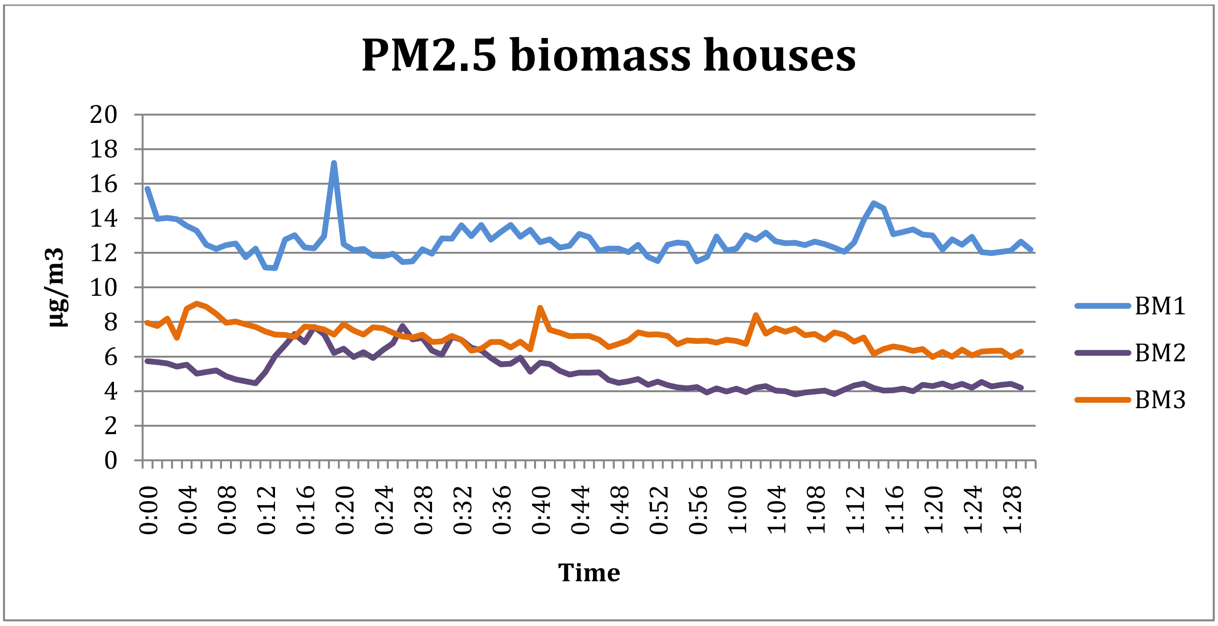


Figure 21: PM2.5 sampling results for biomass houses

As seen in the two previous particle sizes, BM1 shows the highest conc. levels. But in this case the difference is bigger, almost double than BM2 and BM3. The reason of this could be due to the type of wood used as fuel or to the ambient weather conditions. The PM2.5 conc. peak coincides, as in the two previous cases, with the moment in which the fire was set.

BM2 shows a slightly decreasing trend in particle conc., probably due to the fact that the intensity of the fire was lower than in the other cases, as no more wood was added during the entire sampling.

In BM3 two small peaks in PM2.5 conc. can be seen, both of them caused because the stove was open to add more wood. Except from these two moments, the conc. is basically constant with small variations within a range from 6 µg/m^3 to 8 µg/m^3.

d. PM1

As it can be seen in Figure 22, the PM1 mass conc. registered levels are lower than other fractions measured. But due to the mechanism used by Osiris Particulate monitor to measure, it cannot be said that the number of PM1 particles is very low, as it is able to measure the particles weight, not the number.

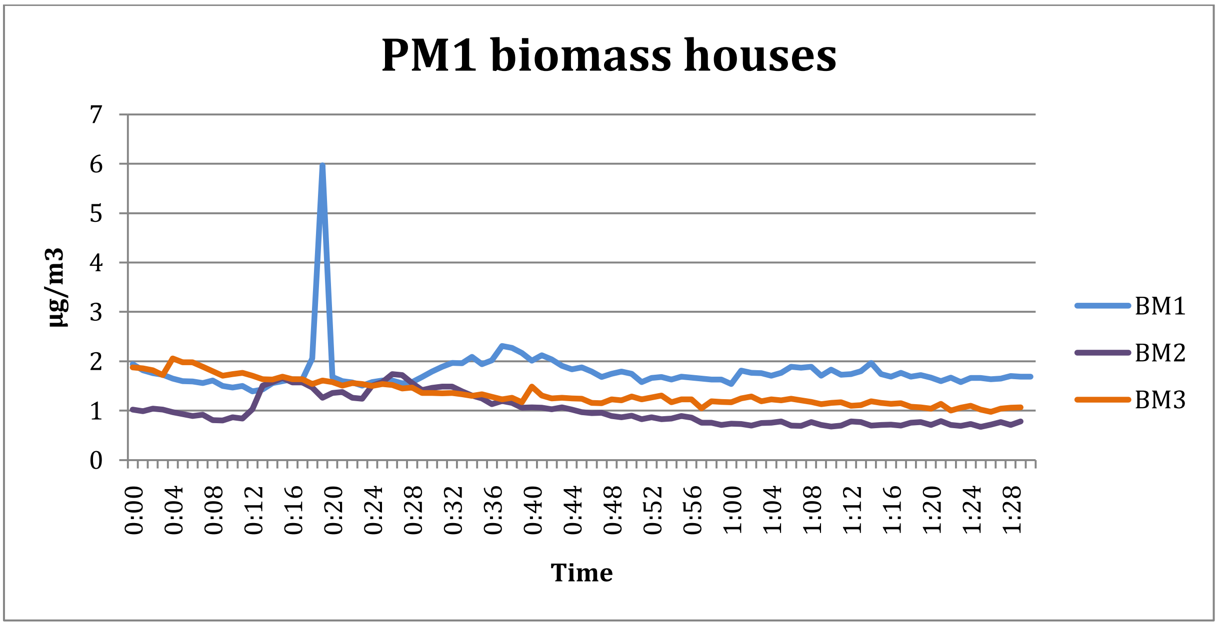


Figure 22: PM1 sampling results for biomass houses

The average PM1 obtained results are BM1 = 1.78 µg/m^3, BM2 = 1.0µg/m^3 and BM3 = 1.36 µg/m^3.

The big peak shown in BM1 corresponds to the moment in which the fire was set.

e. Ultrafine particles

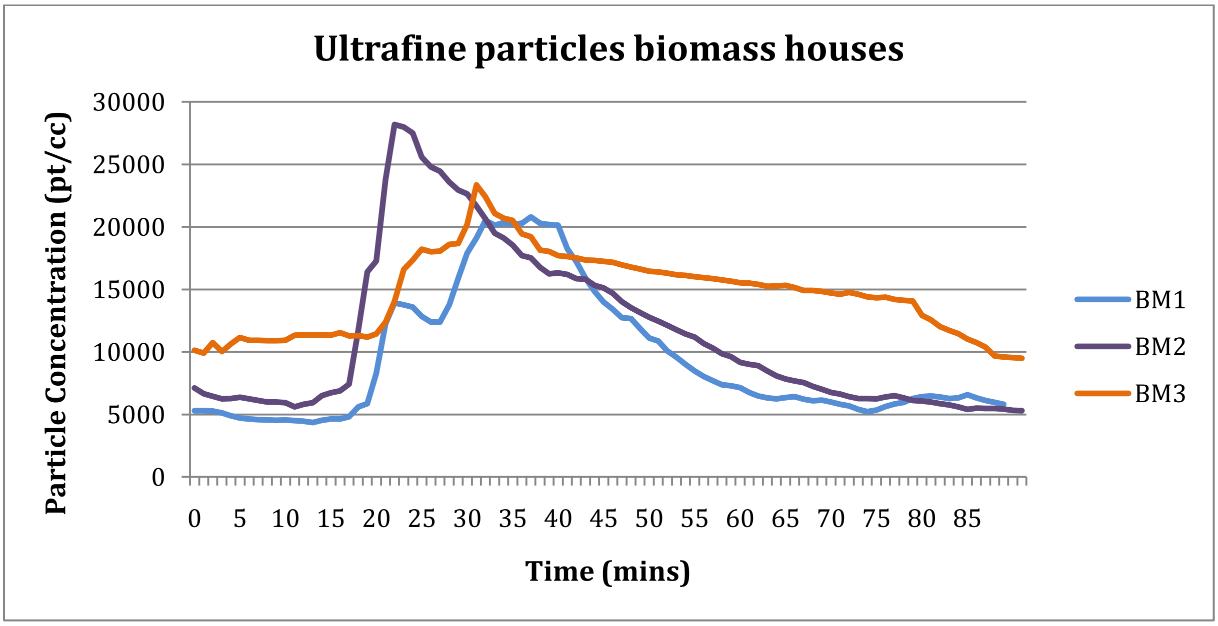


Figure 23: Ultrafine particles sampling results for biomass houses

Figure 23 shows a general trend of a rise in particle conc. between 10 minutes to around 40 minutes among the houses monitored that burnt biomass. The rise coincides with the period when the burning was taking place. As the fires were going down, the conc. began to drop gradually for all the houses.

For BM1 monitoring started 15 minutes before burning. This could be the reason for the low particle conc. at the beginning of the monitoring up until the 20th minute before a rise which could be attributed to the burning of biomass.

BM2 has the highest level of particle conc. This could be due to the distance between the fire place and the measuring equipment. The equipment was much closer to the fire place, about 0.5m away in BM 2 than in any of the other houses measured.

BM3 shows a higher conc. of particles at the start of monitoring than BM1 and BM2. Burning started before monitoring which could be a factor for the high conc. The rise to the peak could have been caused by the opening of the stove to add more wood. This house had only a small window and was poorly ventilation.

4.2.1.2. Carbon monoxide

The CO levels in houses named as BM2 and BM3 according to the PID are presented in the Figure 24.The results are presented as the average for each minute of sampling. This average has been calculated from the 'First Check' values for every second.

The values in the house BM3 have a gap because the device battery failed in the middle of the experiment. However, the results were consistent and it was decided to use them as part of the report.

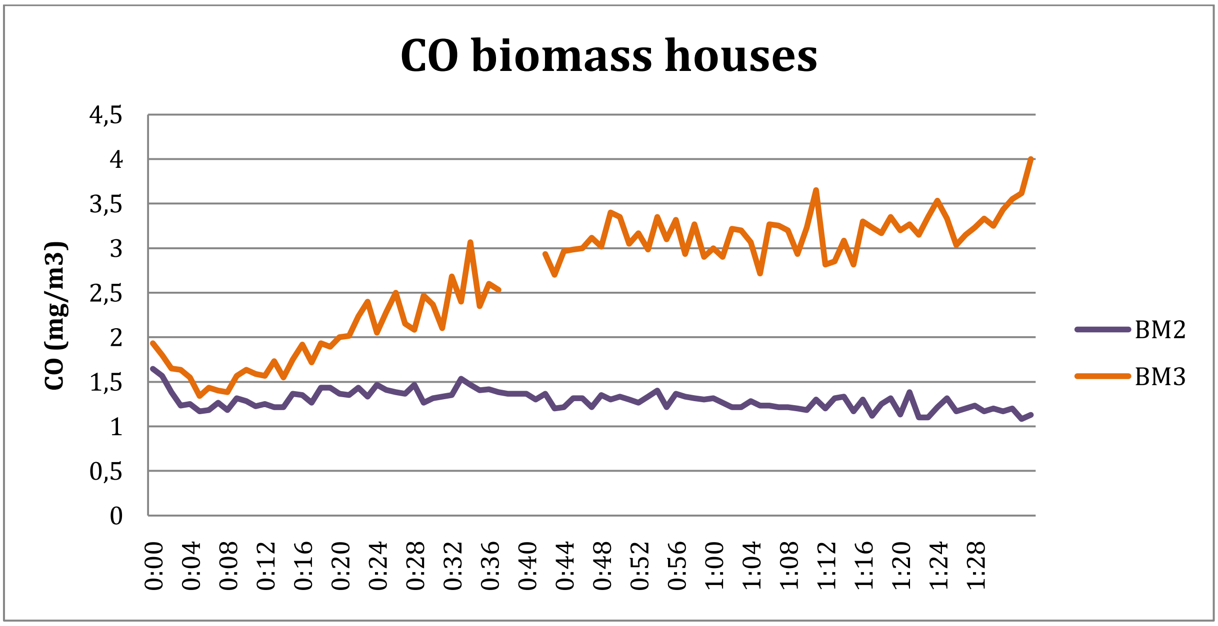


Figure 24: CO sampling results for biomass houses

In the houses BM2 and BM3 there is a noticeable difference in the conc. of the CO. This difference can respond to different factors. The device in BM3 was a closed stove, which is supposed to have less emission than an open fire (BM2). However, according the results, the sealing of the stove was not as good as expected. In addition, the room where the measuring was done in BM3 was much smaller than that of BM2. As it was not ventilated, the CO level increased as the wood was burnt. Moreover, the insulation provided by the rubber sealed windows in BM3 was better than in BM2 where the windows where simple.

In order to compare these results with another device, a Gas Alert Microclip XT was used in some moments over the sampling time. The measured conc. in this appliance was always zero ppm, including BM1 house. This difference in measured conc. is related to the different sensitivity of the devices.

4.2.2. Houses with other types of heating source

Three houses with no wood heating devices were visited in order to measure their air conc. of particulate matter and CO and, from these data, draw a conclusion regarding their indoor air quality.

In all the cases the house counted with a central heating system with radiators distributed over the house. Regarding the type of energy source, for NOBM1 and NOBM2 it was gas, and for NOBM3 electricity.

As for the houses with wood heating devices, the sampling took 90 minutes. While the researchers were carrying out the measurements, the normal daily life continued in the house.

4.2.2.1. Particulate matter

<u>a. Total suspended particles</u>

Figure 25 represents the mass conc. of TSP in three houses without wood heating devices over time. The average data obtained from them are NOMB1 = 91.06 μg/m^3 NOBM= 52.32 μg/m^3 and NOBM3 = 41.51 μg/m^3.

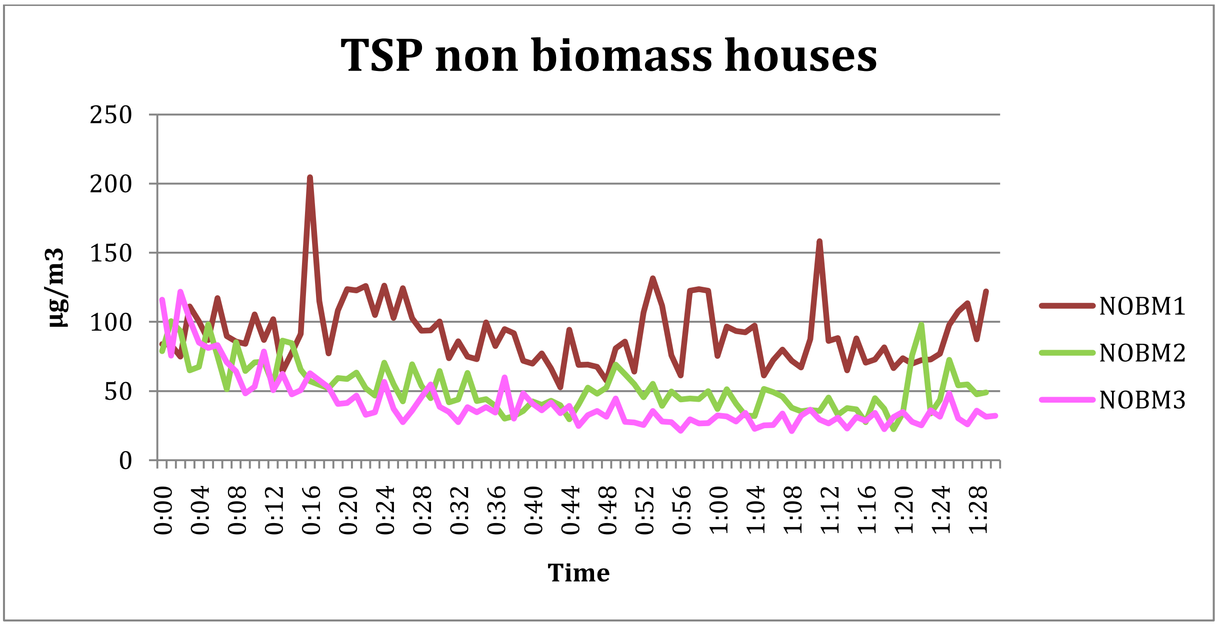


Figure 25: TSP sampling results for non biomass houses

NOBM1 shows higher levels than NOBM2 and NOBM3 and some huge variations in the TSP conc., reaching in some moments peaks that doubled the average value. The possible reason of higher levels of particle conc. could be that the living room where the sampling took place was directly communicated with the kitchen. The sudden conc.peaks could also be related with this fact, as normal daily life activities (preparing coffee or cooking lunch) were realized in the kitchen while sampling.

In the cases of NOBM2 and NOBM3, both appear to have similar levels of TSP conc. with no big variations and also similar trend over time. NOBM3 uses electricity as heating energy source, while NOBM2 uses gas, which could be the reason why NOBM3 has the lowest particles conc. levels. In either of both cases no activities that imply emissions were realized. In NOBM2 an outer window near a road was open while sampling was being carried out, which could explain the higher conc. peaks.

b. PM10

PM10 measurements results in the three houses are shown in Figure 26. The average data obtained from them are NOBM1 = 37.64 µg/m^3 NOBM2= 18.84 µg/m^3 and NOBM3 = 14.18 µg/m^3.

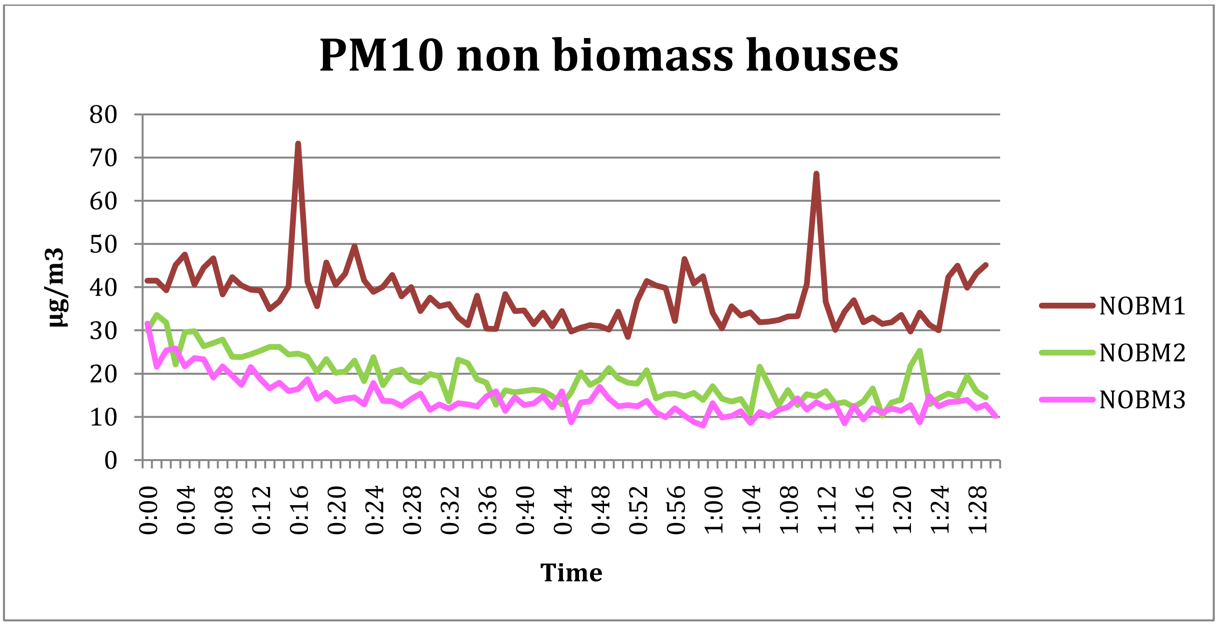


Figure 26: PM sampling results for non biomass houses

The particle conc. trends are expected to be quite like those seen for TSP. Since PM10 are the heaviest particles measured, they are the ones that contribute the most to the total mass conc. The different variations and peaks are caused by the same reasons as the ones exposed for TSP conc.

c. PM2.5

Figure 27 shows the PM2.5 mass conc. over time. The average results yield from it are NOMB1 = 8.33 µg/m^3 NOBM2= 3.94 µg/m^3 and NOBM3 = 1.99 µg/m^3.

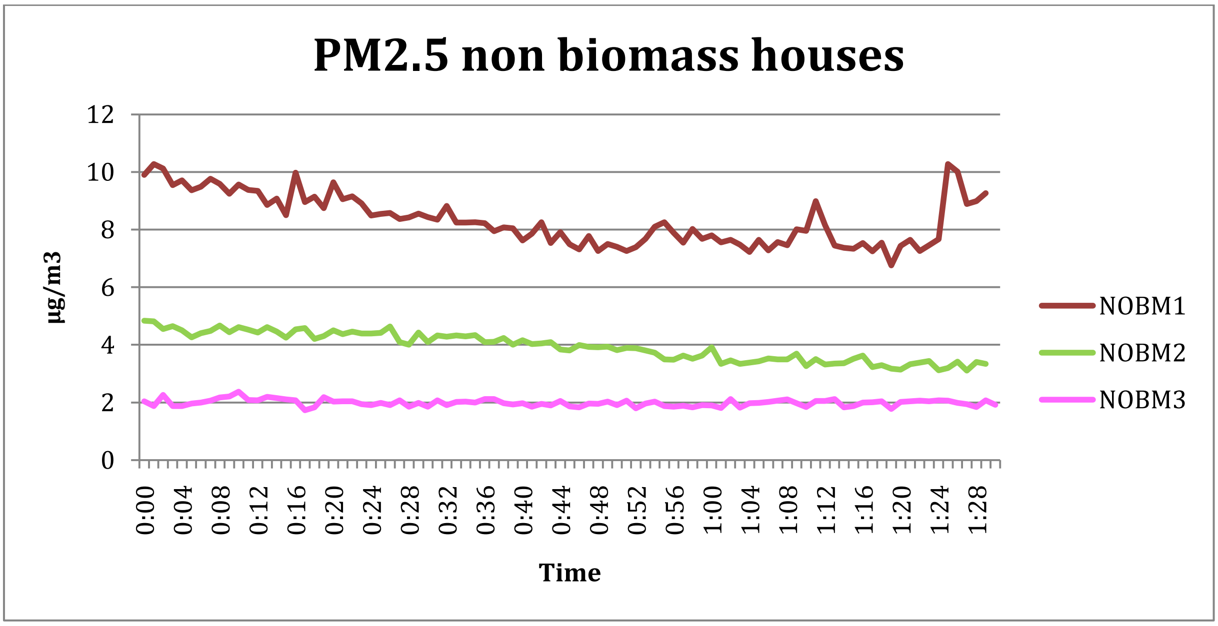


Figure 27: PM2.5 sampling results for non biomass houses

As in the previous particle sizes, the highest registered levels corresponds to NOBM1 and the lowest to NOBM3. In NOBM1 the living room in where the measurements were taken was directly communicated with the kitchen, which makes it more likely to show higher particle mass conc. NOBM2 had a window open while sampling was carried out, so the indoor air could be influenced by the outdoor ambient. NOBM3 is the one with lower particle mass conc. probably because it is the only one with electricity as heating energy source.

d. PM1

Figure 28 represents the PM1 mass conc. over time in the three studied houses. The average data obtained from them are NOBM1 = 1.37 µg/m^3 NOBM2= 1.51 µg/m^3 and NOBM3 = 0.52 µg/m^3.

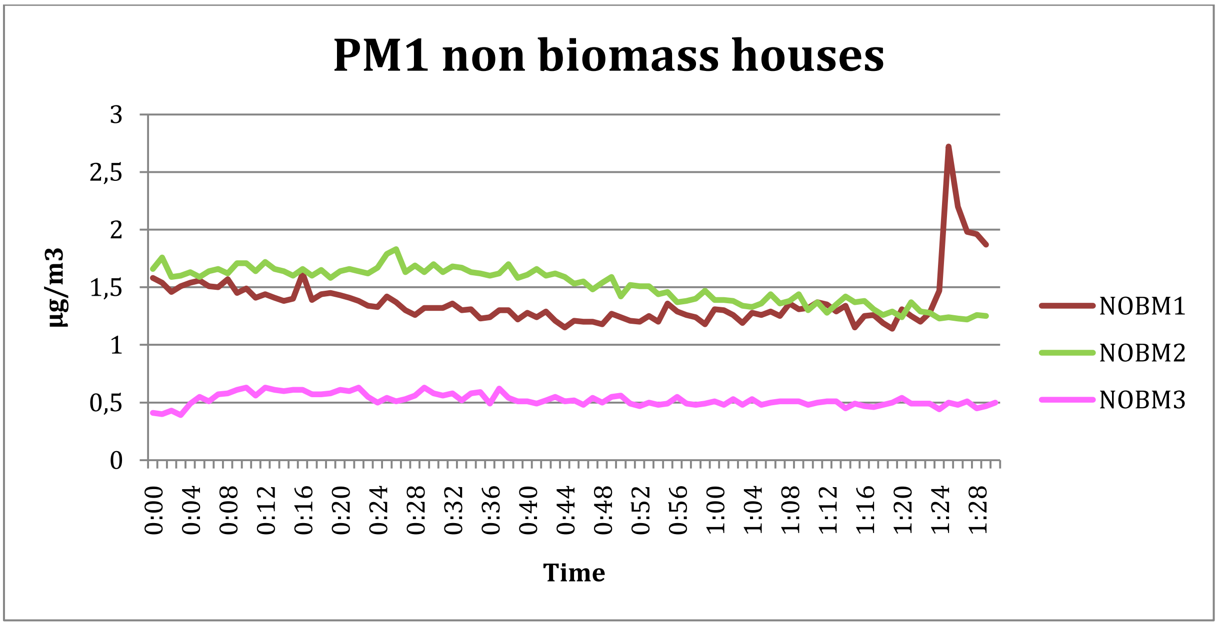


Figure 28: PM1 sampling results for non biomass houses

The PM1 conc. levels were really low in all the cases. It is important to remember that this fact does not mean that the number of PM1 particles in these houses was low; it means that the low data was the total weight of particles of this size.

The shown trend is practically constant in NOBM1, NOBM2 and NOBM3. The only big variation registered occurred in NOBM1, and it coincided with the moment in which lunch was started to be cooked. The rest of the variations are almost negligible.

e. Ultrafine particles

Figure 29 shows a comparison of particle conc. in 90mins between two non-biomass houses.

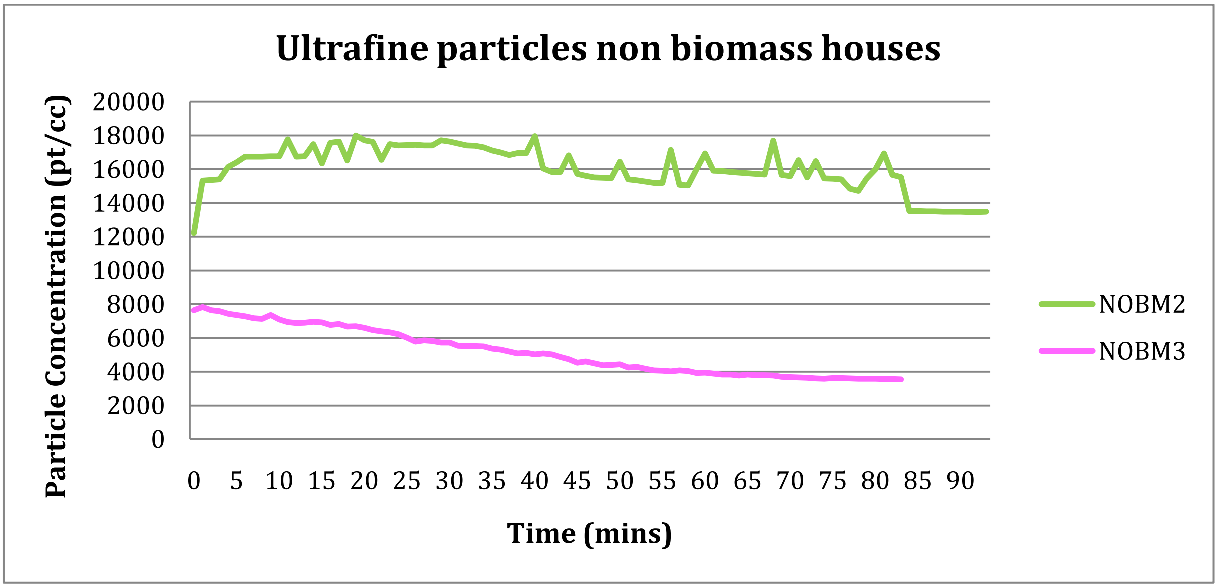


Figure 29: Ultrafine particles sampling results for non biomass houses

NOBM2 shows a much higher particle conc. than that of NOBM3. This could be as result of the window which faces the road being left open while monitoring was taking place in NOBM2. Particles from the outside environment may have entered the house through the window and doors increasing the number particles in the indoor environment. Measurement in BM3 was done with the window and doors closed. Although, the door to the kitchen was left open it seems not to have any effect on the particle concentration since there was no cooking taking place.

4.2.2.2. Carbon monoxide

The carbon monoxide levels in houses named as NOBM2 and NOBM3 according to the FirstCheck + 5000Ex are presented in the Figure 30.

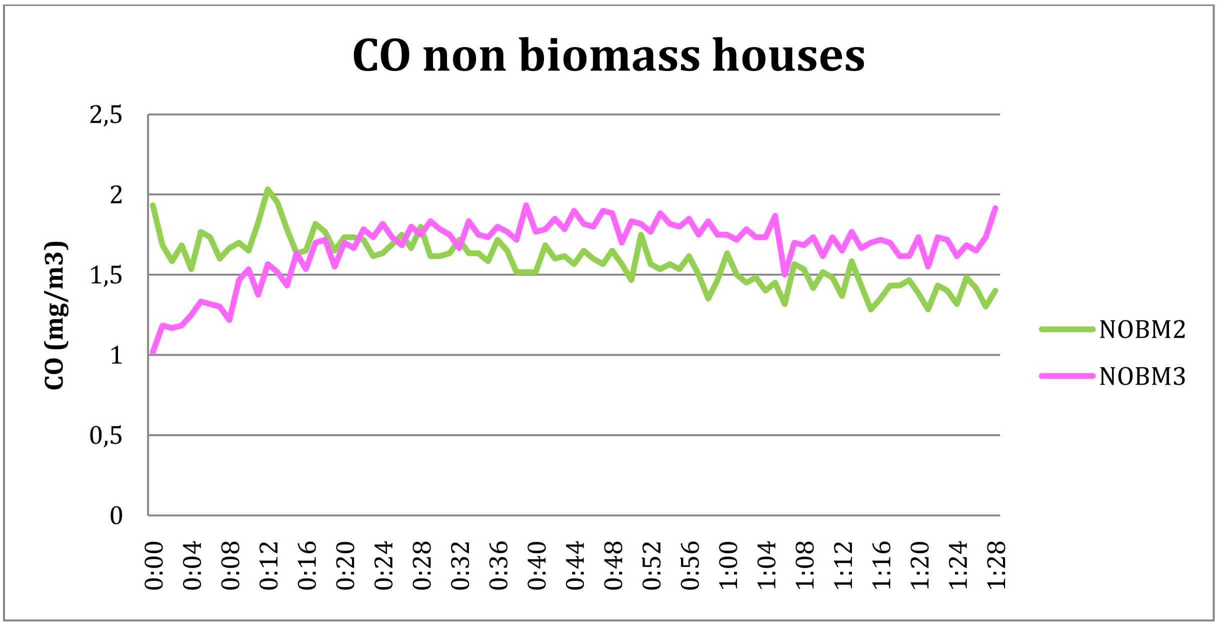


Figure 30: CO sampling results for non biomass houses

The results are presented as the average for each minute of sampling. This average has been calculated from the 'First Check' values for every second.

The average level during the sampling period is slightly higher in NOBM3 (1.66 mg/m^3 against 1.58 mg/m^3). The level of CO in the indoor air does not show big differences during the sampling time, so it can be considered constant in both cases.

In order to compare these results with another device, a Gas Alert Microclip XT was used during the sampling period randomly. The measured conc. in this appliance was always zero ppm, including NOBM1. This difference in conc. is related with the different sensitivity of the devices.

4.3. Discussion

4.3.1. Indoor air quality change due to biomass burning

The aim of these trial measurements was to check the influence of biomass burning on indoor air quality. This influence has been largely proved in the literature and is an important issue especially in developing countries (Oluwole, et al., 2012).

Analysing the obtained data, there is a clear difference between the houses that burn biomass and those which do not, except NOBM1 that showed higher than BM2 values probably due to an external source. The average mass conc. of TSP in biomass burning houses was double the conc. of the other group. This result is repeated in PM10 and PM2.5, while in PM1 the results do not show a clear difference. These differences are stated in Figure 31 and Figure 32.

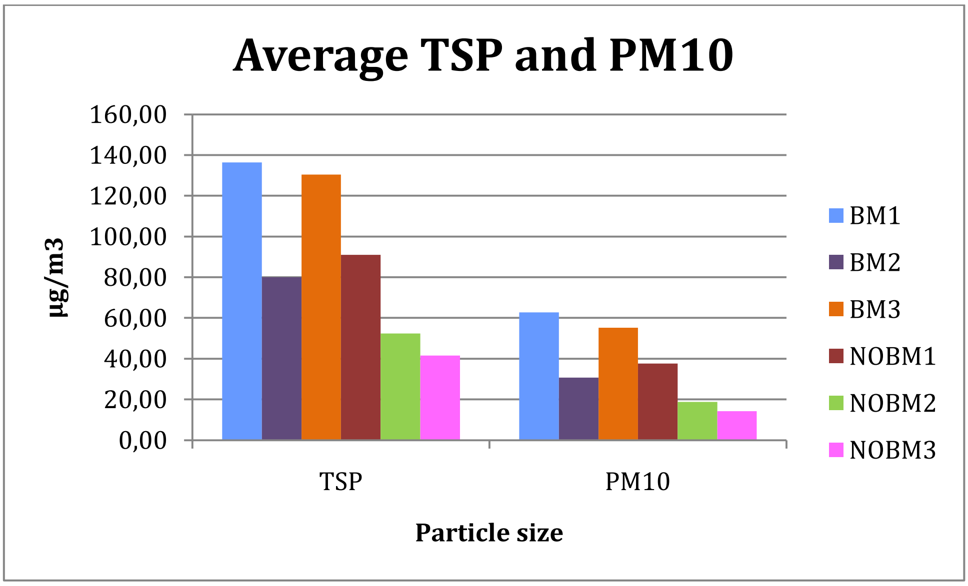


Figure 31: TSP and PM10 average data comparison between both biomass and non biomass houses

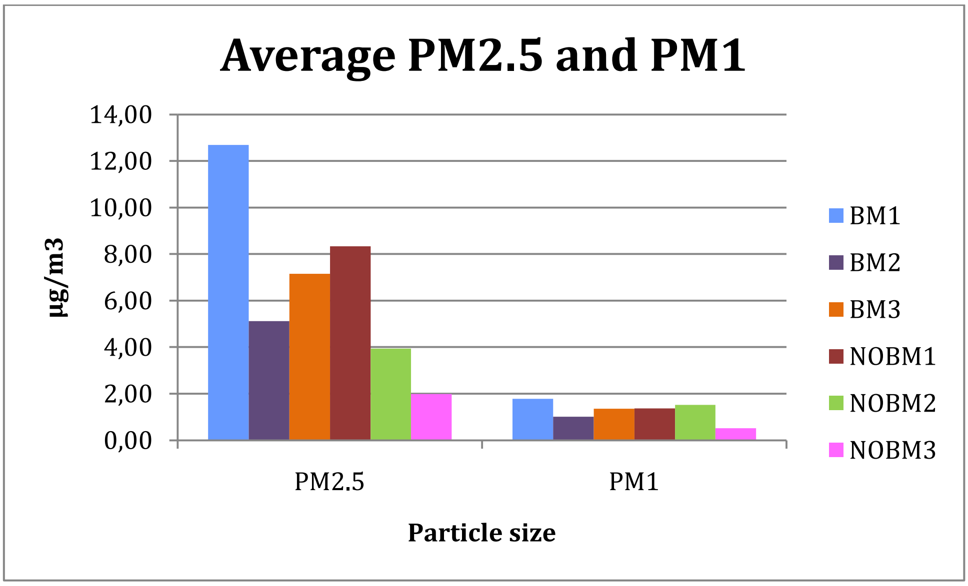


Figure 32: PM2.5 and PM1 average data comparison between both biomass and non biomass houses

The influence of biomass burning on the indoor air quality is especially visible in PM2.5, where peaks in the conc. are always related with biomass burning activities (setting the fire, adding more wood or moving it). Otherwise, the rest of the particle sizes conc. does not show a clear direct relation with the biomass burning activities.

The data found in the literature review regarding PM2.5 match the results obtained in this research. Salthammer, *et. al* (2013), in their study about wood-burning fireplace ovens, recorded minimum values of 4 µg/m^3 and maximum of 55 µg/m^3 in 24 hours sampling. Other related studies (Commodore, *et al.*, 2013, Hartinger, *et al.*, 2013 and Naeher, 2001) registered values of a higher order of magnitude. However, these studies were carried out in developing countries, where the design and maintenance of the devices tends to produce higher internal emissions. In addition, the type of fuel affects the results.

To determine the air quality according to PM the obtained results should be compared with established and scientific based guidelines. But as the WHO stated in their 'Air Quality Guidelines-Global Update 2005', since thresholds have not been identified, PM guidelines to protect against health impact risk are unlikely to be proposed. In spite of this, the US Environmental Protection Agency and the European Commission have developed some recommendations which aim to achieve the lowest level of PM possible. According to this, the WHO designed PM Air Quality Guidelines (AQG), which are shown in Table 12.

Table 12: WHO AQG for PM (WHO)

Particle size	WHO AQG (24 hour mean level)
PM10 (µg/m^3)	50
PM2.5 (µg/m^3)	25

Comparing the obtained results with this WHO AQG (Figure 33 and Figure 34), it can be seen that those guidelines are clearly exceeded by BM1 and BM3 most of the time and by NOBM1 in some occasions. It should be noted that guidelines are just recommendations and there is no current scientific evidence that they guarantee total protection. As McNamara, et. al. (2013) show in their study, elevated short and long term PM conc. are frequently higher than established standard levels. However, for a more accurate comparison, longer sampling time is needed, as the length of the sampling in guidelines (24 hours) and in the research (1 hour 30 minutes) is different.

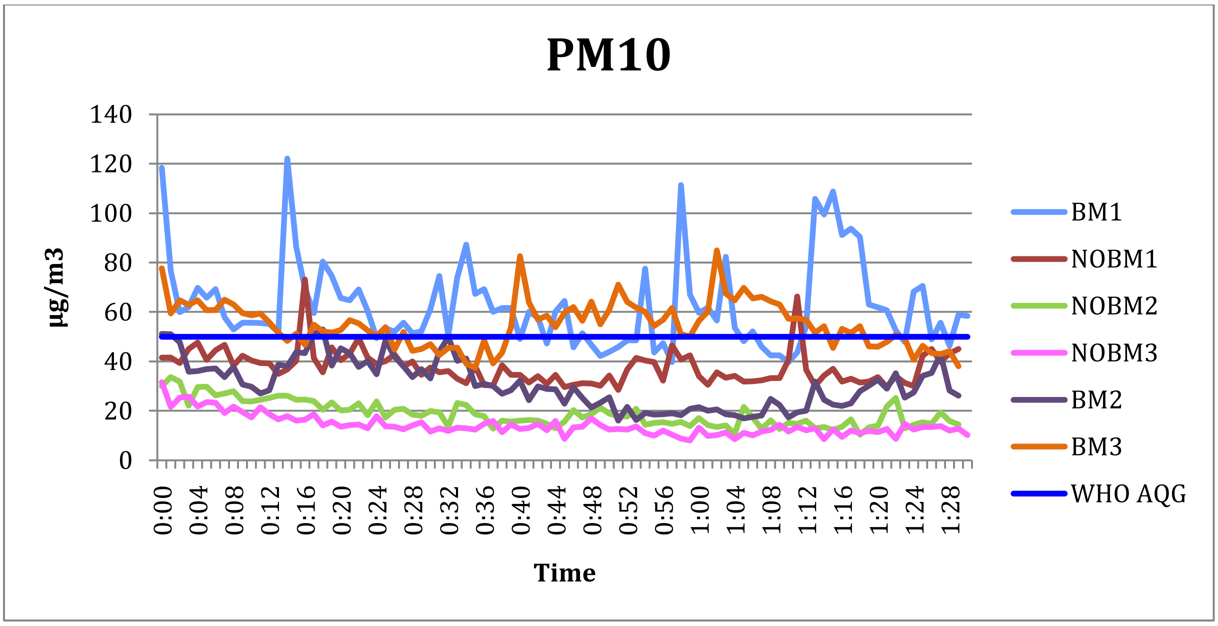


Figure 33: PM10 particles comparison with WHO AQG in both biomass and non biomass houses

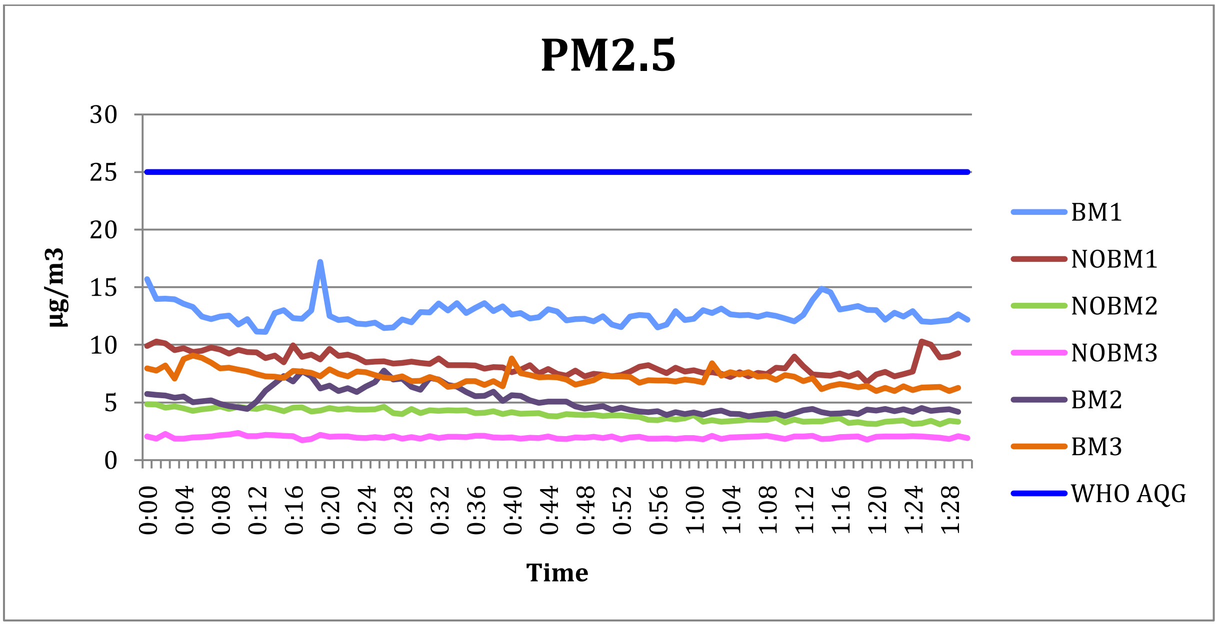


Figure 34: PM2.5 particles comparison with WHO AQG in both biomass and non biomass houses

With respect to ultrafine particles, the results from Figure 35 show higher peaks in houses were biomass was burnt than houses were there was no biomass burning. A rise to this peak could be related to the burning of biomass.

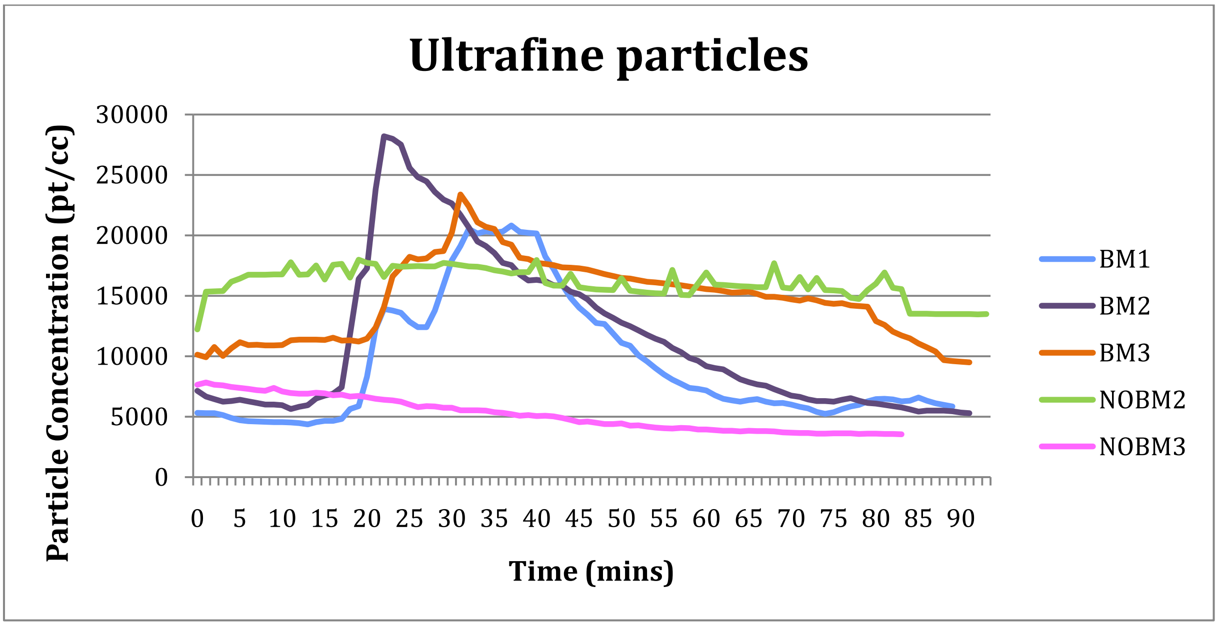


Figure 35: Ultrafine particle concentration in both biomass and non biomass houses

However, comparison of the average conc. of particles shows that NOBM2 had higher conc. than houses with biomass (figure 36). This could be as a result of influence from the outside environment since the window which faces the road was left open. Particles may have filtered indoors from the outdoor environment due to vehicles using the road, outdoor ambient quality and other activities which emit particulates (Zhua *et al.*, 2005).

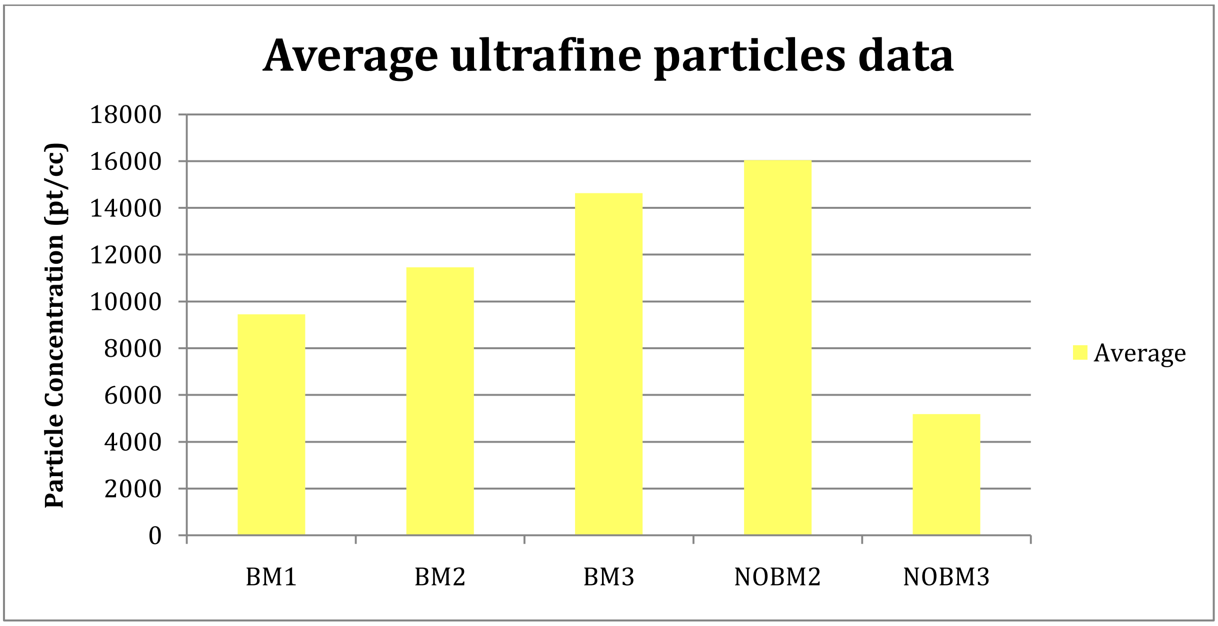


Figure 36: Average ultrafine particle concentration for both biomass and non biomass houses

On the other hand, BM1, BM2 and BM3 showed significantly higher average conc. to that of NOBM3, which tends to show that biomass burning has an effect on increased particle conc. This corresponds with a study in Canada which found that homes using biomass boilers or wood stoves had higher conc. than homes using other types of heating (Weichenthal *et al*., 2007). However, the release of ultrafine particles into the room environment cannot be fully evaluated for health risk because there are no limits or guidelines currently being used for evaluation. Although, the toxicity of ultrafine particles can be said to be evaluated, however, that depends on the chemical composition of each particle (Salthammer *et al*. 2014). Ultrafine particle formation from biomass burning depends on the type of wood used and flame conditions at different times (Lackner *et al*., 2013). The pressure gradient between the fireplace and the chimney are the main influence that releases particles in an indoor environment with a fireplace (Salthammer *et al*., 2014).

Regarding the CO measurements, the average values measured for the whole sampling time in each house are provided in Table 13.The values were converted from mg/m^3 to ppm for 25 ^oC and 1 atmosphere values (close to the temperature in a house). The average values obtained for the houses show clearly that the highest concentration of CO was present in BM3.

Table 13: Average CO results expressed in both mg/m^3 and ppm

Average	mg/m^3	ppm
NOBM2	1.58	1.4
NOBM3	1.66	1.4
BM2	1.29	1.1
BM3	2.59	2.3

The obtained values are not conclusive as it is not possible to relate the biomass burning with the conc. in the house: BM3 shows a higher concentration than houses without biomass burning, while the conc. in BM2 is lower. However, this fact makes sense as BM2 has shown clearly lower values also in PM results, probably due to a better ventilation and bigger size of the room. Ventilation is a factor that ISO 16000-1 highlights when sampling is done, especially in short time sampling.

Comparing all the average values for the sampling time (90 minutes) with the WHO guidelines (see Table 11), it can be stated that all the houses have lower values than the recommendations. Therefore, according to this study the health impact risk produced by the exposure to the CO for the inhabitants of these houses is low.

Results consulted in these papers (Commodore, *et al*., 2013, Hartinger, *et al*., 2013 and Naeher, 2001) show slightly higher conc. As it has been said, type of device, maintenance and fuel used are crucial factors for the indoor air quality.

4.3.2. Limitations

The results obtained and the conclusions drawn from them are limited by the small number of samplings done in the research. The researchers contacted other houses in which measurements could be done, but there was not enough time to do them as a delay in receiving the ethics approval slowed down all the process of trial measurements. Another important limitation has been the short time of sampling; that only has allowed comparison with WHO guidelines for 15, 30 and 60 minutes in CO. In the case of PM, there are not clearly defined limits for air quality and health impact risk, which made it difficult to assess and draw conclusions about possible health risks from the obtained results.

For a more exhaustive research more and longer samplings should be done in each house. It would be useful also to use pellets or other alternative biomass source.

Besides this, the software necessary to manage the data was only accessible in a laboratory where the students needed special permission to access, which caused delays in analysing the results.

Furthermore, the equipment was not always available for the students or did not work correctly, which made more difficult to do a standardized research. More precisely, the P-Trak used for ultrafine particles may not give accurate results as the last recorded calibration was in 2009. In addition, the FirstCheck+ 5000Ex was being calibrated when the sampling time started, and technical problems meant it was not available for sampling houses BM1 and NOBM1. Regarding the EL-USB-CO Data Logger, the two devices used during the experiment showed irregular results due to faults with the device sensors. Therefore, the data gotten from the devices were not used for analysis in this report.

To conclude with the limitations, the Gas Alert Microclip XT was not continuously used in the houses because it has an alarm that could cause disturbance or anxiety to the inhabitants of the houses. The strategy used was not adequate enough in sampling. More rooms in the houses should have been sampled and measurements done in different seasons.

4.4. Conclusions

The average results obtained in the research for PM clearly show a difference in air quality between houses using wood heating devices and houses not using them. Nevertheless exceptions can be found due to external influence. NOBM1 had more TSP than BM2 due to the activities carried out in the house during sampling and NOBM2 had a higher level of ultrafine particles than houses with biomass burning devices possibly due to the outdoor air influence.

It was stated that the particle size more influenced by biomass burning appliances was PM2.5, whereas the rest of the sizes were more likely to be influenced by external factors.

Regarding the CO, the sampling showed the influence of biomass burning in indoor air quality, as the house with higher concentration was BM3. However, other issues as ventilation or size of the room must be taken into account as they can change the results significantly. This is what happened in BM2 a house with an open fire place that has lower level of CO than houses without biomass burning device.

No one of the houses exceeded the WHO guidelines for CO concentration limits. Therefore, it can be stated that the risk linked with inhaling CO due to biomass burning in the houses measured is low.

However, as it has been stated in the report further research must be done to get more conclusive results.

5. Laboratory analysis

5.1. Sampling

Two wood chips (Poplar and Cedar) were collected from Trim-a-Tree Company close to Cranfield University and processed wood pellets and coal from wood and coal industries respectively. These biomass samples were taken to the laboratory for heavy metal analysis and cell toxicity testing. Detailed description of sample preparation, analytical principles and procedures are presented in Appendix E.1.

5.1.1. Samples description

The samples for metal analysis comprised of wood barks, stems, plant materials, and processed small fine cylindrical wood. Description of samples collected is given in Table 14 and pictures presented in Appendix E.3.

Table 14: Description of biomass fuel samples

Sample	Sample no.	Sample description
Poplar chips	1P	Irregular rough tree bark
Cedar chips	2C	Irregular rough stems and plant material
Wood pellets	3W	Processed small fine cylindrical pellets

5.2. Methodology

Each wood sample was weighed to achieve its initial mass and dried in an oven at 105 °C ± 5 °C at specified time to determine its moisture content (British Standard EN 13039, 2000) and then grinded. 5 grams of each biomass sample was heated in a furnace up to a temperature of 550 ± 10 °C for 4 hours and their ash content obtained (British Standard EN 13039, 2000). Furthermore, microwave digestion of approximately 0.5 g of wood material in mixture of nitric acid and hydrogen peroxide was done and the extract was used to determine the heavy metal content using an Inductively Coupled Mass Spectrometry (ICP-MS). Three analyses were done for each sample.

Ash samples of poplar and coal were dissolved in aqueous solution at a conc. of 10mg/ml and run in the Zetasizer at 25^{o}C using the Dynamic Light Scattering (DLS) principle (Gauggel *et al.,* 2012) to determine the amount of particulate sizes 0.1nm, 2.5nm and 10nm.

5.2.1. Statistical analysis

Statistical analyses were conducted using excel statistical packages and zetasizer particle size analyzer of Malvern software. Data were analysed using bar charts for metal analysis and size distribution graphs were used for particle size characterization. Results are expressed as the average.

5.3. Results and discussion

5.3.1. Moisture content, ash and metal analysis

The results of the analysis of moisture content, ash content and heavy metal concentration are shown in Table 15 and a concentration graph of the metals is shown in Figure 37.

Moisture content from samples ranges from 12.15 to 53.74 % with wood pellet having the least at 12.15 % weight of dry sample (Table 15). This is because it has been compressed under high pressure and extruded through a die. Its ash content on dry basis is approximately 0.5 % lower than the chips with values 3.12 % (poplar) and 7.67 % (cedar). This tends to correspond with the European standard specification of < 0.7 % (BS EN 14961-2).

The ash contents derived from all samples were found to contain certain amounts of heavy metals of which Zinc (Zn), Copper (Cu), Lead (Pb), Cadmium (Cd) and Chromium (Cr) were present as shown in Table 15 and Figure 37 (see Appendix E.2. for individual graphs).

Table 15: Heavy metal concentration, moisture content and ash content identified from wood samples

				Heavy metal concentration (mg/kg)									
Sample no.	**Sample**	**Moisture content (%),dry sample**	**Mean Ash content (%)**	**Zn**	**Mean**	**Cu**	**Mean**	**Pb**	**Mean**	**Cd**	**Mean**	**Cr**	**Mean**
1Pa	poplar chips	53.74	3.12	30.67		2.29		0.13		0.59		3.9	
1Pb				29.81		2.41		0.17		0.58		3.52	
1Pc				27.54	29.34	2.5	2.43	0.13	0.14	0.53	0.57	4.59	4
2Ta	cedar chips	49.73	7.67	15.23		3.2		0.62		0.14		2.69	
2Tb				15.97		3.45		0.52		0.14		2.9	
2Tc				15.81	15.67	3.44	3.36	0.52	0.55	0.14	0.14	2.74	2.78
3Wa	wood pellets	12.15	0.49	13.37		3.72		3.97		0.1		2.91	
3Wb				13		3.8		3.46		0.1		2.65	
3Wc				14	13.46	3.85	3.79	2.91	3.45	0.12	0.11	2.32	2.63

From the graph in Figure 37, the concentration (conc.) of Zn for Poplar chips shows a mean of 2.43 mg/kg (range from 2.29-2.5 mg/kg); cedar, a mean of 3.36 mg/kg (range from 15.23-15.97 mg/kg) and wood pellet, from 13-14 mg/kg with a mean of 13.46 mg/kg.

For Cu, poplar with mean 2.43 mg/kg (range from 2.29 -2.5 mg/kg); cedar with mean of 3.36 mg/kg (range from 3.2 -3.45 mg/kg) and wood pellet which ranges 3.72 -3.85 mg/kg with mean of 3.79 mg/kg.

Furthermore, poplar was seen to have the lowest Pd conc. with a mean 0.14 mg/kg (range from 0.13-0.17 mg/kg) in comparison with cedar with mean 0.55 mg/kg (range from 0.52 -0.62 mg/kg) and wood pellet with mean 3.45 mg/kg (range from 2.91- 3.97 mg/kg).

Again, poplar has the highest conc. of Cd with mean of 0.57kg/mg (range from 0.53-0.59 mg/kg) when compared with cedar with mean 0.55 mg/kg (0.14 mg/kg) and wood pellets with mean 0.11mg/kg (range from 2.32-2.91 mg/kg).

Poplar also showed high Cr conc. in comparison with others having a mean of 4 mg/kg (range from 3.9-4.59 mg/kg) whereas cedar showed a mean of 2.78 mg/kg (range from 2.69- 2.9 mg/kg) and wood pellet mean of 2.63 mg/kg (ranging from 2.32-2.91 mg/kg).

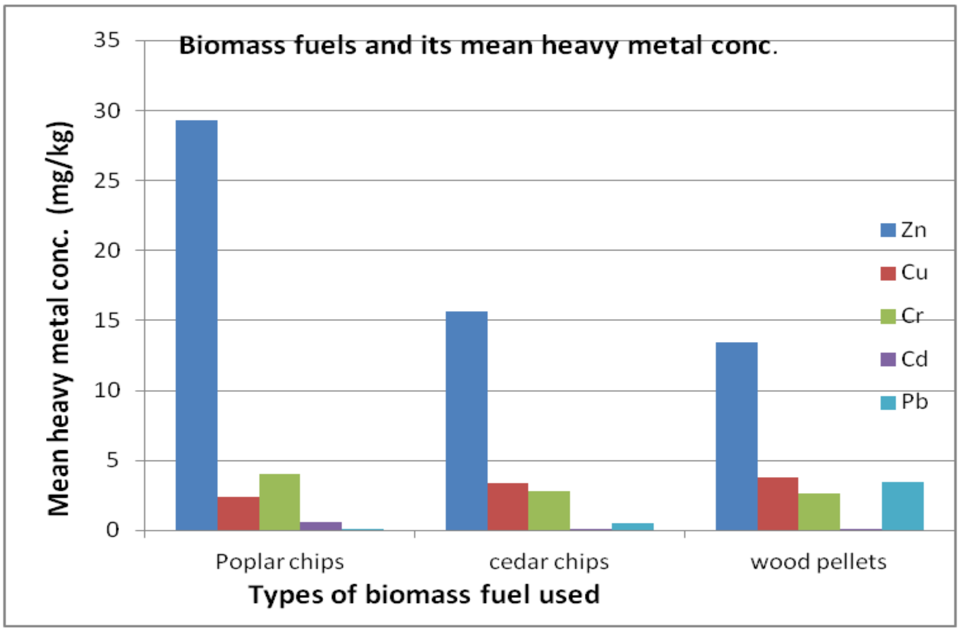


Figure 37: Mean heavy metal concentration (mg/kg) of biomass fuels used

Table 16: Comparison of mean concentrations obtained with their standard values (ECN, 2014)

	Mean Values (mg/kg)			European standards	
Heavy Metal	Poplar	Cedar	Wood Pellet	Poplar &Cedar (EN 14961-4)	Wood Pellet (EN 14961-2)
Zn	29.34	15.67	13.46	100	100
Cu	2.43	3.36	3.79	10	10
Pd	0.14	0.55	3.45	10	10
Cd	0.57	0.14	0.11	2	0.5
Cr	4.01	2.78	2.63	10	10

From Table 16, the mean heavy metal conc. of the three biomass samples used during the experiment does not exceed the European standard values. However, the Zn and Cd content of poplar was highest in comparison with cedar and wood pellet. This is likely due to increased digestion of these metals from poplar as indicated by Kolembkiewicz and Chimclarz (2013). Also, poplar and cedar chips in comparison with wood pellet presented a higher moisture content and metals conc. of Zn, Cr and Cd. This is likely due to the presence of chemical contaminant from soil, water and air resulting from poor storage of fuels used.

It is important to note that in the winter period as more kilograms of fuel are being used, more amount of these metals will be produced which will have potential adverse effects if exposed to high levels via handling of ash for disposal. Such health issues include amnesia and spontaneous abortion caused by exposures to high levels of Pb (Marinela and Elias, 2007), pneumonia by Cr (USEPA, 2013).

5.3.2. Particle characterization

Particle characterization was done for one sample each of biomass sample (poplar) and conventional fuel (coal) (see Appendix E.5.). The sizes of the samples obtained were 569nm (poplar) and 566.8nm (coal) with corresponding Polydispersity Index (PdI) of 0.904 and 0.835 respectively (Table 17), which are higher than the stated International Standard of 0.7 (ISO13321, 1996). This indicates that the particles have very broad size distribution and slow particle diffusion in the medium (Appendix E.4.). This could be because the samples were not properly crushed as there was no suitable equipment available. Particle sizes of 0.1nm, 2.5nm and 10 nm were therefore not detected. This is also evident in Figure 38 and Figure 39 which are right skewed. Such broad size of samples cannot be inhaled and deposited in the lungs like those which range from 0.1nm to 10nm (Cormier et. al., 2006).

Table 17: Poplar and Coal DLS analysis

Sample	Z-Av (d.nm)	PdI	Size (d.nm)	Std.Dev (d.nm)
Poplar	2010	0.904	569	41.77
Coal	1608	0.835	566.8	41.49

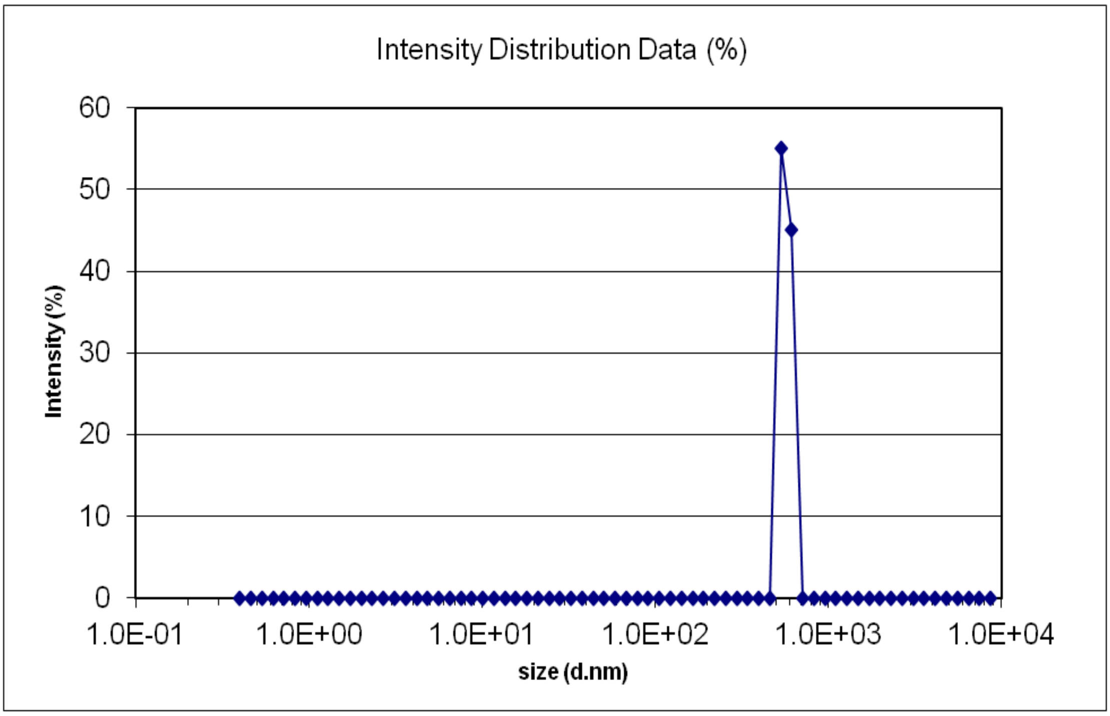


Figure 38: Size distribution of poplar sample by intensity (100ug)

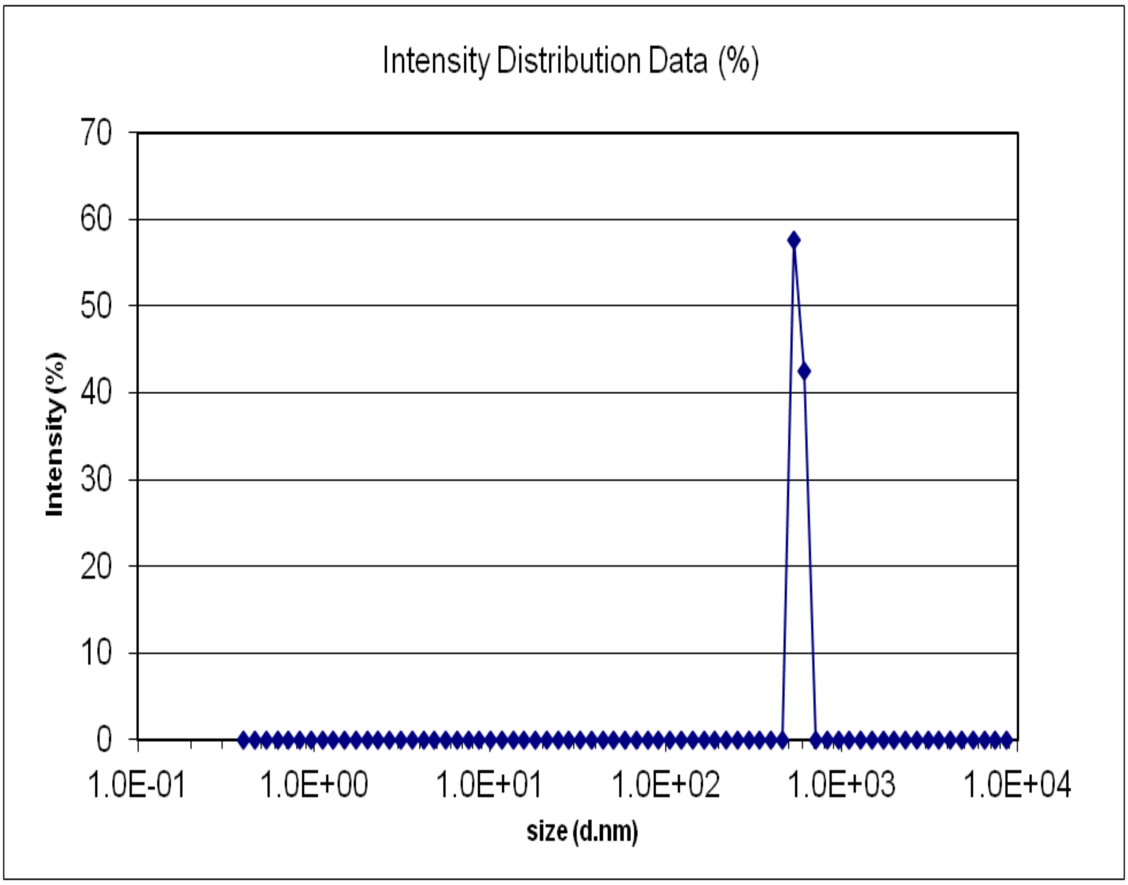


Figure 39: Size distribution of coal sample by intensity (100ug)

5.3.3. Limitations

Unavailability of modern grinding equipment affected the particle characterization. If proper grinding equipment was available, lower particle sizes could have be obtained for analysis.

Elongated ethical approval and underestimated time needed for laboratory inductions.

6. Milton Keynes scenario

Milton Keynes (MK) Council identifies biomass boilers as a viable low carbon technology. For now, 13 biomass boilers using woodland residues are in place in MK with a capacity greater than 1.5 MW (CSE, 2012).

6.1. Local sourcing of biomass fuels

Local sourcing of biomass comes from three major streams: woodland, energy crops and wood waste. The area considered comprises Milton Keynes Borough, circled in red in Figure 40, and the area around Cranfield.

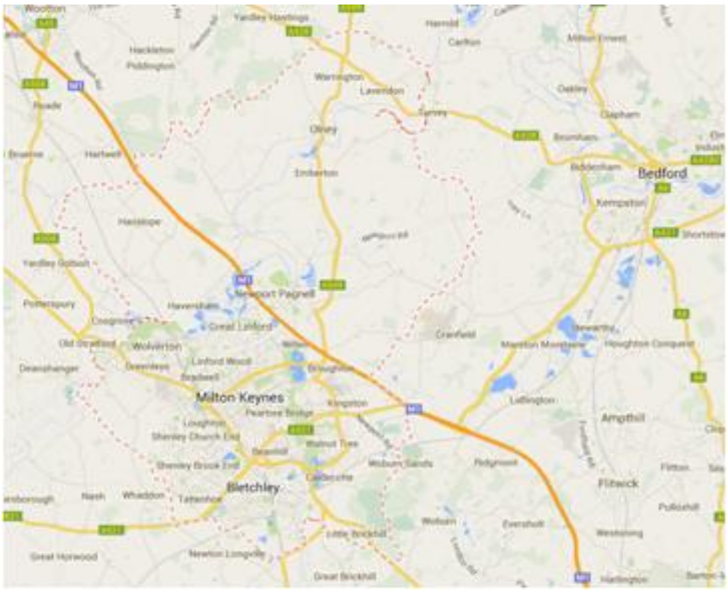


Figure 40: Area of study

6.1.1. Milton Keynes Borough

A great amount of biomass can be obtained from sustainable management of woodland in Milton Keynes Borough (MKB). Data on potential local supply of biomass comes from the Parks Trust and the National Inventory of Woodland and Trees (CSE, 2012). Multiplying the resources in tonnes per annum by the energy content at 30% moisture content, we deduce that 23.2 GWh/a of energy is available. However, the previous data does not include scattered individual trees in parks or in streets, so the Parks Trust gave estimates of this added resource, totalling 8.75 GWh/a of energy.

Wood waste resource is difficult to estimate but this includes at least around 5,918 tonnes/a of waste wood collected in recycling centres. Still, the share of clean and contaminated wood is unknown. As contaminated waste wood is not recommended for small-scale boilers, it could be argued that this resource could be excluded in a first approach.

There are two main types of energy crops; short rotation coppice (SRC) and Miscanthus, for which yield is higher. With DEFRA dataset and all constraints of land use, Centre for Sustainable Energy (CSE, 2012) obtained the number of available hectares to grow energy crops. However, farmers may not be willing to change the use of their land. As a result, we will assume that only 5% of farmland is used to grow Miscanthus. Multiplying the yield by the energy content at 0% moisture, Miscanthus could provide 61.4 GWh/a.

Table 18 below recaps the results from local sourcing of biomass for a year. The power capacity is calculated assuming an average boiler capacity factor of 0.18.

Table 18 Local biomass sourcing for MKB by types (CSE, 2012)

Type	Production (t/ha)	Energy (GWh)	Power (MW)
Wood residues	9,131	31.96	20.25
Wood waste	5,918	20.71	13.13
Miscanthus	12,285	61.43	38.93

6.1.2. Cranfield Area: Marston Vale

As Cranfield area is also included in our study, it could be worthy to consider Marston Vale forest resources in Bedfordshire. We should keep in mind that wood demand does not only concern heating purposes but also paper industry or other applications. According to Burgess et. al. (2012), Marston Vale wood resource is estimated to be 11.7 GWh/a.

6.2. Likely scenarios for future use of biomass

6.2.1. Local demand

The number of households in Milton Keynes Borough is around 100,100 in 2012 and is expected to grow to 116,450 by 2021 (MKC, 2014) and Cranfield includes around 1,900 dwellings (CBC, 2013). The space and water heating share in total domestic energy consumption was around 83% on average in the UK in 2012 (DECC, 2013). One household uses on average 16.1 MWh of energy if we take the average value for the UK in 2011 (ONS, 2011). We deduce from these values a potential heat demand per year of 1,363 GWh/a for Milton Keynes Borough and Cranfield.

Looking at the figures obtained for the available local sourced biomass, less than 100 GWh/a could be provided by our study area (MK borough and Cranfield) so only 8% of households could switch to locally supplied biomass. However, biomass could be imported from within the UK or from other suppliers from Europe or North America.

6.2.2. Drivers and limiters to the use of biomass

Following the recommendations from the Energy Saving Trust (EST, 2012), we will consider that MK inhabitants would use pellet boilers to provide domestic central heating and hot water. For an average 15kW boiler for space and water heating, costs are around £11,500, twice as much as a gas heating appliance. However, pellets price could be lower than other conventional fuels.

The domestic Renewable Heat Incentive (RHI) provides 12.2p/kWh of heat produced over seven years (DECC, 2013). The Department of Energy and Climate Change (DECC, 2013) also incentivised the use of smart meters to monitor the boiler performance. An incentive for inhabitants is the £150 boiler cashback, available to all homeowners in the Milton Keynes area (MKC, 2014).

Besides, biomass boilers require space for biomass fuel storage, and are often set up when heating systems are refurbished (CSE,2012). The growth in use of biomass could come from two main areas: that fraction of new homes that is powered by biomass and the number of existing homes converting from other fuels to biomass.

Table 19 below recaps the drivers and limiters of biomass burning for domestic use.

Table 19 drivers and limiters of biomass use for domestic heating (EST, 2012, DECC, 2013 and MKC, 2014)

Drivers	Limiters
RHI Other financial incentives Local supply of energy	Space needed for fuel storage Upfront costs Social awareness and acceptance

Looking at the UK's target of 15% renewables by 2020, it could be argued that 10% of it could be obtained thanks to biomass, with the remaining 5% coming from solar heat and ground source heat pumps. This target is achievable looking at the results of the survey for MKB inhabitants. Indeed half of the person asked answered that they would like to have a biomass boiler in their homes.

Looking at the biomass sourcing, 80% of it could be locally supplied in 2020. To fulfil the previous target of MK, some biomass should be imported. On a longer timescale, biomass use should continue to rise depending on fuels price and the heat market. Hence, the proportion of biomass locally sourced will decrease if no extension of woodland or efficient forestry management is planned.

7. Conclusions

In order to reduce the carbon footprint of MK inhabitants, the use of biomass for domestic heating seems a good option. However, further adoption of biomass may have some drawbacks.

The fossil fuel displaced by biomass would certainly be natural gas, which has been found in the survey as the main source of heating. This switch of fuels will increase CO, PM and NO_X emissions. Also ash will be produced, which is not the case of natural gas combustion systems.

Results of the survey showed that people are more aware of the benefits of biomass use than of its drawbacks. Indeed, half of the participants from MKB answered that the use of biomass would have a positive impact on climate change, but less than 10% definitively think biomass use over fossil fuels will have a negative impact on air quality. Although people are aware of the health risks associated with CO, a high percentage of the sample group did not know that CO is one of the pollutants emitted when biomass is burnt.

The rise in CO and PM concentration in indoor air in houses with biomass burning appliances has been revealed by the trial measurements, but only fireplaces and stoves were studied. Nevertheless, modern systems have revealed much lower emissions levels. These levels are even lower when using woody pellets. Results showed that other factors, such as poor ventilation and outdoor air quality, can drastically change the concentration levels.

The surge in emissions levels observed during the trial measurements has showed low impact on health according to WHO guidelines. However, this does not mean there is no risk, and further research must be done. Incomplete combustion in an inefficient wood burner has proved to have more risks for human health than burners that optimise the combustion. However, the use of modern biomass boilers will help minimise health risks associated with emissions by achieving a maximum level of combustion which averts formations of incomplete combustion products (organic and soot particles).

The lab analysis showed that the bottom ash from the biomass contains minute concentration of heavy metal. Thus during the winter, when bigger amount of biomass is used for heating, the heavy metal concentration might exceed the European standards. Improper handling and disposal of ash will pose an adverse effect to human health via ingestion and inhalation.

On the other hand, biomass burning is good for health as it combats climate change. The trade-off between air quality drawbacks and climate change benefits on human health related to small-scale biomass combustion should be investigated.

8. Recommendations

For future scenarios using locally supplied energy crops, it is recommended to study the human health impacts of small-scale biomass burning devices for these different types of feedstock.

In order to analyze how a massive change to biomass burning devices would affect Milton Keynes air quality, further research should be done. More houses and during more time should be analyzed to have more conclusive results.

There should be an incentive to improve appliances by replacing old burners by new ones. Also smart use of maintenance and ventilation are advised to reduce health risks.

Awareness should be raised on the risks associated with current fireplaces or old appliances, especially regarding the possible health impact that a long term exposure to the emitted pollutants as CO or PM could have.

A functional ash handling and disposal system should be put in place for homes in the Milton Keynes area, to address the potential risks posed by heavy metals from biomass burning.

9. References

Abbasi T. and Abbasi S. A. (2010), Biomass energy and environmental impacts associated with its production and utilization, Renewable and Sustainable Energy Reviews, Vol. 14 pp. 919-937.

Ahswell Biomass (2012), Manufacturer of Biomass Boilers, available at: http://www.ashwellbiomass.com (accessed 25th April 2014).

Andreae, M. O. and Merlet, P. (2001), Emission of trace gases and aerosols from biomass burning, Global Biogeochemical Cycles, vol. 15, no. 4, pp. 955-966.

Awang M. B., Jaafar A. B., Abdullah A. M., Ismail M. B., Hassan M. N., Abdullah R., Johan S. and Noor H. (2000), Air quality in Malaysia: Impacts, management issues and future challenges, Respirology, vol. 5, no. 2000, pp. 183-196

Barton, A., Basham, M., Foy, C., Buckingham, K., Somerville, M. (2007), The Watcombe Housing Study: The short-term effect of improving housing conditions on the health of residents, Journal of Epidemiology and Community Health, Vol. 61, No. 9, pp. 71-777.

Bayram, H., Rusznak, C., Khair, O.A., Sapsford, R.J. and Abdelaziz, M.M. (2002), Effect of ozone and nitrogen dioxide on the permeability of bronchial epithelial cell cultures of non-asthmatic and asthmatic subjects, Clinical Experimental Allergy, Vol. 32, No. 9, pp. 1285-1292.

Beckett, W.S., Russi, M.B., Haber, A.D., Rivkin, R.M., Sullivan, J.R., Tameroglu, Z., Mohsenin, V. and Leaderer, B.P. (1995), Effect of nitrous acid on lung function in asthmatics: a chamber study, Environmental Health Perspective. Vol. 103, No. 4, pp. 372-375.

Belanger, K., Gent, J.F., Triche, E.W., Bracken, M.B. and Leaderer, B.P. (2006), Association of indoor nitrogen dioxide exposure with respiratory symptoms in children with asthma. American Journal of Respiratory and Critical Care Medicine Vol. 173, No. 3, pp. 297-303.

Bellinger, D.C. (2005), Teratogen update: lead and pregnancy, Birth Defects Research, Part A Clinical and Molecular Teratology, Vol. 73, pp. 409.

Biomass Energy Centre (2010), Biomass and air quality: Reports and studies, vol. 1.

Biomass Energy Centre (2011), Emissions levels, available at: http://www.biomassenergycentre.org.uk/portal/page?_pageid=77,109191&_dad=portal&_schema=PORTAL (accessed 20th March 2014)

Boström, C., Gerde, P., Hanberg, A., Jernström, B., Johansson, C., Kyrklund, T., Rannug, A., Törnqvist, M., Victorin, K. and Westerholm, R. (2002), Cancer risk assessment, indicators, and guidelines for polycyclic aromatic hydrocarbons in the ambient air, Environmental Health Perspective, Vol. 110, No. 3, pp.451-488.

Boy, E., Bruce, N. and Delgado, H. (2002), Birth weight and exposure to kitchen wood smoke during pregnancy in rural Guatemala, Environmental Health Perspective, Vol.110, pp.109-114.

British Standard BS 7755. (1994), Section 3.1, Determination of dry matter and water content on a mass basis by gravimetric method, British Standard International Publication.

British Standard BS EN 13039. (2000), Determination of organic matter content and ash, British Standard International Publication.

British Standards Institution (2006), BS EN ISO 16000-1: Indoor air - Part 1: General aspects of sampling strategy. London. British Standards Institution (online). Available at Cranfield University Library website: https://extranet.cranfield.ac.uk/Download/,DanaInfo=bsol.bsigroup.com,SSL+SubscriptionPdfDocument?materialNumber=000000000030154335 (accessed 28th April 2014).

Buonanno, G., Morawska, L., and Stabile, L. (2009), Particle emission factors during cooking activities, Atmospheric Environment, Vol. 43, No. 20, pp. 3235-3242.

Burg, V.R. (1997), Toxicology Update, Journal of Applied Toxicology, Vol. 19, pp. 329-386.

Burgess et. al. (2012) A framework for reviewing the trade-offs between, renewable energy, food, feed and wood production at a local level, Renewable & Sustainable Energy Reviews 16, pp. 129-142.

BW Technologies. Gas Alert Microclip XT: Product Overview (online), available at: http://www.gasalertmicroclipxt.com/product-overview.php (accessed 26th April 2014).

Carol, P. (2014), Toxicity beyond the Lung connecting PM2.5, inflammation and diabetes, Environmental Health Perspectives, Vol. 122, No. 1, pp. A29.

Central Bedfordshire Council (2013), Cranfield & Marston Moretaine Ward Profile, available at: http://www.centralbedfordshire.gov.uk/Images/Cranfield%20%26%20Marston%20Moretaine%20ward%20profile%20210313_tcm6-10021.pdf (accessed 7th March 2014).

Centre for Sustainable Energy (2012), Milton Keynes Energy Mapping Project - Summary Report.

Chavez, E., Jay, D., Bravo, C. (1987), The mechanism of lead-induced mitochondrial Ca2þ efflux, Journal of Bioenergetics and Biomembranes, Vol. 19, pp. 285.

Commodore, A. et. al. (2013), A Pilot Study Characterizing Real Time Exposures to Particulate Matter and Carbon Monoxide from Cookstove Related Woodsmoke in Rural Peru. Atmospheric environment (Oxford, England : 1994), 79, pp.380–384, available at: http://www.ncbi.nlm.nih.gov/pubmed/24288452 (accessed 26th April 2014).

Core, J.E. and Petersen, L.J. (2001), Air quality monitoring for smoke, in: Hardy, C.C., Ottmar, R.D., Peterson, J.L., Core, J.E. and Seamon, P. (editors), Smoke management guide for prescribed and wildland fire, Boise, ID: National Wildfire Coordination Group, Fire Use Working Team, pp. 179-185

Cormier, S. A., Lomnicki, S., Backes, W. and Dellinger, B. (2006), Origin and Health Impacts of Emissions of Toxic By-Products and Fine Particles from Combustion and Thermal Treatment of Hazardous Waste and Materials, Environmental Health Perspective, Vol. 114, No. 6, pp. 810 - 817.

Corn, M. (2012), Handbook of hazardous materials, Academic Press, California.

Costa, M., Yan, Y., Zhao, D., Salnikow, K. (2003), Molecular mechanisms of nickel carcinogenesis: gene silencing by nickel delivery to the nucleus and gene activation/inactivation by nickel-induced cell signalling, Journal of Environmental Monitoring, Vol. 5, pp. 222.

Cynthia, T. F. (2003), Human Health Impacts of Forest Fires in the Southern United States, Journal of Ecological Anthropology, Vol. 7, pp. 39-63.

Dales, R., Liu, L., Wheeler, A.J. and Gilbert, N.L. (2008), Quality of indoor residential air and health, Canadian Medical Association Journal, Vol. 179, No. 2, pp. 147-152.

De Koning, H.W., Smith, K.R. and Last, J.M. (1985), Biomass fuel combustion and health, Bulletin of the World Health Organisation. Vol. 63, No. 1, pp. 11-26.

Dele, O. O. (2013), Spatial trends in particulate matter concentrations in the near roadside environments of Milton Keynes, Cranfield Health and Environment, Cranfield University.

Delmas, R., Lacaux, J.P., Menaut, J.C., Abbadie, L., Le Roux, X., Helas, G., and Lobert, J. (1995), Nitrogen compound emission from biomass burning in tropical African savannah, Journal of Atmospheric Chemistry, Vol. 22, pp. 175-193.

Demirbas A. (2005), Potential application of renewable energy sources, biomass combustion problems in boiler power system and combustion related environmental issues, Progress in Energy and Combustion, Vol. 31, pp. 171-192.

Demirbas A. (2008), Hazardous emissions from combustion of biomass, Energy Sources, Vol. 30, pp. 170-178

Dennison L, Rolfe K, Graham B. (2000), Review of the Ambient Air Quality Guidelines – Health effects of five common air contaminants and recommended protective ranges, Ministry for the Environment Technical report, No. 12.

Department for Energy and Climate Change (DECC) (2011), UK Renewable Energy Roadmap. Department of Energy and Climate Change

Department for Energy and Climate Change (DECC) (2012), Statutory Guidance for Boilers and Furnaces 20-50MW thermal input.

Department for Energy and Climate Change (DECC) (2013), Domestic energy consumption in the UK between 1970 and 2012, In: Department of Energy and Climate Change, 2013, Energy Consumption in the UK (2013), Ch. 3, available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65954/chapter_3_domestic_factsheet.pdf (accessed 7th March 2014)

Department for Energy and Climate Change (DECC) (2013), Energy Consumption in the UK - Chapter 3 Domestic energy consumption in the UK between 1970 and 2012, available at: https://www.gov.uk/government/publications/energy-consumption-in-the-uk (accessed 24th April 2014).

Department for Energy and Climate Change (DECC) (2013), UK Renewable Energy Roadmap - Update 2013, available at:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/255182/UK_Renewable_Energy_Roadmap_-_5_November_-_FINAL_DOCUMENT_FOR_PUBLICATIO___.pdf (accessed 27th March 2014).

Department for Energy and Climate Change (DECC) (2014), Industrial & Commercial Boilers, available at: http://chp.decc.gov.uk/cms/industrial-commercial-boilers-2, (accessed 24th April 2014).

Department for Environment, Food and Rural Affairs (DEFRA) (2007), UK Biomass Strategy, available at: http://www.biomassenergycentre.org.uk/pls/portal/docs/PAGE/RESOURCES/REF_LIB_RES/PUBLICATIONS/UKBIOMASSSTRATEGY.PDF (accessed 24th April 2014).

Department for Environment, Food and Rural Affairs (DEFRA) (2012), National Air Quality Objectives, Department for Environment Food and Rural Affairs, available at: http://uk-air.defra.gov.uk/documents/National_air_quality_objectives.pdf (accessed 9th March 2014)

Devalia, J.L., Rusznak, C., Herdman, M.J., Trigg, C.J., Davies, R.J. and Tarraf, H. (1994), Effect of nitrogen dioxide and sulphur dioxide on airway response of mild asthmatic patients to allergen inhalation, Journal of Clinical Investigation, Vol. 344, No. 8938, pp. 1668-1671.

Dickey J. H. (2000), Air pollution: overview of sources and health effects, Disease- a Month, vol. 46 pp. 566–89.

Dockery, D.W. and Pope, C.A. (1994), Acute respiratory effects of particulate air pollution, Annual Reviews of Public Health, Vol. 15, pp. 107-132.

Donaldson, K., Stone, V., Cloutter, A., Renwick, L. and MacNee, W. (2001), Ultrafine Particles, Occupational Environmental Medicine, Vol. 58, No. 3, pp. 211-216.

ECN (2014), Energy Research Centre of the Netherlands, available at: https://www.ecn.nl/phyllis2 (accessed 26th April 2014).

Eeden, S.F. (2001), Cytokines involved in the systemic inflammatory response induced by exposure to particulate matter air pollutants (PM10), American Journal of Respiratory and Critical Care Medicine, Vol. 164, No. 5, pp. 826-830.

Energy Saving Trust (2008), Domestic heating by oil: boiler systems – guidance for installers and specifiers.

Energy Saving Trust (2012), A buyer's guide to wood-fuelled heating, available at: http://www.energysavingtrust.org.uk/Publications2/Generating-energy/Buyers-guides/A-buyer-s-guide-to-wood-fuelled-heating (accessed 25th March 2014).

Evans, G.W. and Campbell, J.M. (1983), Psychological perspectives on air pollution and health, Basic and Applied Social Psychology, Vol. 4, No .2, pp. 137-169.

Evans, G.W. and Kantrowitz, E. (2002), Socioeconomic status and health: The potential role of environmental risk exposure, Annual Review of Public Health. Vol. 23, pp. 303-331.

Fowler D. Flechard C. Skiba U. Coyle M. Cape J. N. (1998), The atmospheric budget of oxidized nitrogen and its role in ozone formation and deposition, New Phytologist, vol. 139 no. 1 pp. 11-23.

Garza, A., Vega, R. and Soto, E. (2006), Cellular mechanisms of lead neurotoxicity, Medical Science Monitor, Vol. 12, RA57.

Gas Safety Trust (2010), Carbon Monoxide Trends Report – 1996 to 2010, available at: http://www.gas-safety-trust.org.uk/2010/03/carbon-monoxide-trends-report-1996-to-2010/ (Accessed 25th April 2014).

Gauggel, S., Derreza-Greevan, C., Wimmer, J., Wingfield, M., Burg, B. and Dietrich, D. (2012), Characterization of biologically available wood combustion particles in cell culture medium, ALTEX-Alternatives to Animal Experimentation, Vol. 29, No. 2, pp. 183.

Ghio, A.J. and Huang, Y.C. (2004), Exposure to concentrated ambient particles (CAPs): a review, Inhalation Toxicology, Vol. 16, pp. 53.

Goetz, S., Aneja, V.P. and Zhang, Y. (2008). Measurement, analysis, and modelling of fine particle matter in Eastern North Carolina, Journal of Air and Waste Management Association, Vol. 58, pp. 1208-1214.

Gorguner, M. and Akgun, M. (2010), Acute inhalation injury, The Eurasian Journal of Medicine, Vol. 42, pp. 28-35.

GOV.UK. Increasing the use of low-carbon technologies (online), available at: https://www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/the-renewables-obligation-ro (accessed 7th March 2014).

Hall, D.O., Rosillo-Calle, F., and de Groat, P. (1991), Biomass energy, Energy Policies, Vol. 19, No. 8, pp. 741-734.

Hammond, G.P., Kallu, S. and McManus*, M.C. (2008), Development of biofuels for the UK automotive market, Science Direct (Applied Energy), Vol. 85, pp. 506-515.

Handa, P.K. (2005), Carbon monoxide poisoning: A five year review at Tan Tock Seng hospital, Singapore, Annals Academy of Medicine, Vol. 34, No. 10, pp. 611-614.

Happonen, K. (2011), Torrefied wood pellets as an alternative fuel to coal: Climate benefits and social desirability of production and use, Department of Economics and Management, University of Helsinki, available at: https://helda.helsinki.fi/bitstream/handle/10138/31435/BIOHIILIGRADU_Happonen_2011.pdf?sequence=1 (accessed 29th April 2014)

Hartinger, S.M. et. al. (2013), Chimney stoves modestly improved indoor air quality measurements compared with traditional open fire stoves: results from a small-scale intervention study in rural Peru. Indoor air, 23(4), pp.342–52, available at: http://www.ncbi.nlm.nih.gov/pubmed/23311877 (accessed 26th April 2014).

Helleday, R., Huberman, D., Blomberg, A., Stjernberg, N. and Sandstrom, T. (1995), Nitrogen dioxide exposure impairs the frequency of the mucociliary activity in healthy subjects, European Respiratory Journal, Vol. 8, No. 10, pp. 1664-1668.

Howden-Chapman, P., Matheson, A., Crane, J., Viggers, H., Cunningham, M., Blakely, T., Chris, C., Woodward, A., Saville-Smith, K., O'Dea, D., Kennedy, M., Baker, M., Waipara, N., Chapman, R. and Davie, G. (2007), Effect of insulating existing houses on health inequality: Cluster randomized study in the community, British Medical Journal, Vol. 334, No. 7591, pp. 460-464.

Ion Science Advanced Gas Sensing Technologies, FIRSTCHECK + Key Features, [Brochure], available at: http://www.ionscience.com/assets/files/brochures/FirstCheck+%20V3.6.pdf (accessed 27th April 2014).

ISO13321 (1996), International Standard, Methods for Determination of Particle Size Distribution Part 8: Photon Correlation Spectroscopy, International Organisation for Standardisation, available at: https://www.iso.org/obp/ui/#iso:std:iso:13321:ed-1:v1:en (accessed 24th April 2014).

Jacobson, M. Z. (2010), Short-term effects of controlling fossil-fuel soot, biofuel soot and gases, and methane on climate, Arctic ice, and air pollution health, Journal of Geophysical Research, Vol. 115, Issue D14.

Jain P. C. (1993), Greenhouse effect and climate change: Scientific basis and overview, Renewable energy, vol. 3 no. 4-5 pp. 403-420.

Jarup, L. (2003), Hazards of heavy metal contamination, British Medical Bulletin, Vol. 68, pp. 167

Jaward F. M., Meijer S. N., Steinnes E., Thomas G. O. and Jones K. C. (2004), Further studies on the latitudinal and temporal trends of persistent organic pollutants in Norwegian and UK background air, Environmental Science Technology, vol. 38 pp. 2523–2530.

Jenkins B. M. Baxter L. L. Miles Jr. T. R. Miles T. R. (1998), Combustion properties of biomass, Fuel Processing Technology, vol. 54 pp. 17-46

Kalembkiewicz, J. and Chimielarz (2013), Effects of biomass co-combustion with coal on functional speciation and mobility of heavy metals in industrial ash, Polish Journal of Environmental Studies, Vol. 22, No. 3, pp. 741-747.

Khorshidi Z., et. al. (2013), The impact of biomass quality on the performance and economics of co-firing plants with and without CO2 capture, International Journal of Greenhouse Gas Control.

Knox, E.G. (2005), Childhood cancers and atmospheric carcinogens, Journal of Epidemiology and Community Health, Vol. 59, No. 2, pp. 101-195.

Koenig, J. Q., Lapson, T.V., Hanley, Q.S., Rebolledo, V., Dumler, K., Checkoway, H.,Wang, S.Z., Lin, D. and Pierson, W.E. (1993), Pulmonary function changes in children associated with fine particulate matter, Environmental Research, Vol. 63, No.1, pp. 26-38.

Komarnisky, L.A., Christopherson, R.J. and Basu, T.K. (2003), Sulfur: its clinical and toxicological aspects, Nutrition, Vol. 19, No. 1, pp. 54-61.

Konstantopoulou, S.S. et. al. (2014), Indoor air quality in a bar/restaurant before and after the smoking ban in Athens, Greece. The Science of the total environment, 476-477, pp.136–43, available at: http://www.ncbi.nlm.nih.gov/pubmed/24463032 (accessed 19th March 2014).

Lackner, M. and Winter, F. (2013), Combustion: From Basics to Applications, John Wiley & Sons.

Lascar (2014), EL-USB-CO Carbon Monoxide (CO) Data Logger with USB Interface, [Brochure], available at: http://www.lascarelectronics.com/temperaturedatalogger.php?datalogger=104# (accessed 27th April 2014).

Lee, J.T., Kim, H., Song, H., Hong, Y.C., Cho, Y.S. and Shin, S.Y. (2002), Air pollution and Asthma among children in Seoul, South Korea, Epidemiology, Vol.13, pp. 481–484.

Leskinen J. et. al. (2013), Fine Particle emissions in three different combustion conditions of a wood chip-fired appliance – Particulate physico-chemical properties and induced cell death. Atmospheric Environment. Vol. 86 Pp.129-139, available at: https://extranet.cranfield.ac.uk/S1352231013009473/,DanaInfo=ac.els-cdn.com+1-s2.0-S1352231013009473-main.pdf?_tid=ce335124-cf24-11e3-8bd6-00000aab0f01&acdnat=1398724453_4c90609116ff4e16c8b98bddbdffbf64 (accessed 28 April 2014)

Li, N., Sioutas, C., Cho, A., Schmitz, D., Misra, C., Sempf, J., Wang, M., Oberley, T., Froines, J. and Nel, A. (2003), Ultrafine particulate pollutants induce oxidative stress and mitochondria damage, Environmental Health Perspectives, Vol. 111, No. 4, pp. 455- 460.

Ma'mum S., Svendsen H. F., Hoff K. A. and Juliussen O. (2007), Selection of new absorbents for carbon dioxide capture, Energy Conversion and Management, Vol. 48, No. 1 pp.254-258

Malvern (2014), Zetasizer Nano Z, available at: http://www.malvern.com/en/products/product-range/zetasizer-range/zetasizer-nano-range/zetasizer-nano-z/(accessed%2028th%20April,%202014) (accessed 12th April 2014).

Marilena, K. and Elias, C. (2008), Human health effect of air pollution, Environmental Pollution, Vol. 151, pp. 362-367.

Mary S.B. (2012), Biomass Energy in Pennsylvania: Implications for Air Quality, Carbon Emission and Forests, available at: http://www.pfpi.net/wp-content/uploads/2012/12/PFPI-PA-Biomass-Energy-Report_12_18_12.pdf (accessed 9th March 2014).

Mendell, M. J. (2007), Indoor residential chemical emissions as risk factors for respiratory and allergic effects in children: A review, Indoor Air, Vol. 17, No. 4, pp. 259-277.

Miller, K.A., Siscovick, D.S., Sheppard, L., Shepherd, K., Sullivan, J.H., Anderson, A.L. and Kaufman, J.D. (2007), Long-Term Exposure to Air pollution and Incidence of Cardiovascular Event in Women, The New England Journal of Medicine, Vol. 356, No. 5, pp. 447-458.

Milton Keynes Council (2014), Boiler Cashback Scheme, available at: http://www.milton-keynes.gov.uk/environmental-health-and-trading-standards/low-carbon/milton-keynes-boiler-cashback-scheme (accessed 25th March 2014).

Milton Keynes Council (2014), SNA Population and Growth, available at: http://www.milton-keynes.gov.uk/social-care-and-health/health-and-wellbeing-board/strategic-needs-assessment/jsna/1-population-and-growth (accessed 7th March 2014).

Naeher L. P. Brauer M. Lipsett M. Zelikoff J. T. Simpson C. D. Koenig J. Q and Smith K. R. (2007), Woodsmoke Health Effects: A Review, Inhalation Toxicology, Vol. 19, No. 1, pp. 67-106.

Naeher, L.P. et al. (2001), Carbon monoxide as a tracer for assessing exposures to particulate matter in wood and gas cookstove households of highland Guatemala, Environmental science & technology, 35(3), pp.575–81, available at: http://www.ncbi.nlm.nih.gov/pubmed/11351731 (accessed 25th April 2014).

Najjar Y. S. H. (2011), Gaseous pollutants formation and their harmful effects on health and environment, Innovative Energy Policies, Vol. 1, pp 1-9

Nazaroff, W.M. and Weschler, C.J. (2004), Cleaning products and air fresheners: exposure to primary and secondary air pollutants, Atmospheric Environment, Vol. 38, No. 18, pp. 2841-2865.

Nemmar, A., Holme, J.A., Rosas, I., Schwarze, P.E., and Alfaro-Moreno, E. (2013). Recent advances in particulate matter and nanoparticle toxicology: a review of the in vivo and in vitro studies, Biomed Research International, Vol. 2013, pp. 1-23.

Nielsen, T., Jǿgensen, H.E., Larsen, J.C. and Poulsen, M. (1996), City air pollution of polycyclic aromatic hydrocarbons and other mutagens: occurrence, sources and health effects, Science of The Total Environment, Vol. 189-190, No. 28, pp. 41-49.

Norris, G., Young Pong, S. and Koenig, J.Q (1999), An association between fine particles and asthma emergency department visits for children in Seattle, Environmental Health Perspective, Vol. 107, No. 6, pp. 489-493.

Obaidullah, M., Verma, V. K., De Ruyck, J. and Bram, S. (2012), A review on particle emissions from small scale biomass combustion, International Journal of Renewable Energy Research, vol. 2, no. 1, pp. 147-159.

Oberdorster, G., Oberdorster, E. and Oberdoster, J. (2005), Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles, Environmental Health Perspective, Vol. 113, pp. 823- 839.

Obernberger, I. and Thek, G. (2010), The pellet handbook: the production and thermal utilisation of pellets; Washington, DC : Earthscan, 2010.

Office for National Statistics (2011), Household Energy Consumption in England and Wales, 2005–11, available at: http://www.ons.gov.uk/ons/rel/regional-trends/area-based-analysis/household-energy-consumption-in-england-and-wales--2005-11/art-household-energy-consumption-in-england-and-wales--2005-11.html (accessed 7th March 2014).

Office for National Statistics (2012), 2011 Census - Population and Households Estimates for England and Wales, March 2011, available at: http://www.ons.gov.uk/ons/rel/census/2011-census/population-and-household-estimates-for-england-and-wales/stb-e-w.html (accessed 24th April 2014).

Office for National Statistics (2013), Full Report - Graduates in the UK Labour Market 2013, available at: http://www.ons.gov.uk/ons/rel/lmac/graduates-in-the-labour-market/2013/rpt---graduates-in-the-uk-labour-market-2013.html (accessed 24th April).

Ofgem, Feed-in-Tariff (FIT) scheme (online), Available at: https://www.ofgem.gov.uk/environmental-programmes/feed-tariff-fit-scheme (accessed 7th March 2014).

Oluwole, O. et al. (2012), Indoor air pollution from biomass fuels: a major health hazard in developing countries, Journal of Public Health, 20(6), pp.565–575, available at: http://link.springer.com/10.1007/s10389-012-0511-1 (accessed 26th April 2014).

Pandey R. A. and Chandrashekhar B. (2014), Physicochemical and Biochemical Approaches for treatment of gaseous emissions containing NOx, Critical Reviews in Environmental Science and Technology, vol. 44, no. 1 pp. 34-96

Panoutsou, C., Castillo, A., (2011). Outlook on Market Segments for Biomass Uptake by 2020 in the UK (pdf). Biomass futures. Available at: http://www.biomassfutures.eu/public_docs/final_deliverables/WP2/D2.3%20Outlook%20on%20Market%20Segments%20for%20Biomass%20Uptake%20by%202020%20in%20the%20UK.pdf (accessed 4th March 2014).

Parliament (2010), UK Indoor Air Quality, Postnote, No. 366, available at: www.parliament.uk/briefing-papers/post-pn-366.pdf (accessed 11th April 2014).

Partnership for Policy Integrity (2011), Air pollution from biomass energy, available at http://www.pfpi.net/air-pollution-2 (accessed 30th March 2014).

Paul, K.T., Hull, T.R., Lebek, K. and Stec, A.A. (2008), Fire smoke toxicity: The effect of nitrogen oxides, Fire Safety Journal, Vol. 43, No. 4, pp. 243-251.

Pearson, J.F., Bachireddy, C., Shyamprasad, S., Goldfine, A.B. and Brownstein, J.S (2010), Association between Fine Particulate Matter and Diabetes Prevalence in the US, Diabetes Care, Vol. 33, No. 10, pp. 2196- 2201.

Perera, F.P., Rauh, V., Whyatt, R.M., Tsai, W., Tang, D., Diaz, D., Hoepner, L., Barr. D., Tu, Y., Camann, D. and Kinney, P. (2006), Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first 3 years of life among inner-city children, Environmental Health Perspective, Vol. 114, No. 8, pp. 1287-1292.

Petroleum Review (2010), Biomass supply chain - Biomass potential in future mix (pdf). Energy Institute, available at: http://global.factiva.com/aa/?ref=PETREW0020100420e64k0001t&pp=1&fcpil=es&napc=S&sa_from (accessed 4th March 2014).

Pino, P., Walter, T., Oyarzun, M., Villegas, R. and Romieu, I. (2004), Fine particulate matter and wheezing illnesses in the first year of life, Epidemiology, Vol. 15, pp. 702–708.

Prakash, P., Agarwal, S.K. and Prakash, N. (2010), Carbon monoxide poisoning. Appolo Medicine. Vol. 7, No. 1, pp. 32-43.

Prockop, L.D. and Chichkova, R.I. (2007), Carbon monoxide intoxication: An updated review, Journal of Neurological Sciences, Vol. 262, pp. 122-130.

Ratnaike, R.N. (2003), Acute and chronic arsenic toxicity, Postgraduate Medical Journal, Vol. 79, pp. 391.

Reidiker, M., Cascio, W.E., Griggs, T.R., Bromberg, P.A., Neas, L., Williams, R.W. and Delvin, R.B. (2004), Particulate matter exposure in cars is associated with cardiovascular effects in healthy young men, American Journal of Respiratory and Care Medicine, Vol. 169, pp. 934.

Reisen K. Brown S. K. (2006), Implications for community health from exposure to bushfire air toxics, Environmental Chemistry, Vol. 3 No. 4 pp. 235-243

Rotton, J. (1983), Affective and cognitive consequences of malodorous pollution, Basic Applied Social Psychology, Vol. 4, pp. 171–191.

Rowland, A.S., Baird, D.D., Weinberg, C.R., Shore, D.L., Shy, C.M., and Wilcox, A.J. (1992), Reduced fertility among women employed as dental assistants exposed to high levels of nitrous oxide, New England Journal of Medicine, Vol. 327, No. 14, pp. 993-997.

Rozenberg M. (2003) Summary of PM2.5 produced by wintertime wood burning in 15 US cities, available at: http://burningissues.org (accessed 8th March, 2014)

Rumchev, K., Spickett, J., Bulsara, M., Philips, M. and Stick, S.
(2004), Association of domestic exposure to volatile organic compounds with asthma in young children, Thorax, Vol. 59, No. 9, pp. 746-751.

Saade, G., Seidenberg, A.B., Rees, V.W., Otrock, Z. and Connolly, G.N. (2010), Indoor secondhand tobacco smoke emission levels in six Lebanese cities, Tobacco Control, Vol. 19, No. 2, pp. 138-142.

Salthammer, T. et al. (2014). Impact of operating wood-burning fireplace ovens on indoor air quality. Chemosphere, 103, pp.205–11, available at: http://www.ncbi.nlm.nih.gov/pubmed/24364889 (accessed 27th April 2014).

Sapkota A., Symons J. M., Kleissl J., Wang L., Parlange M. B., Ondor J., Breysse, P. N., Diette G. B., Eggleston P. A., and Buckley T. J. (2005), Impact of the 2002 Canada forest fires on particulate matter air quality in Baltimore city, Environmental Science and Technology, Vol. 39, no. 1 pp. 24-32

Schroeder, H. (2011), Developmental brain and behavioural toxicity of air pollutants: A focus on the effects of polycyclic aromatic hydrocarbons (PAHs), Critical Reviews in Environmental Science and Technology, Vol. 41, pp. 2026-2047.

Schwartz, J. (1994), Air pollution and hospital admissions for the elderly in Birmingham and Alabama, American Journal of Epidemiology, Vol. 139, No. 6, pp. 589-598.

Schwartz, J., Slater, D., Larson, T.V., Pierson, W.E. and Koenig, J.Q. (1993), Particulate air pollution and hospital emergency room visits for asthma in Seattle, American Review of respiratory Disease, Vol. 147, pp. 826-836.

Seaton, A., MacNee, W., Donaldson, K. and Godden, D. (1995), Particulate Air pollution and acute health effect, Lancet, Vol. 345, pp. 176 - 178.

Silbergeld, E.K., Waalkes, M. and Rice, J.M. (2000), Lead as a carcinogen: experimental evidence and mechanisms of action, American Journal of Industrial Medicine, Vol. 38, No. 3, pp. 316-323.

Singha R. and Shuckla A., (2013), A review on methods of flue gas cleaning from combustion of biomass, Renewable and Sustainable Energy Reviews, Vol. 29, January 2014, Pp. 854–864, available at: https://extranet.cranfield.ac.uk/science/article/pii/,DanaInfo=www.sciencedirect.com+S1364032113006643 (accessed 28th April 2014).

SKC Inc. ppm to mg/m3 Conversion Calculator (online), available at: http://www.skcinc.com/converter/converter.asp (accessed 27th April 2014).

Skea, J., Ekins, P. and Winskel, M. (2011), Energy 2050: making the transition to a secure low carbon energy system. Washington, DC : Earthscan, 2011.

Smith, K.R. (2000), National Burden of Disease in India from Indoor Air Pollution, Proceedings of the National Academy of Sciences, Vol. 97, pp. 13286-13293.

Spengler, J. D. and Sexton, K. (1983), Indoor air pollution: a public health perspective, Science, Vol. 221, No. 4605, pp. 9-17.

Stone, P.H. and Godleski, J.J. (1999), First steps toward understanding the pathophysiological link between air pollution and cardiac mortality, American Heart Journal, Vol. 138, No. 5, pp. 804 - 807.

Strand, V., Rak, S., Svartengren, M. and Bylin, G. (1997), Nitrogen dioxide exposure enhances asthmatic reaction to inhaled allergen in subjects with asthma. American Journal of Respiratory and Critical Care Medicine. Vol. 155, No. 3, pp.881-887.

Streets, D.G., and Waldhoff, S.T. (1999), Green-gas emissions from biofuels combustion in Asia, Energy, Vol. 24, pp. 841-855.

Tam, C., Bevan, R., Harrison, P., Youngs, L., and Crump, D. (2012), Public health impacts of exposure to carbon monoxide from gas appliances in UK homes-are we missing something? Indoor and Built Environment, Vol. 21, No. 2, pp. 229-240.

Therriault, S. (2001), Wildfire smoke: A guide for Public Health Officials. Department of Environmental Quality.

Thron, R.W. (1996), Direct and indirect exposure to air pollution, Otolaryngology-Head Neck Surgery, Vol. 114, No. 2, pp. 281-285.

Torres-Duque, C., Maldonado, D., Pérez-Padilla, R., Ezzati, M. and Viegi, G. (2008), Biomass Fuels and Respiratory Diseases: A Review of the Evidence. Proceedings of the American Thoracic Society. Vol. 5, Issue 5, pp. 577–590.

Toscano L. A. and Barriga A. Análisis de los parámetros y Selección de hornos para la combustión de Biomasa. (Aplicación a Biomasas Locales Típicas). Revista Tecnológica ESPOL, available at: http://www.dspace.espol.edu.ec/bitstream/123456789/337/1/619.pdf (accessed 28 April 2014).

Townsend, C.L. and Maynard, R.I. (2002), Effects on health of prolonged exposure to low concentrations of carbon dioxide, Occupational and Environmental Medicine. Vol. 59, No. 10, pp. 708-711.

Trapnell, B.C. (2009), A novel biomarker-guided immunomodulatory approach for the therapy of sepsis, American journal of respiratory and critical care medicine, 180(7), pp.585–6. Available at: http://www.ncbi.nlm.nih.gov/pubmed/19762591 (accessed 26th April 2014).

TSI (2013) Operation and service manual, [brochure], available at: http://www.tsi.com/uploadedFiles/_Site_Root/Products/Literature/Manuals/Model-8525-P-Trak-1980380.pdfb (accessed 27th April 2014).

Turnkey Instruments Ltd, Air Particle Monitor FAQs, [Brochure], available at: http://www.turnkey-instruments.com/about.php?id=28 (accessed 27th April 2014).

Turnkey Instruments Ltd, Osiris operating instructions, [Brochure], available at: http://www.turnkey-instruments.com/environment.php?id=8 (accessed 27th April 2014).

USEPA. (2013), Chromium compounds: Hazards Summary, available at: http://www.epa.gov/ttn/atw/hlthef/chromium.html (accessed 9th March 2014).

USEPA. (2013), Particulate Matter, available at: http://www.epa.gov/pm/ (accessed 6th March 2014).

Vamvakas, S., Bittner, D. and Koster, U. (1993), Enhanced expression of the protooncogenes c-myc and c-fos in normal and malignant renal growth, Toxicological Letter, Vol.67, pp.161

Van Strein, R.T., Gent, J.F., Belanger, K., Triche, E., Bracken, M.B. and Leaderer, B.P. (2004), Exposure to NO2 and nitrous acid and respiratory symptoms in the first year of life. Epidemiology. Vol. 15, No. 4, pp. 471-478.

Wagland, S.T., and Pollard, S.J.T.(2014). Treatment of Toxic Wastes, in Harrison, R.M (5th edition), Pollution: causes, effects and control, Royal Society of Chemistry, pp.140-156

Wallace, L. A., Pellizzari, E., Leaderer, B., Zelon, H. and Sheldon, L. (1987), Emissions of volatile organic compounds from building materials and consumer products, Atmospheric Environment, Vol. 21, No. 2, pp. 385-393.

Wan, M.P., Wu, C.L., Sze To, G.N., Chan T.C. and Chao, C. Y. H. (2011), Ultrafine particles, and PM2.5 generated from cooking in homes, Atmospheric Environment, Vol. 45, No. 34, pp. 6141-6148.

Weichenthal, S., Dufresne, A., Infante-Rivard, C. and Joseph, L. (2007), Indoor ultrafine particle exposures and home heating systems: A cross-sectional survey of Canadian homes during the winter months, Journal of Exposure Science and Environmental Epidemiology, vol. 17, no. 3, pp. 288-297.

Westberg K. Cohen N. And Wilson K. W. (1971), Carbon monoxide: its role in photochemical smog formation, Science, Vol.171 no. 3975 pp. 1013-1015

Wheeler, A. R., Shanine, K. K., Leon, M. R. and Whitman, M. V. (2014), "Student-recruited samples in organizational research: A review, analysis, and guidelines for future research", Journal of Occupational & Organizational Psychology, vol. 87, no. 1, pp. 1-26.

World Health Organization (WHO) (1999), Carbon monoxide. Environment and Health Criteria 213. Geneva: World Health Organisation.

World Health Organization (WHO) (2005), WHO air quality guidelines global update, 2005, available at: http://www.euro.who.int/__data/assets/pdf_file/0008/147851/E87950.pdf (accessed 27th 2014).

World Health Organization (WHO) (2008), The world health report-Primary health care: Now more than ever. Available at: http://www.who.int/whr/previous/en/index.html (accessed 6th March, 2014).

World Health Organization (WHO) (2011), Air quality and health, available at: http://www.who.int/mediacentre/factsheets/fs313/en/ (accessed 17th March 2014).

Zhang, Q. F., Gangupomu, R.H., Amirez D.R. and Zhu, Y.F. (2010), Measurement of Ultrafine Particles 1494 and Other Air Pollutants Emitted by Cooking Activities, International journal of environmental research and public health, Vol. 7, No. 4, pp. 1744-1759.

Zhua, Y., Hindsa, W., Krudysza, M., Kuhna, T., Froinesa, J., Sioutasb, C., (2005), Penetration of freeway ultrafine particles into indoor environments, Journal of Aerosol Science, Vol. 36 pp. 303-322

10. Appendixes

10.1. Appendix A: Project management

A.1. Task repartition

Table A. 1: Task repartition of the project.

Part of the report	Member involved	Contacts
LITERATURE REVIEW		
Conversion technologies	Morgane Giffard	m.giffard@cranfield.ac.uk
Energy and biomass in the UK	Belén Plaza Fernández-Renau	b.plazafernandezrenau@cranfield.ac.uk
Emissions from available types of biomass	Beñat Elduayen Echave Henry Anero	b.elduayenechave@cranfield.ac.u h.m.anero@cranfield.ac.uk
Emissions from conventional fuels	Marie-Luce Baroux	m.h.baroux@cranfield.ac.uk
Environmental impacts of the emissions	Israel Sigalo	i.sigalo@cranfield.ac.uk
Human health impacts of the emissions	Ngiba Bright Koyen Lois Ahiakwo	ngiba.bright@cranfield.ac.uk k.l.ahiakwo@cranfield.ac.uk
QUESTIONNAIRE BASED SURVEY		
	Israel Sigalo Marie-Luce Baroux Morgane Giffard	i.sigalo@cranfield.ac.uk m.h.baroux@cranfield.ac.uk m.giffard@cranfield.ac.uk
TRIAL MEASUREMENTS OF DOMESTIC AIR QUALITY		
	Belén Plaza Fernández-Renau Beñat Elduayen Echave Israel Sigalo	b.plazafernandezrenau@cranfield.ac.ukb.elduaye nechave@cranfield.ac.u
LABORATORY TEST OF EMISSIONS TOXICITY		
	Henry Anero Koyen Lois Ahiakwo Ngiba Bright	h.m.anero@cranfield.ac.uk k.l.ahiakwo@cranfield.ac.uk ngiba.bright@cranfield.ac.uk
MILTON KEYNES SCENARIO		
Potential sourcing & types of biomass in the local area	Morgane Giffard	m.giffard@cranfield.ac.uk

A.2. Planning

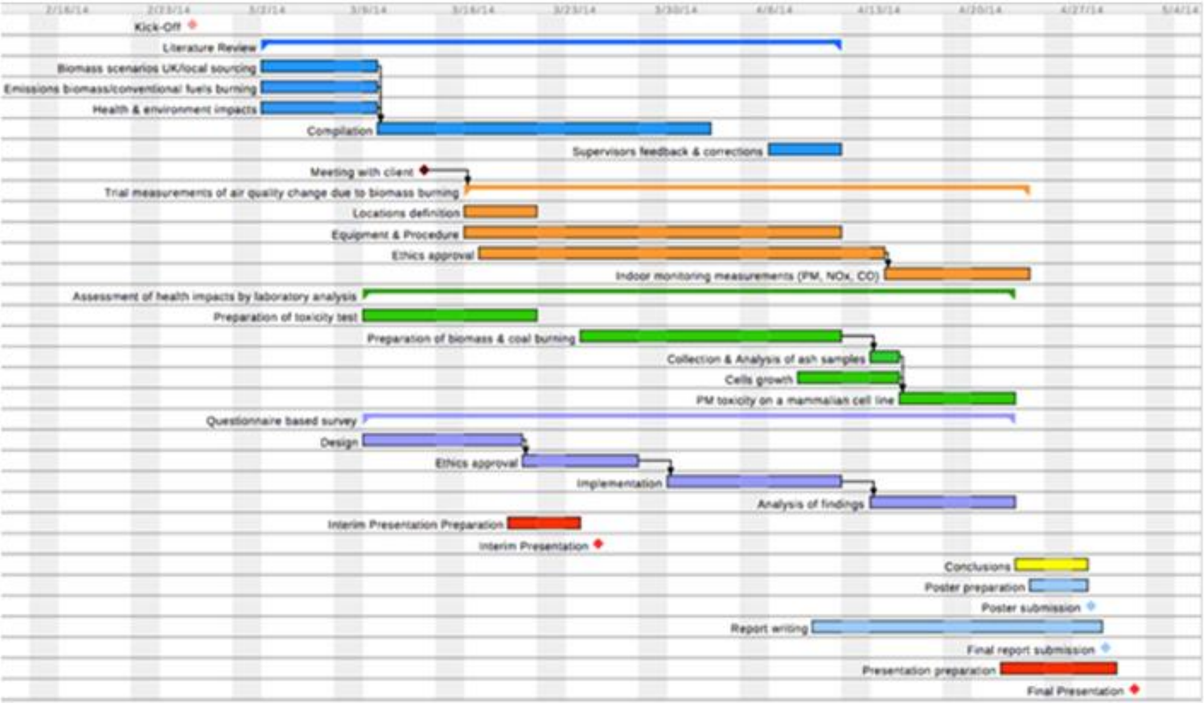


Figure A. 1: Gantt chart for project planning.

10.2. Appendix B: Literature review search strategy

Important publications were identified using various database and web searches. We searched articles from 1980 to 2014 and studied for consistency and contradicting views. Search terms was further narrowed down using key words such as biomass, wood burning, biomass emissions, gaseous pollutants, particulate matter, carbon monoxide, health impacts, environmental impacts, indoor air quality.

Relevant documents were retrieved after examining all identified documents. Documents searched include journal articles, books, library catalogues, government reports, theses, dissertations and websites.

Articles that were cited and referenced in these documents were also checked to pick out useful publications and information relevant to the project topic.

Search engines and databases used are listed below: Scopus, Toxnet, Pubmed, Medline, Google scholar, DECC: Bioenergy, Web of knowledge, UK government website, Milton Keynes Council website.

10.3. Appendix C: Questionnaire-based survey

C.1. Questionnaire form

Cranfield University Survey 20/03/2014

USE OF BIOMASS FOR DOMESTIC HEATING

We are students from Cranfield University undertaking a group project that aims to study the adoption of biomass for domestic heating in the UK, and its health and environmental impacts. The purpose of this questionnaire-based survey is to investigate the attitudes and perception of public towards impacts of domestic biomass burning.

In our case, biomass includes wood and energy crops. Biomass burning is seen as being a key part of the UK's heat supply. A switch from conventional fuels such as natural gas to biomass could help the country hit renewables and CO_2 emissions targets. However, biomass burning could have some impact on air quality.

The data will be collected and analysed anonymously. No confidential information will be used under any circumstances. The questionnaire will take no more than 5 minutes. Please tick the boxes or state.

Personal background

1) Age

☐ 18-24 ☐ 25-34 ☐ 35-49 ☐ 50-64 ☐ 65+

2) Gender

☐ Female ☐ Male

3) Occupation

☐ Employed ☐ Not employed ☐ Student

4) Highest level of education study

☐ GSCE ☐ A-level ☐ Graduate ☐ Postgraduate

5) In which area do you live?

☐ Milton Keynes ☐ Bedford ☐ Cranfield ☐ Other (please state) ____________

6) What currently supplies the heating in your accommodation?

☐ Natural Gas ☐ Coal ☐ Oil ☐ Biomass ☐ Electricity

☐ Do not know ☐ Other (please state) ____________

7) Which of the following technology is used to supply heat in your home/building?

☐ District heating ☐ Individual heating ☐ Do not know

8) Do you have a smoke detector or a carbon monoxide (CO) monitor in your home?

☐ Smoke detector ☐ CO monitor ☐ Both ☐ None

Biomass use for domestic heating

9) Have you heard of biomass (e.g. wood) as an energy source for domestic heating?

☐ Yes ☐ No

10) Do you think UK inhabitants should switch to biomass for heating their homes?

☐ Definitely ☐ Probably ☐ No ☐ Do not know

11) Would you like to have a biomass heating device in your home?

☐ Yes ☐ No

Biomass impact on the environment

12) Do you think biomass (e.g. wood) over fossil fuels (e.g. gas, coal, oil) use is beneficial in mitigating climate change (e.g. greenhouse effect)?

☐ Yes ☐ No ☐ Do not know

13) Do you think biomass is a renewable energy source?

☐ Yes ☐ No ☐ Do not know

14) Do you think biomass is a sustainable fuel?

☐ Yes ☐ No ☐ Do not know

15) How do you rate air quality in your area? (1 is bad, 5 is very good)

Indoor	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Outdoor	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

16) Do you think biomass use over fossil fuels will have a negative impact on air quality?

☐ Definitely ☐ Probably ☐ No ☐ Do not know

Biomass impact on health & wellbeing

17) Do you think air quality affects your health?

☐ Definitely ☐ Probably ☐ No ☐ Do not know

18) Do you know if biomass burning could emit:

CO (carbon monoxide)	☐ Yes	☐ No	☐ Do not know
CO2 (carbon dioxide)	☐ Yes	☐ No	☐ Do not know
NO_x (nitrogen oxides)	☐ Yes	☐ No	☐ Do not know
Particulate matter (e.g. ash, soot)	☐ Yes	☐ No	☐ Do not know

19) Health risks associated with these emissions (1 is lowest, 5 is highest)

CO	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ Do not know
CO2	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ Do not know
NO_x	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ Do not know
Particulate Matter	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ Do not know

20) What impact do you think wood burning (boiler or fireplace) will have on the following in terms of the smoke, ash or storage?

	1-Very negative	2-Negative	3-None	4-Positive	5-Very positive	6-Do not know
Odour	☐	☐	☐	☐	☐	☐
Indoor activities	☐	☐	☐	☐	☐	☐
Outdoor activities	☐	☐	☐	☐	☐	☐
Health	☐	☐	☐	☐	☐	☐

THANK YOU FOR YOUR PARTICIPATION

Figure C. 1: Questionnaire form

C.2. Design of the survey

The design of the questionnaire itself was guided by the expectations of the supervisors, with two questions proposed in the project brief:

- Are people concerned about the possible deterioration of air quality such as odour and soiling of washing dried outdoors?
- Are they aware of the possible risks associated with products of combustion such as carbon monoxide and particulates if using biomass fuels in their homes?

Some questions were deleted after the feedback from supervisors and clients. For instance, the nationality was asked when the targeted population was only Cranfield area, as the population is very international. When the aim shifted to focus on MK population (on MKC staff wish), this question was deleted.

The questions were then focused on small-scale devices such as stoves and boilers, and not on district heating facilities. Finally, SO_x, heavy metals and VOCs were deleted from the questions on emissions from biomass combustion to make those questions easier to understand.

The length of the questionnaire was limited at two pages from the start, with a front page including a short explanation of the survey background. It was useful to have only one paper sheet of questions, not too tightly written, with some nice pictures on the front, such as not to scare people right from the start concerning the time needed to fill in the questionnaire.

The number of questions reached 25, and then a comment was made on it being too long to ask people in the streets (they would most probably run away). Hence the necessity of keeping it below 20 questions, which proved to be an uneasy choice between the need for information and the fact that people will not answer long questions.

C.3. Regarding ethical approval and implementation

Some concerns were raised during the process to obtain ethical approval: they are all addressed below.

- For the person-to-person method, the people were selected above 18 years old and approached on a voluntary basis in shopping centres and railway station in MK. The method used was to ask if they could give us 5min of their time to answer a survey for a project involving Cranfield University students supported by Milton Keynes Council.
- If there was a doubt that the people approached were above 18, an ID card was asked. If people were not willing to show it, the questionnaire was not given.
- The use of tablets has been advised against on safety purpose, as paper is much less tempting for thieves.
- Regarding Health and Safety for the researchers themselves, the team went to public places only, during daytime and always in groups of two persons minimum. All had mobiles in case of an emergency.

- Permission was obtained beforehand from the shopping centre and the railway station authorities to undertake the surveys, in order to reassure the security body.

Regarding debriefing, since the survey was mainly online, participants could access a display of the results via a link directly at the end of the questionnaire. During the person-to-person method, the link could have been written on the paper, but no one asked for it.

C.4. Delimitation of towns area

- Milton Keynes Borough: Milton Keynes, Woburn sands, Newport Pagnell, and Olney
- Cranfield area (close to Marston Vale): Cranfield, Ampthill, Flitwick, Marston Moretaine, Husborne Crawley, Stewartby, MK43 0AL, MK43 0FD
- Bedford area: Bedford
- Others: Aylesbury, Cambridge, Colmworth, Coventry, Cranford Village, Derby, Devon, Dunstable, East midlands, Essex, Hatfield, Hemel, Hertfordshire, Houghton Regis, Kent, Leicestershire, London, Luton, Maidenhead, Manchester, Melton Mowbray, Northampton, Oxford, Portugal, Scotland, Saint Neots, Stratford upon Avon, Suffolk, Tring, Walsall, Watford, and Wellingborough

C.5. Comparison of sample characteristics with national statistics

There is a significant proportion of people living out of Milton Keynes in the answers obtained since the School of Applied Sciences of Cranfield University was emailed and some questionnaires were given around the Railway Station, where people are mostly travelling.

In the sample at study, the percentage of people older than 65 years is low compared to the national population statistics. Indeed, there were 20% of people aged from 65 and above in England and Wales in 2011 (Office for National Statistics, 2012), and only 3% in the questionnaires collected. Taking only MK inhabitants' questionnaires (MKB sample), the age range is closer to the national statistics, since there are twice less people aged from 18 to 24 compared to the general sample.

Regarding the gender, the general sample includes 46% of female and 54% of male. For only MKB residents, the percentage of female (53%) is higher and vice-versa. The samples averages are therefore close to the national values of 49% of female and 51% of male (Office for National Statistics, 2012).

Concerning the trend of occupation, 41% of the general sample is student. For MKB sample, this percentage drops to 26%. The reason of this difference is that the study includes Cranfield University, with a population consisting mainly of students (and some staff). It is therefore above the national average (which is hard to decide upon because of the turnover of the number of student, especially in Master's courses).

Looking at the highest level of education, there is almost twice less post-graduate in MKB residents' sample than in the general population. This is due also to the presence of the university campus of Cranfield in the target area.

The proportion of graduates is almost similar in both cases, around 23%. However, the proportion of people with A-level or GCSE as the highest level of study is near doubled in MKB sample. Comparing MKB sample with national statistics (Office for National Statistics, 2013), there is 11% more graduated people in the sample. The proportion of A-level is the same but MKB sample has a higher GCSE proportion. There were only two cases of people having no degree, i.e. 7% less than at the national level. Hence, the sample and in particular the general one present a population with quite a high education level. This is linked to the place where the survey took place, a shopping centre with a lot of expensive stores for well-off people, and the involvement of postgraduate only Cranfield University.

Natural gas and electricity prevalence is logical in regard of the domestic energy consumption in the UK in 2012 (DECC, 2013). It seems that the MKB sample shows a higher level of biomass use than the one existing at a national level, but this is the difference is not significant.

10.4. Appendix D: Trial measurements

D.1. Information of the houses

Table D. 1Information of the houses

INFORMATION ABOUT THE SELECTED HOUSES	H1	H2	H3	H4	H5	H6
Location of sampling/measurement	BM1	NOBM1	NOBM2	NOBM3	BM2	BM3
Type of building/utilisation	Residential building	Residential building	Residential building	Residential Building	Residential building	Residential building
Age of building	>20 years	>20 years	10 to 20 years	>20 years	>20 years	>20 years
Environment around the building	Rural	Urban suburb	Urban suburb	Urban suburb	Urban suburb	Urban suburb
Outdoor parameters during measurement						
Utilization and heating of room	Living room	Living room	Living room	Living room	Living room	Living room
Type of heating	Central heating&open fireplace	Central heating (radiator)	Central heating (radiator)	Central heating (radiator)	Central heating (radiator) and open fireplace	Central heating (radiator) and fire stove
Position of open fireplace		None	None	None		
Type of heating energy source	Gas	Gas	Gas	Electric	Gas	Gas
Position of room in building						
Windows directed to	2 west 1 east	1 NE 1 NW	1 W	1 N	2 NO and SE	1 NE
Room directed to	N/A	N/A	West	North	N/A	NE
Sitting of sampling equipment/measuring instrument in room						
Distance from wall	2m	1.5 m	1 m	1 m	0.5 m	0,3
Height above floor	0.7m	0.8 m	1 m	0.8 m	0.5-1 m	1m
Floor of room in building	Ground floor	Ground floor	Ground floor	Ground floor	Ground floor	Ground floor
Ventilation conditions before sampling/measurement						
Room with window ventilation (openable windows)						

Type of window:	Single window	Insulated glass window with rubber seal	Insulated glass window with rubber seal	Insulated glass window with rubber seal	Single window	Insulated glass with rubber seal
The sealing is obviously:	Poor	Good	Good	Good	Good	Good
Ventilation state before measurement						
Room thoroughly ventilated	No	No	Yes	Yes	No	No
Windows and doors kept closed	Yes	10 hours	No	Open door to the kitchen	Yes	Yes
Normal ventilation pattern used by room occupants		twice a day (after cooking)	Usually closed	twice a day	Yes (not open usually)	Door opened, no the window
Room with ventilation and air-conditioning system	N/A	N/A	N/A	N/A	N/A	N/A
Information on ventilation and air-conditioning system						
System is fitted with humidification	N/A	N/A	N/A	N/A	N/A	N/A
Room climate and ventilation conditions during sampling/measurement						
Room with window ventilation	Windows and doors closed	Windows and doors closed	Windows and doors opened	Window closed, door opened to the kitchen	Windows and door closed	Window and door closed
Room with ventilation and air-conditioning system	N/A	N/A	N/A	N/A	N/A	N/A
Indoor-air parameters						
Mean room temperature						
Mean relative room humidity						
Room fittings and condition						
Wall and floor	Stonefloor (carpeted)	Painted plaster and	painted plaster	Painted plaster	Wood panelling	Painted plaster

		wood	and wood	and wood	and carpeted floor	and carpeted floor
Renovation (last three months)	no	no	no	no	no	no
New furniture within the last three months	no	no	no	no	no	no
Water damage	no	no	no	Yes, pipe broken 5 months ago. Visible.	no	no
Visible mold	no	no	yes	No	no	no
Activities of room users						
Normal occupancy	2	2	4	2	4 or 5	2
People in the room during sampling	4	4	3	1	3	4
	Present airwick product	There was smoking in the adjacent room before the sampling	Product for the mold used un adjacent room	Smoking in the room 2 days before	Non-smoking room	Fire finished 15 mins before
		Incense and candles often upstairs room	Product for the floor used the day before	Candles used sometimes	Candles and incense used	Non smoking room
		Flash wooden floors product once a week		Products used for floor cleaning often	spray for the furniture used often	
		One window communicated with kitchen		Radiator in use while sampling		

D.2. Ethical approval

In this appendix the forms filled to obtain the ethical approval and the documents for the volunteers are attached. The personal data of the participants has been deleted for this appendix. Those documents are:

1. **Protocol for development of sampling methodology to assess the impact of biomass burning on indoor air quality in homes.**
2. **Background Note**: Includes the FAQ that the volunteer may ask to the students and the answers that this should provide.
3. **Letter for the participants**: The letter provided to the Milton Keynes City Council staff and the School of Applied Sciences staff in Cranfield University.
4. **Participant info sheet:** The information sheet that the participants interested in collaborating with the project must read and fill before the sampling is done.
5. **Letter for the volunteer 'scenario 1':** Letter for the volunteers when the CO measurements do not exceed the WHO guidelines.
6. **Letter for the volunteer 'scenario 2':** Letter for the volunteers when the CO measurements exceed the WHO guidelines.
7. **Activity Diary:** A paper for the volunteer to fill with the activities realized when sampling.
8. **Low Risk Proposal:** The original proposal submitted for the ethical approval.
9. **High Risk Proposal:** The high risk ethical approval accepted by the SEREC.

1-Protocol for development of sampling methodology to assess the impact of biomass burning on indoor air quality in homes. ES&T, School of Applied Sciences, March 2014.

Aim

To develop an appropriate sampling strategy for the assessment of the impact of burning of biomass fuels on the indoor air quality of homes.

Background

The Environment theme MSc taught courses within the Environmental Science and Technology (ES&T) Department require students to conduct a group project during March and April. One project involving 15 students is the assessment of the environmental and health impact of the increased uses of biomass fuels in Milton Keynes and the surrounding districts. The project is supported by Milton Keynes Council and the Gas Safety Trust.

One aspect of the project is the possible changes in indoor air quality associated with the use of this fuel rather than other fuel types such as gas, electricity and coal. Biomass fuel can be wood or waste products such as wood pellets and they may be used in open fireplace or specialised stoves, including boilers. As with all forms of combustion potentially harmful pollutants can be produced such as carbon monoxide, nitrogen oxides and airborne particulate matter (e.g. PM2.5, PM10, ultrafine particles).

Objective

Assess appropriateness of several types of monitors to assess the concentration of pollutants before during and after use of a biomass appliance to ascertain if there is any change in concentrations of pollutants. For this short project options for monitoring equipment and appropriate placement will be reviewed based on literature studies of IAQ and limited measurements of some pollutants of interest will be conducted in approximately 5 homes of volunteers.

Methodology

Literature review of IAQ and pollutant measurement methods.

Familiarity and laboratory testing of monitoring equipment

Request for volunteers by written approach to Cranfield University staff and students and staff at MK council. Obtain written consent of volunteers.

Conduct monitoring for ~1 day in each of 5 homes.

Assess results and propose appropriate methodology and /or need for further work to finalise a sampling strategy appropriate for a possible subsequent comprehensive study.

Inform volunteers of findings in writing. If any results indicate a possible cause for concern the volunteer will be advised to have their appliance checked by an appropriately qualified and registered engineer.

Output

Contribution to group project report and presentation.Brief written feedback to volunteer.

2-Background Note

Biomass and indoor air quality; Cranfield University MSc Group Project, April 2014.

Background Note for researcher giving feedback to volunteers about measured concentrations of airborne substances in their home.

Q&A

What is carbon monoxide

Carbon monoxide (CO) is a colourless, non-irritant, odourless and tasteless toxic gas. It is produced by the incomplete combustion of carbonaceous fuels such as wood, petrol, coal, natural gas and kerosene.

What are airborne particles

Airborne particles are matter suspended in the air that originate from natural and man-made sources such as wind-blown soil and smoke from burning of fuels. They cover a wide range of sizes and have wide ranging chemical and physical properties. The sizes are usually described as the diameter expressed as the unit microns (µm).

What are health risks of carbon monoxide (CO)

There are several health concerns associated with exposure to carbon monoxide. The best understood health effects appear to be produced by hypoxia due to the binding of carbon monoxide to haemoglobin, which reduces the oxygen carrying capacity of the blood as well as decreasing the dissociation of oxygen into tissues. High-level exposures (over several hundred mg/m3) can cause unconsciousness and death. There can be severe and permanent CNS damage, even in cases where individuals do not experience loss of consciousness.

What are health risks of airborne particulates

Fine particles can be inhaled deep into the lung. Depending on their chemical properties they can cause effects ranging from irritation, provocation of asthma and damage to tissues (including effects such as cancer). Tobacco smoke is a major source of exposure to harmful particulates. Traffic exhausts are also harmful and there are limits to the concentrations of particulates in outdoor air to protect human health. These limits do not apply indoors.

What are WHO guidelines

The World Health Organisation (WHO) has produced guidelines for the protection of public health

from health risks due to a number of chemicals commonly present in indoor air. This includes carbon monoxide. Established guidelines for 15 minutes duration are to protect against short-term peak exposures that might occur from, for example, an unvented stove; for 1 hour to protect against excess exposure from, for example, faulty appliances. Our measurements will enable comparison against these guidelines.

In addition there are guidelines for 8 hours (which is relevant to occupational exposures

and has been used as an averaging time for ambient exposures) and for 24 hours to address chronic exposure. Our measurements will not enable comparison against these guidelines.

The guidelines recommended by WHO are as follows: 100 mg/m3 for 15 minutes and 35 mg/m3 for 1 hour (assuming light exercise and that such exposure levels do not occur more often than one

per day).

There are no WHO guidelines for particulate concentrations in indoor air.

Can I continue living in my home

Yes. Problems associated with CO are due to a continuous exposure to high concentrations over years. If the appliance is checked and the problem is solved, the risks associated with the biomass burning would decrease immediately.

Will it be safe to go to bed tonight

The situation is as safe as it has been until now. The measurement has only been done for one hour and the quantity of CO in the air can vary a lot as many factors (smoking, ventilation, cooking, etc.) must be taken into account. If the biomass burning activity stops, the concentration would decrease immediately.

Will my baby be safe?

It is true that there are some groups of people in which the risk is higher than in others. These groups include children. However, if the biomass burning stops and the room in which the high concentration is ventilated the people under exposure is going to be safe.

Is the situation an emergency?

The situation is not an emergency (if the concentration is not extremely high) but it would be a good idea to contact an expert engineer to check the appliance and to ventilate the room.

How quickly will I need to get my appliance checked?

The appliance should be checked as soon as possible. Meanwhile it is recommendable to avoid using it.

How should I get my appliance checked

Cranfield researchers are not qualified to advise on the safety of combustion appliances. In the event of concentrations being measured that exceed WHO guidelines we advise householders to ensure their appliance is functioning safely by appropriate maintenance by a qualified engineer.

Who can I approach for further information

Your GP for any advice concerning health concerns.

The Gas Safety Trust and the Gas Safe Register for further information about hazardous substances produced during fuel combustion.

www.gas-safety-trust.org.uk/ Tel; 0207 706 5111

www.gassaferegister.co.uk/learn/carbon_monoxide_poisoning.aspx Tel ; 0800 408 5500

The Gas Safety register to provide contact details of qualified engineers to check and service appliances.

If your property is rented and the combustion appliance is owned by the landlord the tenant should consider checking with their landlord to ascertain when your appliance was last serviced.

Anyone without a carbon monoxide alarm will be informed about the availability of battery powered carbon monoxide monitors from most hardware / DIY stores. Advice available from Gas Safe Register.

Reference

WHO (2010). WHO guidelines for indoor air quality: selected pollutants. The WHO European Centre for Environment and Health, Bonn Office, WHO Regional Office for Europe

3- Letter for the participant:

Cranfield
MK43 0AL
Bedfordshire
England
Tel +44 (0)1234 750111
www.cranfield.ac.uk

March 2014

Invitation to participate in a study of air quality in your home

I am a postgraduate student at the University researching air quality in homes that burn wood and other biomass fuels for heating and or cooking. The project is supported by Milton Keynes Council and the Gas Safety Trust.

As part of my study I am seeking volunteers who would allow me to place some small and unobtrusive air quality monitors in their home. These monitors would be located in the vicinity of your biomass burning appliance for a few hours. These monitors are battery powered and quiet in operation and will not interfere with your daily activities. I plan to conduct the monitoring during April.

If you do have a biomass burning device I would be most grateful if you would consider participating. I would be pleased to provide further details and answer any questions about what is involved.

Yours faithfully,

Beñat Elduayen Echave

Environmental Science and Technology Department
School of Applied Sciences
Cranfield University
mob 07547890032
B.elduayenechave@cranfield.ac.uk

4-Participant information sheet:

Participant:……………………………

Identification Number:………………….

Title of Project: Impact of use of biomass fuel on the indoor air quality of homes

Participant Information Sheet; April 2014

Thank you for your interest in this study.

Before you decide whether to take part, we would like you to understand why the research is being conducted and what it would involve for you.

(Part 1 tells you the purpose of this study and what will happen to you if you take part. Part 2 gives you more detailed information about the conduct of the study).

If, after having read this information sheet, you would like to participate, please sign and return the enclosed consent form. If you have any queries, please contact the researcher – Name; Beñat Elduayen Echave, mobile: 07547890032

email: b.elduayenechave@cranfield.ac.uk

Part 1

What is the purpose of the study?

The study aims to develop and appropriate sampling methodology to monitor combustion products including carbon monoxide that may be present in the indoor air in the vicinity of a biomass (such as wood and wood based pellets) burning appliance; before, during and, if practicable, after burning of a biomass fuel in homes. We wish to investigate the possible impact of use of the fuel on the indoor air quality.

Why have I been chosen?

You have been chosen because you expressed interest in our study and we understand you have an appliance that uses biomass fuel in your home.

Do I have to take part?

No. furthermore, if you agree to participate, you are free to withdraw at any time without giving reason.

Will I receive any payment?

Unfortunately not.

Will I be informed of the outcomes of my monitoring if I take part?

The person signing the consent form will be informed about the carbon monoxide levels and how they compare to World Health Organisation recommended air quality guidelines for maximum 15 minute and one hour exposures for protection of human health. However our measurements will be limited to one occasion and cannot be considered as representative of other days where factors such as rates of ventilation and outdoor wind speed may influence the internal conditions and performance of the biomass appliance.

If the results are higher than the recommendations, we will provide the results in order they can be made available to a qualified engineer. If the results are below the WHO guidelines we will make them available to you if you so request on the consent form.

<u>Part 2</u>

2.1 What will happen if I do not want to carry on with the study?

If you decide at any time that you no longer wish to carry on, you are free to withdraw at any time without giving any reason.

In case you withdraw when results are not yet available to the researcher, all the gathered information will be destroyed.

If you decide to stop with the study once the data is available to the researcher, there are two possibilities:

The measured quantities are not above the recommendations of the WHO: You will not receive more information from us and any associated information will be destroyed.

The measured quantities are above the recommendations of the WHO: You will receive a letter from us, informing you of your results and contact details for further information.

2.2 What if I have a complaint?

Please contact the project officer, Derrick Crump, at the following address:

Dr D R Crump,
Building 42, School of Applied Sciences.
Cranfield University,
Milton Keynes
Bedfordshire
MK43 0AL
Email: d.crump@cranfield.ac.uk
Telephone: +44 (0)1234 752996
www.cranfield.ac.uk

2.3 Will my taking part in this study be kept confidential?

Your identity will not be revealed and all data will be stored securely. The stored measurement data will be linked only to your participant code and not to your name or address.

2.4 What will happen to the results of the research study?

The information that we will obtain from the monitoring will be used for research purposes and data will be used in a group project thesis and possibly subsequent published literature.

2.5 Who is funding the research?

The Gas Safety Trust, a charitable organisation, has provided financial support. Milton Keynes Council is providing technical advice and some measuring equipment.

2.6 How long will my involvement in the study last?

The sampling would take place during one day when your biomass appliance is subject to normal use. We will ask if some portable battery operated instruments can be left in your home to log data for a period of several hours.

2.7 Further information and contact details

Please do not hesitate to contact us in the next telephone number or email addresses.

Beñat Elduayen Echave
Environmental Science and Technology Department
School of Applied Sciences
Cranfield University
E: B.elduayenechave@cranfield.ac.uk
T: +44 07547890032

The Supervisor:
Dr. Derrick Crump
Reader in Environmental Toxicology
Environmental Science and Technology Department
School of Applied Sciences
E: d.crump@cranfield.ac.uk
T. +44 (0) 1234 752996

Cranfield UNIVERSITY

Participant:…………………… Identification Number:………

Contact details; phone no.;………………………….e-mail…………………….

Title of Project: Impact of use of biomass fuel on Indoor air quality

Monitoring Study Consent Form

Thank you for agreeing to take part in this study. If you have any questions, please ask the researcher before you sign this form. We would appreciate you providing contact details including phone number & e-mail address. Please tick the following boxes and sign the form to show you have understood and agree the terms of the study.

☐ I confirm that I have read, understood and kept a copy of the "Participant Information Sheet" dated April 2014 for the above study.

☐ I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

☐ I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without my legal rights being affected.

☐ I understand that my identity will not be revealed and that all data will be stored securely.

☐ I understand that information I provide will only be used for research purposes.

☐ I agree to a researcher placing air quality monitors in my home and to providing some information about the building and occupant activities during the study period.

☐ I agree that monitoring data obtained can be published as part of a research report providing that my identity is not revealed.

☐ I *wish/ do not wish* to be informed of the results of the monitoring. I understand that I would be informed of any results that exceed available WHO guideline values for the protection of human health.

I……………………………………………………………………………(print name)

Consent to take part in this study and understand I may withdraw at any time.

Signed……………………………………………… Date………………………

Researcher signed……………………………… Date………………………

5-Letter for the participant ´Scenario 1´

IEHRF
Building 42
Cranfield University
Cranfield
MK43 0AL
Bedfordshire
England
Tel +44 (0)1234 750111
www.cranfield.ac.uk

April 2014
To Mr X

Cranfield University's study of air quality and biomass fuels

Thank you for taking part in this research study.

I am writing to inform you that the results of the monitoring in your home have shown that levels found of carbon monoxide were below that of the 15 minute and one hour World Health Organisation recommended guideline levels to protect human health (our measurements were not of sufficient duration to compare with 8 hour and 24 hour guidelines). Please note that our measurements were limited to one occasion and cannot be considered as representative of other days where factors such as rates of ventilation and outdoor wind speed may influence the internal conditions and performance of the biomass appliance.

We also monitored airborne particles in your home but there are currently no recommended guidelines for indoor concentrations.

If you wish to know your results in further detail or have any query, please do not hesitate to contact me or my supervisor, Dr. Derrick Crump.

Yours faithfully,

Benat Elduayen Echave
Environmental Science and Technology Department
School of Applied Sciences
Cranfield University
Mob +44 (0) 7547 890032
b.elduayenechave@cranfield.ac.uk

The Supervisor:
Dr. Derrick Crump
Reader in Environmental Toxicology
Environmental Science and Technology Department
School of Applied Sciences
E: d.crump@cranfield.ac.uk
T. +44 (0) 1234 752996

Certificate No EMS 98287

ISO 14001

6-Letter for the Participant ´Scenario 2´

IEHRF
Building 42
Cranfield University
Cranfield
MK43 0AL
Bedfordshire
England
Tel +44 (0)1234 750111
www.cranfield.ac.uk

April 2014

To Mr X

Cranfield University's research study of air quality and biomass fuels

Thank you for taking part in this research study.

I am writing to inform you that the results of the monitoring in your home have shown that levels found of carbon monoxide exceed the 15 minute/ one hour recommended World Health Organisation guideline levels for the protection of human health (our measurements were not of sufficient duration to compare with 8 hour and 24 hour guidelines).

We also monitored airborne particles in your home but there are currently no recommended guidelines for indoor concentrations.

We recommend that you obtain the services of a qualified gas engineer to check your combustion appliances to ensure that any fumes released are not a risk to the health and well being of occupants.

I attach a summary of the results found which you may wish to discuss with the engineer. It should be noted that our measurements are limited to one occasion and cannot be considered as representative of other days where factors such as rates of ventilation and outdoor wind speed may influence the internal conditions and performance of the biomass appliance.

Please find attached my contact details and do not hesitate to contact me for further information at any time. The contact details of Derrick Crump, the supervisor of the project, are also included.

Yours faithfully,

Benat Elduayen Echave
Environmental Science and Technology Department
School of Applied Sciences
Cranfield University
Mob +44 (0) 7547 890032
b.elduayenechave@cranfield.ac.uk

The Supervisor:
Dr. Derrick Crump
Reader in Environmental Toxicology
Environmental Science and Technology Department
School of Applied Sciences
E: d.crump@cranfield.ac.uk
T. +44 (0) 1234 752996

Certificate No EMS 98287

ISO 14001

7- Activity Diary

Participant No. Date:

Please record activity in room with biomass appliance;

Time	Cooking	Water Heating	Smoking (number of cigarettes)	Door open	Window open	Other activity (use of chemicals…)
0-2						
2-4						
4-6						
6-8						
8-10						
10-12						
12-14						
14-16						
16-18						
18-20						
20-22						
22-24						

Please return to Beñat Elduayen, Cranfield University

8- Low Risk Approval

Appendix F: Guidance on submitting a Low Risk proposal

Science & Engineering Research Ethics Committee

Low Risk Project Submission Form

This form is to be completed by researchers seeking ethical review and approval of research projects involving human subjects and who consider their project to constitute a low risk to their participants. The form is designed to both collect information about your proposed research activities and screen for projects which might be high risk so please complete it carefully.

This form should be completed in full, saved, and emailed to serec@cranfield.ac.uk . If you are a student then your supervisor should review this form before you submit it. You should both provide electronic signatures at the foot of the form. Your submission will be reviewed by one or more members of the Science & Engineering Research Ethics Committee. You will receive an email confirming you can go ahead with the research if it is accepted as a low risk activity.

SEREC aims to complete reviews of proposals within seven working days of submission.

Submissions may be approved conditionally with feedback provided to ensure steps are taken to minimise risk to research participants.

Section A

Please provide the following information about your research:

Title of research project or activity	The use of biomass fuels in the UK, and the potential health and environmental impacts
Name of researcher(s) conducting the fieldwork	Benat Elduayen Echave
Email of researcher conducting the fieldwork	b.elduayenechave@cranfield.ac.uk
Name and department of staff member responsible for the work (e.g. Principal Investigator / thesis supervisor)	Dr Derrick Crump IEHRF, School of Applied Sciences
Email of responsible staff member	e.crump@cranfield.ac.uk
Name of research client or sponsor	Milton Keynes Council and the Gas Safety Trust

Please indicate if the research is part of a:	Taught Masters	☑
	MSc by Research	☐
	MPhil	☐
	PhD	☐
	EngD	☐
	Research Contract	☐
If it is part of a taught Masters programme please give the title of the course	MSc Energy Supply for Low Carbon Future	
Intended start date of fieldwork	1 April 2014	
Intended end date of fieldwork	30 April 2014	
Who are the intended research participants? (e.g. those who you will be surveying, observing, or speaking to)	Volunteers students and staff of Cranfield University and volunteer staff of Milton Keynes Council	

Will the research client or sponsor be providing access to research participants?		
No	☑	
Yes	☐	If yes, please provide detail as to how you will ensure anonymity and confidentiality for your participants in the box below:

We need to fully understand what information/data is being collected from your participants. Please provide a short description (approximately 150 words) of your research aims, objectives and methodology in the box below.
The research aims to develop an appropriate sampling methodology for the evaluation of the impact of use of biomass fuels such as wood and wood pellets on the indoor air quality of homes. The project will demonstrate the proposed methodology by application in a small number of homes (~5). The concentration in air of several potential air pollutants will be measured in the homes of the participants during a period of time when a biomass fuel is being burnt and during a period with no biomass burning. Some details of the property will be noted such as number of rooms, type of structure and number of occupants to inform interpretation of results in the format of a record of sampling. A protocol for the project is attached. If you are using questionnaires and/or interview schedules, please ensure that a copy is attached to your research proposal. You will also need to provide a copy of your participant consent form/statement. Information to be provided to participant and consent form is attached.

Section B

Please answer the following questions to help us evaluate the level of risk associated with your research. If you answer 'Yes' to any of the statements in Section B you should prepare and submit a high risk to SEREC using the guidance provided here

Does your proposed research involve;	
[1]Vulnerable groups such as children, people with physiological and/or psychological impairments (e.g. the disabled, mentally impaired, people with learning difficulties)?	☐ Yes ☑ No
Talking about or referencing sensitive topics (e.g. Sexual behaviour, illegal or political behaviour, experience of violence, abuse or exploitation, mental health, gender or ethnic status conflict situations, psychologically disturbing events?	☐ Yes ☑ No
Questioning or activities which could risk inducing psychological stress, anxiety or humiliation or cause physical pain or harm?	☐ Yes ☑ No
Intrusive interventions - for example, the administration of drugs or other substances, physical exercise, or techniques such as hypnotherapy?	☐ Yes ☑ No
Groups where permission of a gatekeeper is required for initial access to members (e.g. children, residents of institutions)?	☐ Yes ☑ No
The use of payments and / or incentives to encourage or reward participation?	☐ Yes ☑ No
Deception, withholding information, or activities which are conducted without participants' full and informed consent at the time the study is carried out?	☐ Yes ☑ No
Access to records of personal or confidential information, including genetic or other biological information, concerning identifiable individuals?	☐ Yes ☑ No
The collection of human tissue or other human biological samples?	☐ Yes ☑ No

[1]If your research involves children or other vulnerable groups; you may need to apply to the Criminal Records Bureau for clearance. Detailed guidance can be found on the CRB website (http://www.direct.gov.uk/crb)

Further details of many of the issues covered in the table can be found in the guidance available on the SEREC website

Section C

Please complete the two tables below using the check boxes on the right hand side. If you cannot confirm all the statements you should prepare and submit a high risk proposal to SEREC using the guidance provided here.

I confirm that as part of the research activity described above;	
I will secure and record the informed consent of all human subjects	☑
I will ensure that no-one is coerced or compelled to participate in the research	☑
I will not use any inducements or incentives to secure participation	☑
I will not use any form of deception as part of the research method	☑
I will explain to participants the level of confidentiality which they can expect and will aim to maintain participant confidentiality wherever practicable.	☑
I will design and execute the research in a way which protects participants from harm (including but not restricted to - physical, psychological, emotional, social, spiritual, career, reputational, financial or legal harm)	☑
I will, prior to any data gathering activity, brief participants about the project and their rights	☑
I will, prior to any data gathering activity, brief any individuals involved in data gathering on my behalf (e.g. translators or interviewers) about ethical research practices.	☑
I will, following any data collection activity, debrief participants.	☑
I will not be using any observationally intrusive methods	☑
I will store any data I obtain in accordance with the Data Protection Act	☑
I also confirm that:	
The information I have provided on this form is accurate to the best of my knowledge and belief.	☑
I have read the advice on research ethics contained on the webpage 'Basic principles of ethical research involving human subjects.'	☐

The project described above will abide by the University's Ethics Policy.	☐
There is no potential material interest that may, or may appear to, impair the independence and objectivity of researchers conducting this project.	☐
Subject to the research being approved, I undertake to adhere to the project description and statements provided above.	☐
I undertake to inform SEREC of any significant changes to the research activity which might invalidate the statements made above	☐
I understand that the project, including research records and data, may be subject to inspection for audit purposes, if required in future.	☐
I understand that personal data about me as a researcher in this form will be held by those involved in the university ethical research review procedure and that this will be managed according to Data Protection Act principles.	☐

The person completing this form is the:

Researcher conducting the work ☑

Supervisor of the project ☐

Electronic signature of the researcher conducting the work

Electronic signature of the project supervisor

If you have any queries about this form or the SEREC review process, please email the SEREC administrator at serec@cranfield.ac.uk.

Please email your completed form to serec@cranfield.ac.uk

9-High Risk Ethical Approval

HIGH RISK ETHICAL APPROVAL FORM

Project:

The use of biomass fuels in the UK, and the potential human health and environmental impacts

Applicant:

Beñat Elduayen Echave (MSc 'Energy Supply for Low Carbon Future')
Email: B.elduayenechave@cranfield.ac.uk
Mobile: 07547890032

Date:
8th April 2014

Background

Please see the description in the attached document 'Protocol IAQ and biomass'.

This is supported by some further information in the SEREC Appendix F document (attached).

Methodology

Please see the description in the attached document 'Protocol IAQ and biomass'.

This is supported by some further information in the SEREC Appendix F document (attached).

Ethical principles

- Informed consent

The participant is informed about the project nature as it can be stated in the attached document: 'Participant info sheet IAQ homes'. This information is provided to those expressing interest in the study in response to the open invitation letter sent to students and staff (Draft homes introductory. letterMar14). The participant information sheet gives details of a contact for further information. All participants must sign and return a detailed consent form before they partake in the study.

- Additional safety

The research does not involve contacting vulnerable members of the population. Inclusion criteria are adults who are staff or postgraduate students at Cranfield University and staff of Milton Keynes council.

In case that there are children in the houses while the sampling is being done, special care is going to be taken. The measurement devices will be placed out of the reach of young children and pets. The adults who are responsible for them will be asked to prevent children interfering with the measuring devices.

- Deception

The participant has the necessary information as it can be seen in the attached documents. In addition, he/she has the opportunity to contact the researcher and the supervisor at any time, as a telephone number and an email address are provided.

- Freedom of participation

The participant is a volunteer that has agreed to be part of the project by filling the attached consent form (see: Participant info sheet IAQ homes). If they have any concerns it is clearly stated they can withdraw from the study at any time.

- Confidentiality and anonymity

The identity of the participant will not be revealed and the obtained data is only going to be used for research purposes. No persons names or addresses are placed on record forms. No computer data records will contain names of persons or addresses. Paper copy linking participant code and addresses will be kept in a draw in a lockable (supervisor's) office. This will be destroyed on completion of the study.

- Protection from harm

As it is stated in the document 'Ethics Lecture Notes' (Ethical principles, protection from harm):

"The BPS acknowledges that risks are present throughout life and therefore participating in the research *"should not increase the probability that they would come to any form of harm"*. The BPS (2006) also state that participants must *"not [be] induced to take risks that are greater than those they would normally encounter in their life outside the research"*(p2).".

This project wants to <u>determine</u> the implications that biomass burning in the <u>daily life</u> has on the indoor air quality. It is not the objective to change the daily routine of our participants, as the idea is totally the opposite. Therefore, this research will not induce the participant to take any risk greater than those they would normally encounter in their life outside the research and will not increase the probability they would come to any form of harm.

- Observation

The participant will be asked to complete a simple activity diary (attached) for the hours that the device may be measuring at the home, in order to know if possible changes in measured pollutants are due to the use of biomass or other activity. The researcher is not observing and recording any activity.

- Debriefing

Participants are informed about the project and the results obtained will be available for them if they request them. Please, find attached the two models of letters available for the participants after the research is done. In the unlikely event the CO concentrations exceed the guidelines the results letter will be delivered by hand to the address as soon as results are available.

The results will be provided only to the person that has signed the consent form linked to the 'Participant info sheet IAQ homes' document. In the case that the person is not available at the time we have arranged to meet we would contact again to arrange another meeting time, as we will maintain the details of the person until the results are provided. The personal telephone number and email address of the researcher conducting the sampling is provided for any further queries that the volunteer may have, as is the telephone and email address of the supervisor. We include a document (Background note) showing how we would answer the FAQ that the volunteer may have.

In the unlikely event that the CO concentrations exceed the guidelines in the home of a volunteer who has not requested to be informed of their results contact will be made with the householder by a visit to explain the circumstances and provide a copy of the letter.

- Right to withdraw

The participant has the opportunity to withdraw at any time without giving any reason, as it is stated in the attached document 'Participant info sheet IAQ homes' that the participant must have read before being accepted as a participant in the study.

- Giving advice

If the concentration of carbon monoxide exceeds the recommended World Health Organisation guideline levels for the protection of human health, the participant is going to be advised to obtain the services of a qualified gas engineer to check the combustion appliances, as it is stated in the letter model for the client attached. Further advice will be offered when delivering the letter and contact details provided for any subsequent follow up queries.

- Professional conduct

The researchers have read and understood the professional conduct notes and will follow them in order to cause as few problems as possible to the participant. The professional conduct includes:

Make the appointments taking into account the availability of the participant.

Arranging with the participant the position of the measuring device in order to avoid any disruption in their daily life.

Abide the ISO 16000-1, which is the international guidance document for conducting IAQ measurements.

Abiding by a risk assessment for fieldwork to measure air quality.

Being sympathetic and seeking to allay any concerns expressed by the volunteer.

Attached Documents:

Please find in the attached document, relevant information and documents used in the process.

Protocol IAQ and biomass: Background and methodology of the project.

SEREC-AppendixF- Low Risk Proposal: The form that was filled for the low risk approval that may be for some interest.

Participant info sheet IAQ homes: A document where the nature of the project is explained to the client and that has to fill before starting with the sampling.

Draft homes introductory letterMar14: The letter used to contact with the participants.

Activity Diary: For the participant.

Homes scenario1 belowletterMar14: The letter we are going to use if the concentration of CO is below the recommended levels.

Homes scenario2 belowletterMar14: The letter we are going to use if the concentration of CO is higher than the recommended levels.

Background Note.

NOTE: Please do not hesitate to contact me or my supervisor with any query or further information needed you may have.

The applicant:

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D.3. Osiris results

Table D. 2: BM1 results

Time	Total particles	PM10 particles	PM2.5 particles	PM1 particles
16:37	287.5	118.3	15.71	1.94
16:38	157	76.6	13.97	1.82
16:39	108.6	59.9	14.02	1.76
16:40	142.7	62	13.94	1.73
16:41	171.9	69.8	13.56	1.65
16:42	152.2	65.8	13.28	1.6
16:43	154.7	69.2	12.46	1.59
16:44	100.2	57.9	12.22	1.56
16:45	106	52.9	12.45	1.61
16:46	125.9	55.7	12.54	1.5
16:47	104.7	55.7	11.75	1.47
16:48	99.5	55.5	12.24	1.5
16:49	119.7	55.1	11.15	1.39
16:50	111	51.8	11.12	1.43
16:51	300.1	122.1	12.76	1.56
16:52	202.4	86.4	13.02	1.6
16:53	166	69.6	12.32	1.64
16:54	123.7	59.6	12.26	1.63
16:55	164.7	80.4	12.97	2.06
16:56	142.1	74.5	17.19	5.97
16:57	149.7	65.6	12.5	1.68
16:58	127.1	64.7	12.15	1.6
16:59	163.6	69.1	12.22	1.57
17:00	122.7	60.4	11.84	1.51
17:01	101.5	49.5	11.79	1.58
17:02	117.8	53.4	11.94	1.61
17:03	96.1	52.1	11.46	1.61
17:04	112.7	55.7	11.51	1.55

17:05	84.5	51.4	12.2	1.58
17:06	134	52.2	11.95	1.68
17:07	139.5	61.1	12.84	1.79
17:08	170.7	74.5	12.82	1.89
17:09	117.3	50.5	13.6	1.97
17:10	155.8	73.9	12.97	1.96
17:11	243.8	87.3	13.61	2.09
17:12	161.3	67.3	12.76	1.94
17:13	167.2	69.2	13.21	2.02
17:14	131.4	60.1	13.61	2.31
17:15	130.4	61.6	12.93	2.27
17:16	127.5	61.6	13.34	2.17
17:17	105.2	49.1	12.62	2.01
17:18	129.4	60.1	12.77	2.12
17:19	115.3	57.7	12.29	2.04
17:20	96.1	47.2	12.41	1.91
17:21	152	60.2	13.09	1.84
17:22	142.2	64.4	12.9	1.88
17:23	106.9	45.7	12.11	1.79
17:24	107.7	51.4	12.24	1.68
17:25	79.4	46.7	12.25	1.75
17:26	74	42.2	12.03	1.79
17:27	86.2	43.9	12.47	1.75
17:28	88.9	45.8	11.77	1.58
17:29	93.6	48.6	11.53	1.66
17:30	154.9	48.6	12.46	1.68
17:31	162.2	77.6	12.59	1.63
17:32	98.3	43.6	12.53	1.69
17:33	83.2	47.4	11.51	1.67
17:34	70	39.8	11.77	1.65

17:35	280	111.3	12.94	1.63
17:36	143.5	67	12.14	1.63
17:37	128.4	59.7	12.25	1.54
17:38	138.9	61.7	13.02	1.81
17:39	116.8	56.6	12.76	1.77
17:40	212.6	82.3	13.16	1.76
17:41	136.7	53.6	12.66	1.71
17:42	83.4	48.1	12.56	1.77
17:43	125.2	52.2	12.58	1.89
17:44	75.6	46	12.44	1.87
17:45	72.1	42.5	12.64	1.89
17:46	63.6	42.4	12.51	1.71
17:47	67.9	39.8	12.3	1.83
17:48	83.2	43.6	12.05	1.73
17:49	134.7	54.3	12.6	1.74
17:50	235.6	105.8	13.89	1.8
17:51	210.1	99.4	14.87	1.97
17:52	257.8	108.7	14.57	1.74
17:53	193.2	91.1	13.07	1.69
17:54	244.9	93.7	13.21	1.77
17:55	208	90.3	13.36	1.69
17:56	134.1	63	13.05	1.72
17:57	155.1	61.9	13	1.67
17:58	117.5	60.7	12.19	1.6
17:59	110	52.5	12.78	1.67
18:00	81.2	47.9	12.46	1.58
18:01	180.1	68.2	12.93	1.66
18:02	174.1	70.6	12.03	1.66
18:03	89.5	48.9	11.99	1.64
18:04	108	55.7	12.06	1.65

18:05	87.2	46.4	12.14	1.7
18:06	108.6	58.9	12.65	1.69
18:07	110.6	58.4	12.18	1.69
Average	136.36	62.67	12.69	1.78

Table D. 3: BM2 results

Time	Total particles	PM10 particles	PM2.5 particles	PM1 particles
14:10	162.6	51.1	5.74	1.02
14:11	164.8	51	5.67	0.99
14:12	117.3	47.7	5.6	1.04
14:13	102	35.8	5.41	1.02
14:14	107.4	36.1	5.53	0.97
14:15	103.4	36.9	5.02	0.93
14:16	104.4	37.2	5.1	0.89
14:17	88.7	33.7	5.2	0.92
14:18	107.8	37.8	4.87	0.81
14:19	84.4	30.7	4.68	0.8
14:20	71.9	29.8	4.57	0.87
14:21	59.2	27	4.45	0.84
14:22	84.2	28.3	5.08	1.03
14:23	104.5	38.7	6.02	1.51
14:24	107.7	38.1	6.65	1.58
14:25	119.9	43.8	7.3	1.66
14:26	127.6	43.4	6.83	1.57
14:27	125.4	51.1	7.72	1.57
14:28	142.4	52.9	7.28	1.47
14:29	85.7	38.3	6.22	1.26
14:30	130.2	45.3	6.46	1.36
14:31	123.9	43.4	5.98	1.38
14:32	122	37.8	6.25	1.26
14:33	129.9	40.1	5.92	1.24

14:34	86.3	34.8	6.38	1.51
14:35	118	48.6	6.77	1.58
14:36	112.2	41.9	7.77	1.74
14:37	112.2	38	6.99	1.72
14:38	84.4	33.6	7.08	1.56
14:39	102.2	36.9	6.34	1.42
14:40	99.6	33.1	6.1	1.46
14:41	91.3	44	7.13	1.49
14:42	131	49.8	6.98	1.49
14:43	96.1	40.3	6.51	1.39
14:44	85.3	41.2	6.37	1.31
14:45	81.8	30	5.91	1.25
14:46	86.3	30.9	5.55	1.13
14:47	56.9	30	5.58	1.2
14:48	78.3	26.9	5.94	1.16
14:49	52.7	28.3	5.13	1.06
14:50	64.8	32.2	5.64	1.07
14:51	46.5	24.3	5.57	1.06
14:52	67.3	29.9	5.18	1.03
14:53	73.2	28.8	4.96	1.07
14:54	62.6	28.7	5.07	1.02
14:55	49.2	22.9	5.07	0.97
14:56	62.5	29.5	5.08	0.95
14:57	63.3	25.3	4.65	0.96
14:58	50.1	21.4	4.47	0.89
14:59	44.6	23.3	4.57	0.87
15:00	58.9	25.5	4.7	0.9
15:01	41.6	16	4.36	0.83
15:02	62.4	21.6	4.55	0.87
15:03	44.7	16.3	4.35	0.83

15:04	32.9	19.2	4.21	0.84
15:05	44.3	18.5	4.16	0.89
15:06	37.4	18.6	4.24	0.86
15:07	38	19	3.92	0.76
15:08	31.6	18.3	4.16	0.76
15:09	43.2	20.9	3.98	0.71
15:10	49.5	21.5	4.14	0.74
15:11	47.1	20.1	3.94	0.73
15:12	43.9	20.6	4.2	0.7
15:13	39.8	18.7	4.29	0.75
15:14	42.7	18.3	4.03	0.76
15:15	36	16.9	3.99	0.78
15:16	39.6	17.6	3.81	0.7
15:17	35.6	18.1	3.92	0.69
15:18	66.7	24.9	3.98	0.77
15:19	63.5	22.4	4.04	0.71
15:20	38.8	17.4	3.83	0.68
15:21	50.9	19.4	4.08	0.7
15:22	58.8	20	4.32	0.78
15:23	101.5	31.9	4.44	0.77
15:24	67.9	24.5	4.17	0.7
15:25	57.2	22.5	4.03	0.71
15:26	44.5	22	4.05	0.72
15:27	49.2	23	4.14	0.7
15:28	74.9	28	4	0.76
15:29	92.4	30.2	4.37	0.77
15:30	93.8	32.6	4.29	0.71
15:31	90.5	29	4.43	0.79
15:32	85.9	35.2	4.24	0.71
15:33	65.3	25.4	4.42	0.69

15:34	68.5	27.4	4.2	0.73
15:35	95.1	34.2	4.53	0.67
15:36	108	35.3	4.28	0.72
15:37	137.3	43	4.36	0.77
15:38	102.9	28.2	4.41	0.71
15:39	75.7	26.2	4.2	0.78
Average	79.94	30.66	5.11	1.01

Table D. 4: BM3 results

Time	Total particles	PM10 particles	PM2.5 particles	PM1 particles
9:15	193.1	77.7	7.96	1.88
9:16	177.6	59.4	7.76	1.86
9:17	155.7	64.7	8.2	1.82
9:18	146.2	62.9	7.08	1.72
9:19	162.6	64.7	8.77	2.06
9:20	130.1	60.7	9.07	1.98
9:21	133.2	60.9	8.88	1.98
9:22	187.2	65	8.47	1.89
9:23	145.2	63.1	7.95	1.8
9:24	157.5	59.5	8.02	1.71
9:25	126.4	58.7	7.86	1.74
9:26	170.6	59.4	7.71	1.77
9:27	127.8	55.8	7.46	1.71
9:28	107.5	51.7	7.26	1.64
9:29	137.3	48.3	7.24	1.63
9:30	123.8	51.2	7.13	1.69
9:31	117.9	46.7	7.73	1.64
9:32	113.7	54.9	7.69	1.64
9:33	128.9	52.2	7.56	1.54
9:34	110.5	51.6	7.26	1.61
9:35	131.1	52.7	7.88	1.58

9:36	133.4	56.7	7.5	1.51
9:37	127.3	55.4	7.27	1.56
9:38	111	52.6	7.69	1.54
9:39	101.7	50.2	7.64	1.5
9:40	114.6	53.8	7.37	1.54
9:41	95	44.8	7.15	1.52
9:42	109.6	51.9	7.11	1.45
9:43	104.7	44.3	7.27	1.47
9:44	90.5	45.1	6.84	1.36
9:45	133.4	47	6.87	1.36
9:46	94.7	42.6	7.2	1.35
9:47	81.6	45.4	6.97	1.36
9:48	113.8	45.6	6.34	1.33
9:49	92.3	39.1	6.45	1.3
9:50	68.7	37.4	6.85	1.33
9:51	107.7	48.6	6.84	1.28
9:52	94.3	39.2	6.53	1.23
9:53	92.6	43.5	6.86	1.26
9:54	131	53.8	6.42	1.17
9:55	204	82.6	8.82	1.49
9:56	168.1	63.8	7.55	1.31
9:57	147.2	56.9	7.37	1.25
9:58	153.8	58.5	7.18	1.26
9:59	146.9	53.9	7.2	1.25
10:00	162.6	59.7	7.19	1.24
10:01	143	62	6.98	1.16
10:02	141.6	56.4	6.55	1.15
10:03	168.3	64.2	6.73	1.23
10:04	139.2	55	6.93	1.21
10:05	150.9	61	7.39	1.29

10:06	181.3	71.1	7.26	1.23
10:07	151.2	64.1	7.28	1.27
10:08	155.2	61.7	7.2	1.31
10:09	153.9	60.1	6.71	1.17
10:10	146.3	54.4	6.93	1.23
10:11	137.3	56.8	6.9	1.23
10:12	144.6	61.6	6.91	1.05
10:13	111.1	51	6.81	1.19
10:14	110.2	50.1	6.98	1.18
10:15	119.7	56.5	6.9	1.17
10:16	144.5	60.2	6.74	1.25
10:17	199	84.9	8.4	1.29
10:18	172.3	67.4	7.32	1.19
10:19	156	64.7	7.64	1.23
10:20	163.3	69.8	7.44	1.21
10:21	160.2	65.5	7.62	1.24
10:22	140.3	66.2	7.23	1.21
10:23	146.4	64.3	7.3	1.18
10:24	139.4	63.1	6.97	1.13
10:25	156.4	57.2	7.39	1.16
10:26	146.6	57.5	7.25	1.17
10:27	128.2	56.8	6.86	1.1
10:28	110.5	51.6	7.11	1.11
10:29	126.2	54.3	6.15	1.19
10:30	103.4	45.4	6.43	1.16
10:31	114.5	53.2	6.59	1.14
10:32	104.1	51.5	6.49	1.15
10:33	118.4	54.2	6.32	1.08
10:34	122.8	46.1	6.43	1.07
10:35	102.1	45.9	5.98	1.04

10:36	115.5	47.9	6.26	1.14
10:37	104.4	50.7	6	1
10:38	95.3	49.3	6.4	1.06
10:39	73.5	40.7	6.07	1.1
10:40	118.9	46.4	6.29	1.02
10:41	93.3	43.4	6.32	0.98
10:42	96.1	43	6.34	1.04
10:43	102.1	44.2	5.98	1.06
10:44	64.4	38.1	6.28	1.07
Average	130.40	55.15	7.15	1.36

Table D. 5: NOBM1 results

Time	Total particles	PM10 particles	PM2.5 particles	PM1 particles
11:20	84	41.5	9.9	1.58
12:20	83.4	41.5	10.28	1.54
13:20	74.8	39.3	10.12	1.46
14:20	111.2	45.1	9.54	1.51
15:20	100.3	47.6	9.71	1.54
16:20	86.8	40.6	9.37	1.56
11:26	117.2	44.5	9.49	1.51
12:26	89.6	46.7	9.77	1.5
13:26	85.7	38.3	9.59	1.57
14:26	84.1	42.3	9.24	1.45
15:26	105.4	40.4	9.57	1.49
16:26	87	39.4	9.38	1.41
17:26	101.9	39.2	9.34	1.44
18:26	64.3	34.9	8.85	1.41
19:26	77.6	36.7	9.08	1.38
11:35	91.3	40.2	8.5	1.4
11:36	204.6	73.2	9.97	1.62
11:37	115.2	41.3	8.95	1.39

11:38	77.2	35.6	9.14	1.44
11:39	108.1	45.7	8.74	1.45
11:40	123.7	40.5	9.64	1.43
11:41	122.8	43.1	9.05	1.41
11:42	126	49.5	9.15	1.38
11:43	105	41.6	8.91	1.34
11:44	126.2	38.9	8.49	1.33
11:45	102.8	40.1	8.54	1.42
11:46	124.3	42.8	8.58	1.37
11:47	102.6	37.9	8.37	1.3
11:48	93.7	40	8.42	1.26
11:49	93.9	34.5	8.55	1.32
11:50	100.4	37.6	8.43	1.32
11:51	73.7	35.6	8.34	1.32
11:52	86	36.1	8.82	1.36
11:53	75	33	8.24	1.3
11:54	73.1	31.2	8.24	1.31
11:55	99.7	38	8.25	1.23
11:56	82.6	30.4	8.22	1.24
11:57	94.8	30.3	7.94	1.3
11:58	91.7	38.4	8.08	1.3
11:59	71.9	34.5	8.05	1.22
12:00	69.7	34.6	7.62	1.28
12:01	77.2	31.4	7.86	1.24
12:02	66.4	34.1	8.25	1.29
12:03	52.8	30.9	7.53	1.21
12:04	94.3	34.5	7.91	1.15
12:05	68.9	29.7	7.49	1.21
12:06	69.2	30.6	7.31	1.2
12:07	67.4	31.2	7.78	1.2

12:08	57.6	31	7.26	1.18
12:09	80.9	30.2	7.5	1.27
12:11	85.7	34.3	7.4	1.24
12:12	64.1	28.5	7.26	1.21
12:13	106.8	36.8	7.39	1.2
12:14	131.6	41.4	7.68	1.25
12:15	111.6	40.4	8.1	1.2
12:16	75.8	39.8	8.25	1.36
12:17	61.2	32.2	7.89	1.29
12:18	122.5	46.5	7.54	1.26
12:19	123.6	40.8	8.02	1.24
12:20	122.6	42.5	7.68	1.18
12:21	75.4	34	7.8	1.31
12:22	96.7	30.5	7.56	1.3
12:23	93.4	35.6	7.64	1.26
12:24	92.5	33.4	7.48	1.19
12:25	97.4	34.2	7.22	1.28
12:26	61.3	31.9	7.64	1.26
12:27	72.3	32	7.28	1.29
12:28	79.9	32.4	7.57	1.25
12:29	71.9	33.2	7.46	1.36
12:30	67	33.3	8.01	1.31
12:31	87.7	40.7	7.96	1.32
12:32	158.3	66.3	8.99	1.37
12:33	86.2	36.6	8.16	1.35
12:34	88.2	30.1	7.44	1.29
12:35	65	34.3	7.37	1.34
12:36	88	37	7.33	1.15
12:37	70.4	31.9	7.53	1.25
12:38	72.9	33	7.24	1.26

12:39	81.6	31.5	7.54	1.19
12:40	66.6	31.9	6.76	1.14
12:41	73.7	33.6	7.43	1.31
12:42	69.7	29.7	7.65	1.25
12:43	72.3	34.1	7.26	1.2
12:44	72.9	31.3	7.46	1.28
12:45	76.9	30	7.67	1.47
12:46	97.7	42.3	10.28	2.72
12:47	107.5	45	10.01	2.2
12:48	113.5	39.9	8.89	1.98
12:49	87.4	43.2	8.99	1.96
12:50	122	45.1	9.27	1.87

Table D. 6: NOBM results

Time	Total particles	PM10 particles	PM2.5 particles	PM1 particles
15:28	78.9	30	4.84	1.66
15:29	100.6	33.6	4.82	1.76
15:30	93.5	31.8	4.55	1.59
15:31	65	22.1	4.65	1.6
15:32	67.4	29.6	4.5	1.63
15:33	98.3	29.8	4.26	1.59
15:34	75.2	26.3	4.4	1.64
15:35	51.3	27.1	4.48	1.66
15:36	85.2	27.9	4.67	1.62
15:37	64.5	23.9	4.44	1.71
15:38	70.7	23.8	4.62	1.71
15:39	71.1	24.5	4.53	1.64
15:40	54.2	25.3	4.43	1.72
15:41	86.5	26.2	4.62	1.66
15:42	84.7	26.2	4.46	1.64
15:43	65.3	24.4	4.25	1.6

15:44	57.1	24.6	4.54	1.66
15:45	54.6	23.9	4.58	1.6
15:46	52	20.4	4.21	1.65
15:47	59.3	23.4	4.3	1.58
15:48	58.8	20.2	4.51	1.64
15:49	63.3	20.5	4.37	1.66
15:50	52	23	4.46	1.64
15:51	46.7	18.3	4.39	1.62
15:52	70.4	23.8	4.39	1.67
15:53	55	17.3	4.42	1.79
15:54	42.5	20.4	4.64	1.83
15:55	69.3	20.9	4.09	1.63
15:56	53.9	18.5	4	1.69
15:57	44.8	18	4.43	1.63
15:58	64.6	19.9	4.09	1.7
15:59	41.8	19.4	4.33	1.63
16:00	43.8	13.6	4.28	1.68
16:01	63.2	23.2	4.33	1.67
16:02	42.7	22.4	4.29	1.63
16:03	44.2	18.7	4.34	1.62
16:04	39.2	17.9	4.09	1.6
16:05	30	12.8	4.1	1.62
16:06	32	16.1	4.24	1.7
16:07	35.7	15.7	4	1.58
16:08	42.6	16	4.16	1.61
16:09	39.9	16.3	4.03	1.66
16:10	43	16	4.05	1.6
16:11	39.8	14.8	4.09	1.62
16:12	29.5	12.9	3.84	1.59
16:13	40.1	15.7	3.81	1.53

16:14	52.5	20.3	3.99	1.55
16:15	48.1	17.4	3.93	1.48
16:16	52.5	18.6	3.92	1.54
16:17	69	21.3	3.94	1.59
16:18	62.1	18.9	3.82	1.42
16:19	55	17.9	3.89	1.52
16:20	45.6	17.7	3.88	1.51
16:21	55.3	20.8	3.81	1.51
16:22	39.2	14.3	3.73	1.44
16:23	49.8	15.2	3.49	1.46
16:24	44	15.4	3.48	1.37
16:25	44.7	14.7	3.63	1.38
16:26	44.1	15.5	3.52	1.4
16:27	49.9	13.9	3.63	1.47
16:28	36.9	17.1	3.92	1.39
16:29	51.2	14.2	3.34	1.39
16:30	41	13.5	3.46	1.38
16:31	32.3	14.1	3.34	1.34
16:32	32	10.7	3.38	1.33
16:33	51.5	21.6	3.43	1.36
16:34	49.2	17.3	3.53	1.44
16:35	45.9	12.7	3.49	1.36
16:36	37.8	16.2	3.5	1.38
16:37	35.3	12.7	3.69	1.44
16:38	36.2	15.2	3.26	1.3
16:39	35.5	14.7	3.51	1.37
16:40	45.4	16	3.32	1.28
16:41	32.7	13	3.35	1.35
16:42	37.6	13.4	3.36	1.42
16:43	36.7	12.3	3.52	1.37

16:44	27.6	13.6	3.63	1.38
16:45	44.8	16.6	3.23	1.31
16:46	37.3	10.3	3.29	1.26
16:47	22.5	13.3	3.17	1.29
16:48	34	14	3.14	1.24
16:49	75.7	21.8	3.33	1.37
16:50	98.1	25.3	3.38	1.29
16:51	33.7	12.9	3.44	1.28
16:52	43.7	14.3	3.12	1.23
16:53	72.6	15.4	3.2	1.24
16:54	54.1	14.7	3.42	1.23
16:55	54.8	19.4	3.11	1.22
16:56	47.6	15.9	3.41	1.26
16:57	48.9	14.5	3.34	1.25
Average	52.32	18.84	3.94	1.51

Table D. 7: NOBM3 results

Time	Total Particles	PM10 particles	PM2.5 particles	PM1 particles
17:29	116.1	31.6	2.04	0.41
17:30	75.5	21.6	1.87	0.4
17:31	121.8	25.4	2.26	0.43
17:32	101.7	25.8	1.87	0.39
17:33	85	21.7	1.87	0.49
17:34	81.2	23.6	1.96	0.55
17:35	83.2	23.3	2	0.51
17:36	70.8	19.1	2.06	0.57
17:37	64.2	21.7	2.17	0.58
17:38	48.3	19.5	2.21	0.61
17:39	53.1	17.4	2.37	0.63
17:40	78.7	21.5	2.09	0.56
17:41	50.7	18.7	2.08	0.63

17:42	62.3	16.6	2.2	0.61
17:43	47.6	17.9	2.15	0.6
17:44	50.7	16	2.11	0.61
17:45	62.9	16.4	2.08	0.61
17:46	57.7	18.7	1.73	0.57
17:47	52.6	14.1	1.83	0.57
17:48	40.7	15.6	2.19	0.58
17:49	41.3	13.6	2.03	0.61
17:50	46.8	14.2	2.04	0.6
17:51	32.8	14.5	2.04	0.63
17:52	34.6	12.9	1.94	0.55
17:53	56.7	17.8	1.91	0.5
17:54	37.2	13.7	1.99	0.54
17:55	27.6	13.6	1.91	0.51
17:56	35.8	12.5	2.07	0.53
17:57	45.6	14.1	1.85	0.56
17:58	54.7	15.4	1.99	0.63
17:59	38.5	11.6	1.85	0.58
18:00	34.8	12.9	2.08	0.56
18:01	27.6	11.9	1.91	0.58
18:02	38.4	13.2	2.02	0.52
18:03	34.6	12.9	2.03	0.58
18:04	38.4	12.4	2	0.59
18:05	34.5	14.7	2.12	0.49
18:06	59.8	15.9	2.12	0.62
18:07	30.1	11.4	1.97	0.54
18:08	48.3	14.5	1.93	0.51
18:09	40.8	12.7	1.98	0.51
18:10	36	13.1	1.85	0.49
18:11	41.6	14.8	1.95	0.52

18:12	34	12.2	1.9	0.55
18:13	39.2	15.9	2.05	0.51
18:14	24.7	8.7	1.86	0.52
18:15	32.5	13.3	1.83	0.48
18:16	35.5	13.6	1.96	0.54
18:17	31.5	16.9	1.95	0.5
18:18	44.5	14.2	2.03	0.55
18:19	27.7	12.4	1.91	0.56
18:20	27.2	12.7	2.06	0.49
18:21	25.4	12.4	1.8	0.47
18:22	35.7	13.7	1.96	0.5
18:23	28	11	2.03	0.48
18:24	27.6	9.9	1.87	0.49
18:25	21.3	12	1.85	0.55
18:26	29.6	10.3	1.89	0.49
18:27	26.5	8.8	1.83	0.48
18:28	26.9	8	1.91	0.49
18:29	32.3	13.2	1.9	0.51
18:30	31.6	9.8	1.81	0.48
18:31	28	10.2	2.12	0.53
18:32	34.1	11.3	1.82	0.48
18:33	22.7	8.6	1.97	0.53
18:34	25.2	11.1	1.99	0.48
18:35	25.4	10.1	2.02	0.5
18:36	33.8	11.6	2.06	0.51
18:37	21	12.3	2.11	0.51
18:38	32.1	14.3	1.98	0.51
18:39	36.5	11.7	1.84	0.48
18:40	29.4	13.4	2.05	0.5
18:41	26.5	12.2	2.05	0.51

18:42	30.8	12.9	2.12	0.51
18:43	22.9	8.5	1.83	0.45
18:44	31.1	12.5	1.87	0.49
18:45	28.4	9.4	2	0.47
18:46	34.3	12	2.01	0.46
18:47	22.3	11	2.04	0.48
18:48	31.1	11.9	1.78	0.5
18:49	34.9	11.4	2.02	0.54
18:50	27.7	12.7	2.04	0.49
18:51	25.3	8.7	2.06	0.49
18:52	36.1	14.8	2.04	0.49
18:53	31.4	12.4	2.07	0.44
18:54	48.2	13.4	2.06	0.5
18:55	30.3	13.5	1.99	0.48
18:56	25.8	13.9	1.94	0.51
18:57	35.8	12	1.84	0.45
18:58	31.5	12.8	2.08	0.47
18:59	32.2	10.2	1.92	0.5
Average	41.51	14.18	1.99	0.52

D.4. FirstCheck+ 5000Ex results

The tables with the results for every second are included in the flash drive memory attached with the report. This appendix shows the graphs that the software gave for the measured species in the houses.

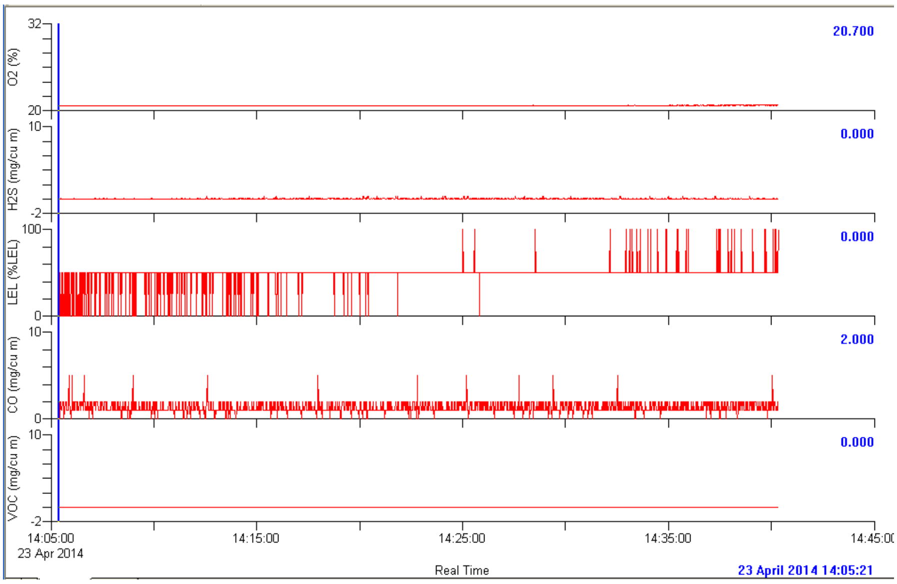

Figure D. 1: BM2 CO results (part 1of 2)

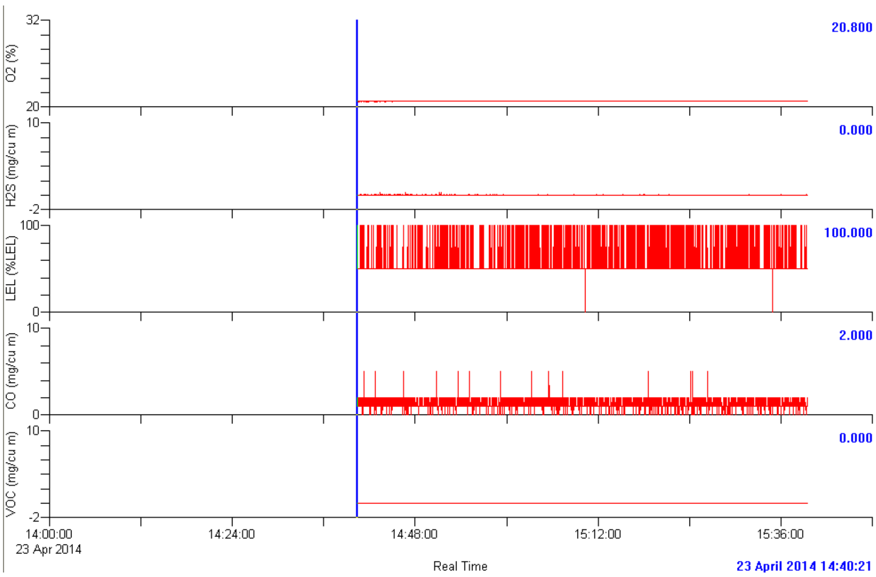

Figure D. 2: BM2 CO results (part 2 of 2)

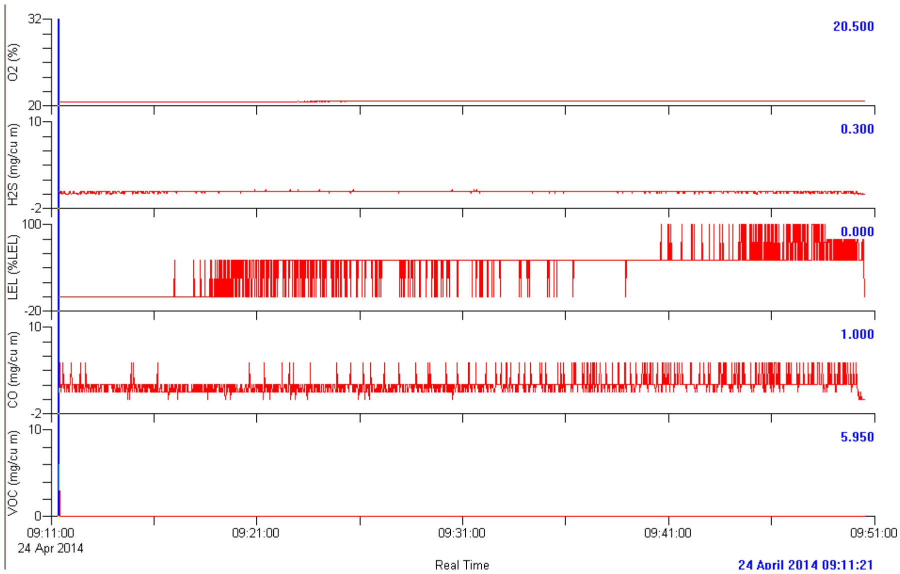

Figure D. 3: BM3 CO results (part 1 of 3)

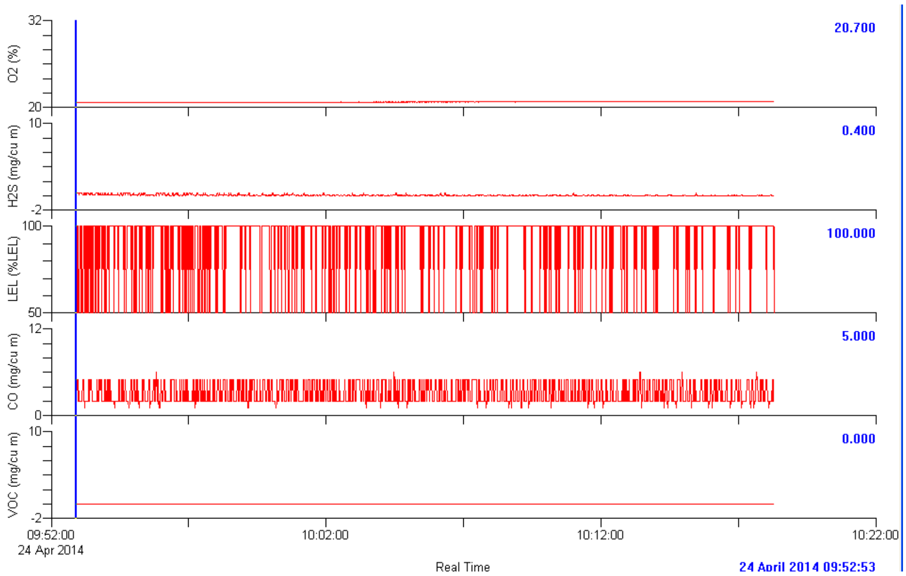

Figure D. 4: BM3 CO results (part 2 of 3)

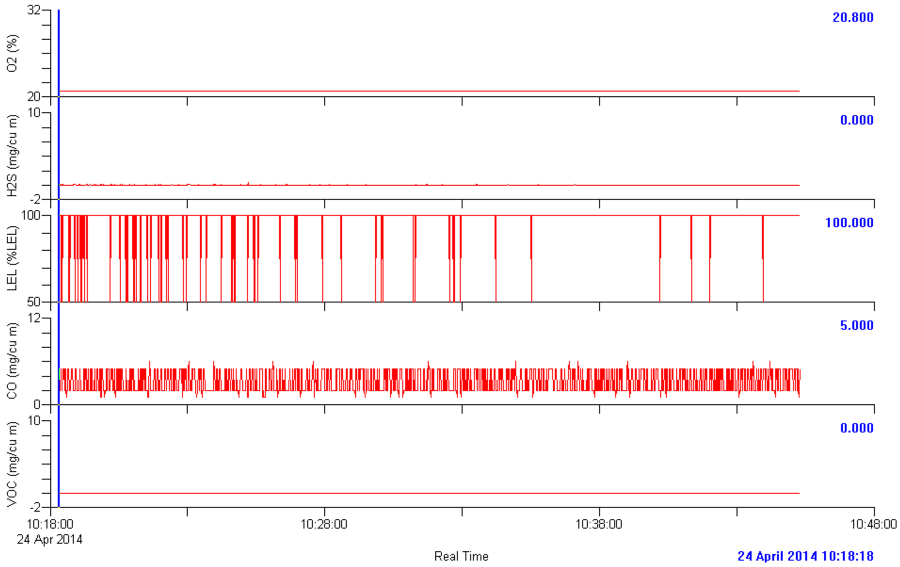

Figure D. 5: BM3 CO results (part 3 of 3)

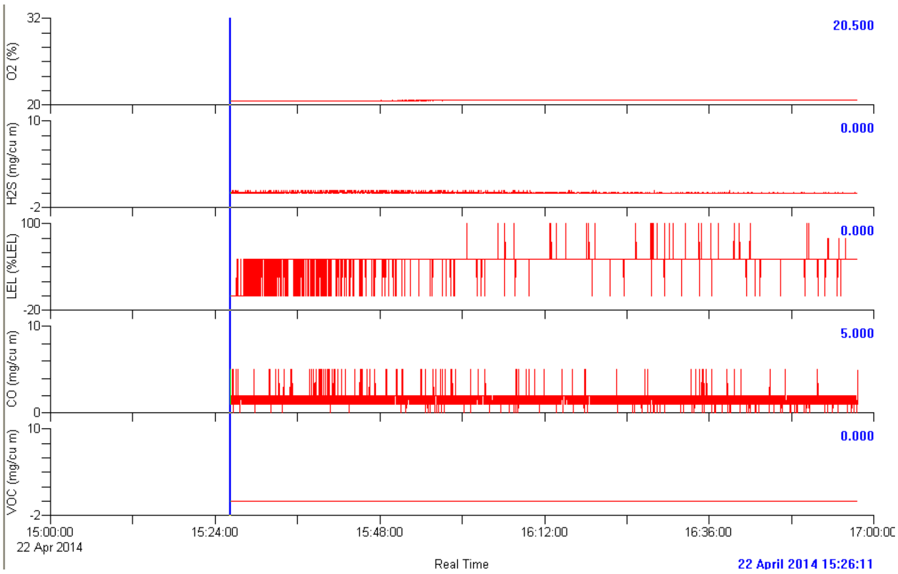

Figure D. 6: NOBM2 CO results

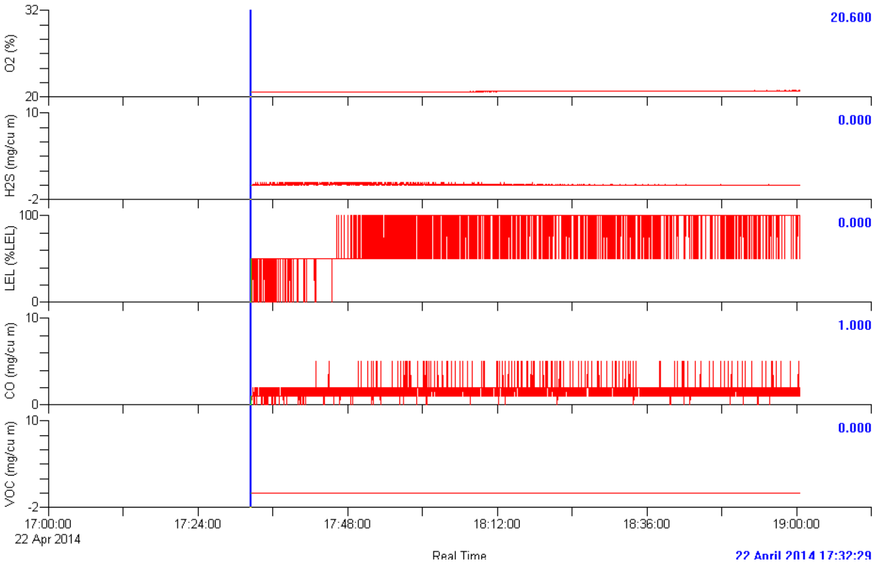

Figure D. 7: NOBM3 CO results

D.5. P-Track results

Table D. 8: P-Track results of both biomass houses and non biomass houses

Time	BM1	BM2	BM3	NOBM2	NOBM3
0	5302	7129	10134	12222	7652
	5296	6658	9912	15329	7825
	5284	6443	10755	15366	7635
	5125	6246	10032	15395	7584
	4895	6289	10650	16148	7442
5	4706	6388	11166	16411	7364
	4634	6253	10921	16741	7285
	4588	6131	10933	16743	7178
	4568	6008	10898	16738	7129
	4550	6007	10905	16761	7365
10	4552	5949	10928	16771	7091
	4506	5620	11328	17770	6946
	4463	5811	11368	16745	6888
	4359	5948	11365	16771	6903
	4533	6504	11370	17495	6966
15	4638	6727	11340	16346	6925
	4641	6900	11533	17570	6763
	4819	7424	11280	17643	6829
	5618	11785	11305	16510	6671
	5870	16405	11198	17990	6702
20	8306	17278	11446	17718	6605
	12255	23788	12380	17626	6472
	13916	28185	14062	16561	6386
	13765	27981	16610	17486	6341
	13588	27498	17347	17406	6231
25	12860	25581	18216	17421	6005
	12388	24793	18018	17451	5785
	12390	24461	18076	17420	5870

	13783	23596	18615	17416	5829
	15890	22948	18685	17718	5732
30	17923	22645	20214	17635	5728
	19115	21681	23365	17520	5531
	20518	20640	22403	17414	5514
	20143	19500	21080	17396	5529
	20340	19128	20707	17290	5498
35	20225	18543	20517	17111	5365
	20295	17715	19443	16994	5308
	20801	17538	19219	16838	5198
	20290	16758	18132	16960	5076
	20193	16256	18038	16961	5116
40	20141	16326	17705	17960	5035
	18251	16196	17640	16037	5083
	17218	15875	17527	15835	5027
	15903	15826	17351	15840	4879
	14841	15336	17326	16818	4741
45	14005	15130	17258	15718	4538
	13420	14688	17168	15601	4606
	12741	14018	16969	15519	4499
	12663	13546	16787	15492	4377
	11871	13165	16633	15479	4397
50	11103	12778	16461	16449	4445
	10875	12468	16411	15402	4244
	10082	12135	16293	15342	4281
	9582	11778	16167	15267	4170
	9006	11453	16112	15193	4088
55	8479	11195	16021	15187	4051
	8051	10684	15951	17146	4027
	7720	10325	15856	15079	4079

	7383	9852	15771	15039	4036
	7299	9628	15662	15995	3924
60	7154	9167	15542	16927	3940
	6775	9023	15498	15910	3885
	6478	8907	15396	15884	3836
	6336	8478	15258	15841	3827
	6245	8082	15281	15795	3772
65	6358	7844	15333	15770	3830
	6438	7676	15149	15715	3796
	6238	7564	14914	15693	3796
	6107	7260	14923	17692	3779
	6142	7006	14845	15669	3704
70	6000	6751	14708	15590	3681
	5824	6633	14608	16544	3658
	5688	6422	14767	15520	3639
	5403	6288	14621	16477	3604
	5240	6281	14400	15459	3584
75	5355	6250	14321	15435	3617
	5638	6409	14380	15400	3628
	5849	6517	14204	14845	3609
	5980	6329	14141	14726	3577
	6264	6132	14084	15465	3583
80	6436	6081	12915	15986	3585
	6475	5985	12577	16930	3576
	6414	5855	12040	15661	3576
	6274	5774	11720	15541	3552
	6315	5601	11464	13517	
85	6590	5404	11043	13517	
	6318	5504	10743	13501	
	6113	5495	10391	13497	

	5971	5488	9679	13478	
	5828	5439	9599	13483	
90		5329	9546	13484	
		5296	9492	13474	
				13468	
				13489	

Table D. 9: P-Track average results for both houses with biomass and without biomass

	Average
BM1	9453.456
BM2	11454.46
BM3	14636.36
NOBM2	16038.17
NOBM3	5183.607

10.5. Appendix E: Laboratory analysis

E.1. Sampling

Prior to the metal analysis, moisture content, ash content and trace elements soluble in nitric acid and hydrogen peroxide were determined.

a) Determination of moisture content (British Standard BS 7755, 1994)

Principle: Wood samples are dried at 105 °C ± 5 °C. The difference in the amount of wood before and after drying is used to calculate the dry matter contents on mass basis.

Materials: Weighing balance, crucible, wood samples (poplar chips, cedar chips and wood pellet)

Procedure:

1. Weigh approximately 5g of each sample into crucible. Record the mass of crucible and the mass of crucible plus sample, both to 0.0001g.
2. Dry crucibles containing samples in an oven set at 105 °C ± 5 °C for a minimum of 24 hours.
3. Cool crucibles with content in desiccators. Remove immediately and determine the mass, again to 0.0001g.

b) Determination of ash content (British Standard EN 13039, 2000)

Principle: The sample is heated in air atmosphere up to a temperature of (550 ± 10) °C under rigidly controlled conditions of time, sample mass and equipment specifications. The ash content is determined by calculation from the mass of the residue remaining after heating.

Materials: weighing balance, crucible, furnace, desiccators, wood samples (poplar chips, cedar chips and wood pellet).

Procedure:

1. Weigh approximately 5g of each sample into crucible. Record the mass of crucible and the mass of crucible plus sample, both to 0.0001g.
2. Place the crucible and content into muffle furnace and raise temperature to 450-550 °C, overnight.
3. Remove crucible and place in desiccators to cool and determine the mass, again to 0.0001g.

Procedure for microwave digestion of plant material in mixture of nitric acid and H_2O_2

1. Weigh 0.5g of the biomass sample into each of nine (9) microwave digestion liners.
2. Pipette 5ml of nitric acid (1.42 specific gravity) and allow digesting overnight at room temperature.
3. Add 5mls of hydrogen peroxide solution (100volumes, >30%) and leave to stand for 2hours at room temperature.

4. Evenly place the digestion liner in the carousel of the Mars Xpress microwave.
5. Turn the machine on, allow initializing and running till completion.
6. Filter the liners into 100ml volumetric flask each using Whatman 542 or equivalent
7. Rinse each liner and its seal with demineralised water, adding this to the appropriate flask.
8. Make up the volume with demineralised water.
9. Samples are run in an inductively coupled plasma mass spectrometry (ICP-MS) to determine its heavy metal concentration.

Table E. 10: Moisture content biomass fuel.

ANALYSIS OF MOISTURE CONTENT OF BIOMASS FUEL USED									
Sample	Mass of tin (g)	Mass of fresh sample +tin(g)	Mass of a fresh sample (g)	Drying at 105 °C (hrs)	Mass of dry sample +tin (g)	Mass of a dry sample (g)	Mass of evaporated water (g)	Moisture content (%),dry basis	Moisture content (%), wet basis
poplar chips	686.8	2296.6	1609.8	50	1733.9	1047.1	562.7	53.74	34.95
cedar chips	671.5	2308.3	1636.8	50	1764.7	1093.2	543.6	49.73	33.21
wood pellets	23.7	673.4	649.7	22	603	579.3	70.4	12.15	10.84

Table E. 11: Ash content of biomass fuel

ANALYSIS OF ASH CONTENT OFBOMASS FUEL USED								
Sample no.	Mass of crucible [g]	Mass of a dry sample + crucible [g]	Mass of sample (g)	Heating time at 550 °C [hr]	Mass of ashes + crucible [g]	Ash Content [%],dry basis	Mean	Standard deviation
1Pa	40.3472	45.0066	4.7		40.4897	3.06		
1Pb	42.243	47.0638	4.8		42.3958	3.17	3.12	0.06
1Pc	37.8759	42.0433	4.2		38.006	3.12		
2Ta	32.9769	37.8457	4.9		33.3559	7.78		
2Tb	32.6097	37.462	4.9	4	32.9756	7.54	7.67	0.12
2Tc	39.784	44.6771	4.9		40.1609	7.7		
3Wa	31.8558	36.7468	4.9		31.8814	0.52		
3Wb	39.167	44.3749	5.2		39.1963	0.56	0.49	0.09
3Wc	42.7157	47.4388	4.7		42.734	0.39		

Table E. 12: Heavy metal (Zn, Cu, Pb) analysis of biomass fuel

ANALYSIS OF HEAVY METALS FROM THE BIOMASS FUELS USED																	
Sample	Sample no.	Sample mass (g)	Zn (µg/l)	Zn (µg/kg)	Zn(mg/kg)	Mean	Std dev	Cu (µg/l)	Cu(µg/kg)	Cu(mg/kg)	Mean	Std dev	Pb (µg/l)	Pb (µg/kg)	Pb(mg/kg)	Mean	Std dev
	1Pa	0.5057	163.00	32232.5489	32.23			14.70	2906.8618	2.91			2.17	429.108	0.43		
poplar chips	1Pb	0.5035	158.00	31380.3376	31.38			14.70	2919.5631	2.92			2.36	468.719	0.47		
	1Pc	0.5014	146.00	29118.4683	29.12	30.91	1.61	15.10	3011.5676	3.01	2.95	0.06	2.16	430.794	0.43	0.44	0.02
	2Ta	0.5073	85.20	16794.796	16.79			18.80	3705.8939	3.71			4.62	910.704	0.91		
cedar chips	2Tb	0.5014	88.00	17550.8576	17.55			19.90	3968.8871	3.97			4.12	821.699	0.82		
	2Tc	0.5007	87.10	17395.6461	17.4	17.25	0.4	19.80	3954.4638	3.95	3.88	0.14	4.10	818.854	0.82	0.85	0.05
	3Wa	0.5033	75.20	14941.3868	14.94			21.30	4232.0683	4.23			21.50	4271.81	4.27		
wood pellets	3Wb	0.5023	73.20	14572.9644	14.57			21.70	4320.1274	4.32			18.90	3762.69	3.76		
	3Wc	0.5019	78.20	15580.793	15.58	15.03	0.51	21.90	4363.419	4.36	4.3	0.07	16.10	3207.81	3.21	3.75	0.53

Table E. 13: Heavy metal (Cd, Cr) analysis of biomass fuel

ANALYSIS OF HEAVY METALS FROM THE BIOMASS FUELS USED												
Sample	Sample no.	Sample mass (g)	Cd (µg/l)	Cd(µg/kg)	Cd (mg/kg)	Mean	Std dev.	Cr (µg/l)	Cr (µg/kg)	Cr (mg/kg)	Mean	Std dev.
	1Pa	0.5057	2.91	594.5026696	0.59			22.40	3901.523	3.9		
poplar chips	1Pb	0.5035	2.83	581.2115194	0.58			20.40	3521.351	3.52		
	1Pc	0.5014	2.58	533.7854009	0.53	0.57	0.03	25.70	4593.139	4.59	4	0.54
	2Ta	0.5073	0.60	137.8671398	0.14			16.30	2686.773	2.69		
cedar chips	2Tb	0.5014	0.63	144.0765856	0.14			17.20	2897.886	2.9		
	2Tc	0.5007	0.58	135.0908728	0.14	0.14	0	16.40	2742.161	2.74	2.78	0.11
	3Wa	0.5033	0.41	100.0198689	0.1			17.30	2906.815	2.91		
wood pellets	3Wb	0.5023	0.42	101.8116663	0.1			16.00	2653.793	2.65		
	3Wc	0.5019	0.53	124.4072524	0.12	0.11	0.01	14.30	2317.195	2.32	2.63	0.3

c) Principle behind Dynamic Light Scattering (Malvern, 2014)

Particles, emulsions and molecules in suspension undergo Brownian motion. This is the motion induced by the bombardment by solvent molecules that themselves are moving due to their thermal energy.

If the particles or molecules are illuminated with a laser, the intensity of the scattered light fluctuates at a rate that is dependent upon the size of the particles as smaller particles are “kicked” further by the solvent molecules and move more rapidly. Analysis of these intensity fluctuations yields the velocity of the Brownian motion and hence the particle size using the Stokes-Einstein relationship.

E.2. Metal analysis results

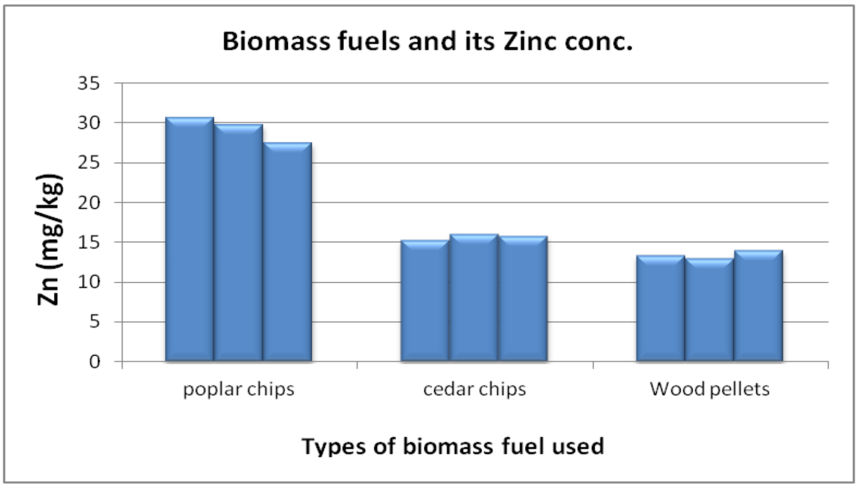

Figure E. 8: Zn concentration (mg/kg) of biomass fuel

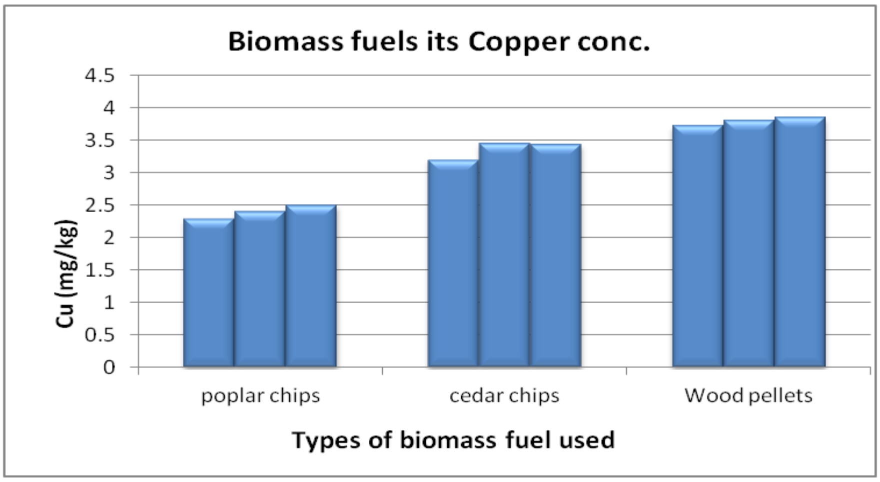

Figure E. 9: Cu concentration (mg/kg) of biomass fuel used

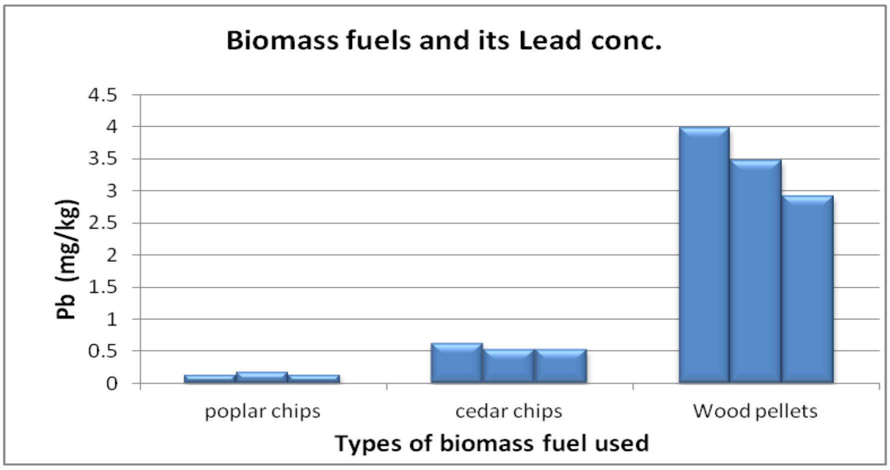

Figure E. 10: Pb concentration (mg/kg) of biomass fuel

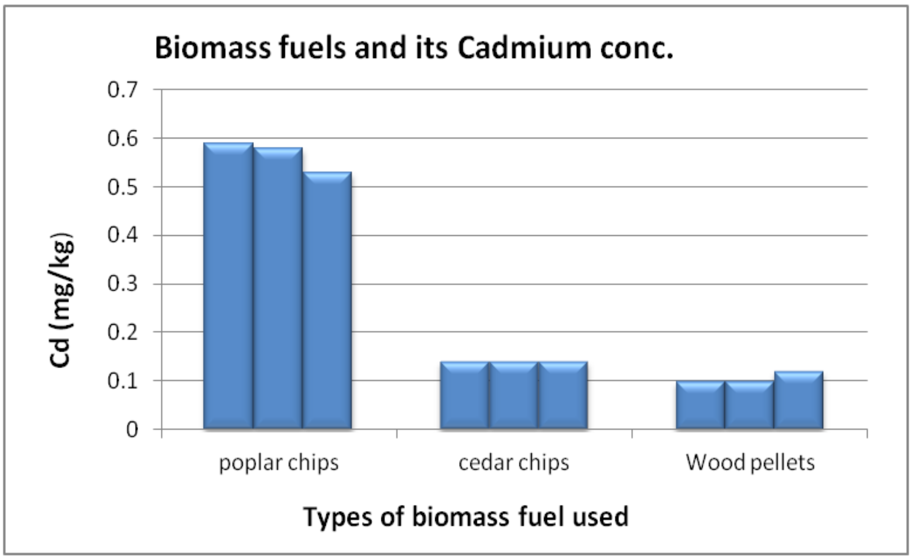

Figure E. 11: Cd concentration (mg/kg) of biomass fuel used

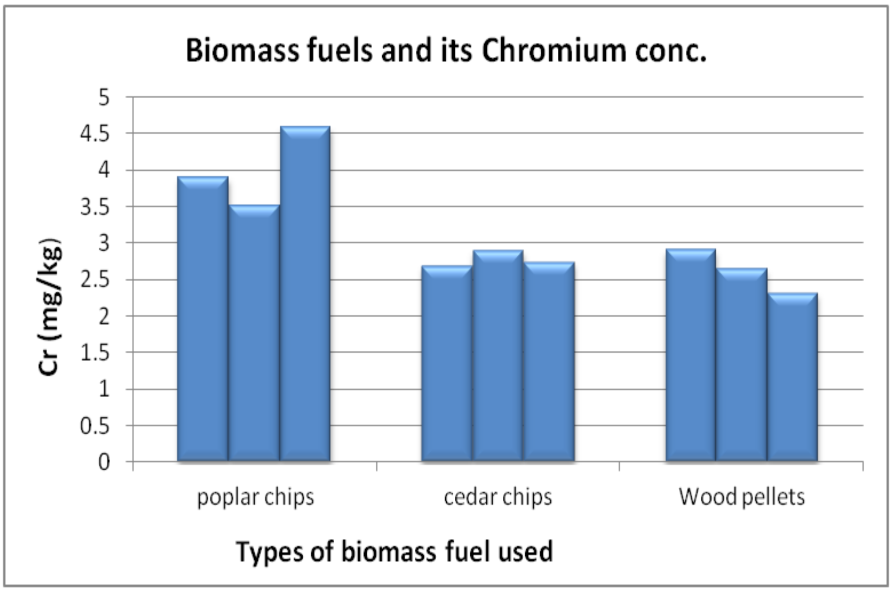

Figure E. 12: Cr concentration (mg/kg) of biomass fuel used

E.3. Pictures of samples

Figure E. 13: Samples used – from left to right: wood pellets, Cedar chips and Poplar chips

E.4. Particle diffusion

Figure E. 14: Sample showing diffusion of particles in aqueous solution

E.5. Particle distribution

Table E. 14 : Poplar (100 ug) - particle distribution

Poplar (100ug)	
Size classes (nm)	Intensity Distribution Data (%)
0.400000006	0
0.463231683	0
0.536458969	0
0.621261954	0
0.719470561	0
0.833203912	0
0.96491611	0
1.117449284	0
1.294094801	0
1.49866426	0
1.735571861	0
2.009929657	0
2.3276577	0
2.695611954	0
3.121732235	0
3.615213156	0
4.186703205	0
4.84853363	0
5.614985943	0
6.502598763	0
7.530524254	0
8.720943451	0
10.09954357	0
11.69607067	0
13.54497623	0
15.68615532	0
18.16580963	0
21.03744698	0
24.36302948	0
28.21431732	0
32.67441559	0
37.83956146	0
43.82120895	0
50.74842834	0
58.77069855	0
68.06112671	0
78.82017517	0
91.28000641	0
105.7094727	0
122.4199448	0
141.7719879	0
164.183197	0
190.1371307	0
220.1938629	0
255.0019379	0
295.312439	0

341.9951782	0
396.0575256	0
458.6659546	0
531.1715088	55.00428009
615.1386719	44.99571991
712.3793335	0
824.9916992	0
955.4057007	0
1106.435425	0
1281.339844	0
1483.893066	0
1718.465698	0
1990.119385	0
2304.71582	0
2669.043457	0
3090.963867	0
3579.580811	0
4145.437988	0
4800.745605	0
5559.643555	0
6438.507813	0
7456.301758	0
8634.988281	0

Table E. 15: Coal (100 ug) - particle distribution

Coal (100ug)	
Size classes (nm)	Intensity Distribution Data (%)
0.400000006	0
0.463231683	0
0.536458969	0
0.621261954	0
0.719470561	0
0.833203912	0
0.96491611	0
1.117449284	0
1.294094801	0
1.49866426	0
1.735571861	0
2.009929657	0
2.3276577	0
2.695611954	0
3.121732235	0
3.615213156	0
4.186703205	0
4.84853363	0
5.614985943	0
6.502598763	0
7.530524254	0
8.720943451	0
10.09954357	0
11.69607067	0
13.54497623	0

15.68615532	0
18.16580963	0
21.03744698	0
24.36302948	0
28.21431732	0
32.67441559	0
37.83956146	0
43.82120895	0
50.74842834	0
58.77069855	0
68.06112671	0
78.82017517	0
91.28000641	0
105.7094727	0
122.4199448	0
141.7719879	0
164.183197	0
190.1371307	0
220.1938629	0
255.0019379	0
295.312439	0
341.9951782	0
396.0575256	0
458.6659546	0
531.1715088	57.61782074
615.1386719	42.38217926
712.3793335	0
824.9916992	0
955.4057007	0
1106.435425	0
1281.339844	0
1483.893066	0
1718.465698	0
1990.119385	0
2304.71582	0
2669.043457	0
3090.963867	0
3579.580811	0
4145.437988	0
4800.745605	0
5559.643555	0
6438.507813	0
7456.301758	0
8634.988281	0