Department of Mechanical Engineering

Development of a carbon footprinting tool for domestic households with very high levels of fuel poverty

Author: Jeremy Laycock

Supervisor: Paul Touhy

A thesis submitted in partial fulfilment for the requirement of degree in Master of Science in Renewable Energy Systems and the Environment

2010

Copyright Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: Jeremy Laycock Date: 10-09-2010

.

Abstract

The Scottish Government has high ambitions for the eradication of fuel poverty by 2016 and the reduction of carbon dioxide by 80% by 2050. With 26.5% of Scottish households continuing to live in fuel poverty it is clear that there is still quite a long way to go to meeting these targets and therefore an urgent need to find an efficient, low cost and low carbon solution for the 9% of Scottish households that are currently using electric heating; the most expensive and high carbon emitting heating system that exists. Many households that are currently using electric heating are located in high rise tower blocks where individual gas boilers in each household are not an option due to building safety regulations. Therefore it is necessary to look at alternative solutions.

This thesis looks at the case study of West Whitlawburn Housing Co-operative which is based in one of the most deprived areas of Scotland and has high fuel poverty levels. This housing association is investigating options for upgrading the old electric heating systems in its buildings. The thesis develops a new tool which can be used to calculate both the baseline carbon footprint and fuel poverty levels of the households which can then be employed to analyse the effects of any new potential heating systems on these. The tool models both biomass district heating and gas powered combined heat and power district heating systems including modelling the heat distribution network and associated heat losses.

The results of the investigation show that although the average carbon footprint of the residents surveyed was very low at 6.7 tonnes CO_2e per year due to their very low consumption of goods and services and very infrequent travel there is significant room for improvement in the emissions from energy use in the home due to the electric heating in the flats. The study illustrates that gas CHP could reduce total energy costs of an average household in West Whitlawburn by 57% and reduce the carbon footprint by 12% per year while biomass could reduce the carbon footprint of a household by 17% but only reduce energy costs by 40% on average. Although biomass district heating represents a significant financial saving over electric heating and the largest reduction in carbon dioxide emissions, the results show that it can not currently compete on costs with gas powered CHP. In a situation like West Whitlawburn, where cost is the overriding factor, it would be necessary to

secure grant funding or the instigation of the Renewable Heat Incentive for biomass to be able to compete with gas CHP.

Acknowledgements

I would like to thank Paul Touhy for his guidance and support and especially for his flexibility and understanding over the last few months.

I would also like to thank Neil Phillips and everyone at West Whitlawburn Housing Co-operative, especially Stephanie Marshall for their support and practical assistance throughout the project.

Contents

List of figures

List of Tables

1 Introduction

The Scottish Government has set ambitious targets to both reduce carbon dioxide and to end fuel poverty in Scotland.. If these twin aims are to be achieved there is one particular area that must be a priority for action; the 9% of Scottish homes which are currently heated by electricity. Electricity is an extremely inefficient method of heating homes and is not only expensive but also results in a very high carbon footprint. It is also often imposed on the poorest members of society who do not have sufficient income to pay the higher tariffs yet do not have the freedom to change their system

Electric heating is especially common in densely populated areas or in high rise buildings due to the costs and technical challenges of installing a gas network and ensuring that the building is safe and explosion proof (CE55 Energy Saving Trust 2004). These types of buildings and developments are often social housing, where the poorest and most vulnerable members of society live, yet they are forced to use the least cost effective heating systems.

Electric heating is neither a cost effective nor environmentally friendly heating method. Electricity generation is an inefficient process, with the most efficient gas power stations up to around 50% efficient and further losses through the distribution of electricity. There are also further losses associated with converting the electricity back to heat in an electric heater. This compares with the most efficient gas condensing boilers which can be up to 95% efficient, and suggests that with current electricity generation methods, electric heating can never be less than double the price and have double the carbon footprint compared with burning gas directly in a condensing boiler.

The responsibility for these heating systems often comes down to the housing associations which own and run much of the social housing in Scotland but may have limited knowledge or expertise on the impact that different heating systems can have on both fuel poverty levels and greenhouse gas emissions. Grant funding is often available to these housing associations to make changes to heating systems but they would be required to show the impact that a proposed new system would have.

There is a need for a tool which is simple enough for non experts to use and which can accurately analyse the benefits of upgrading the heating systems, both in terms of carbon dioxide emissions and energy costs of the system.

Whilst there are many carbon footprint tools available the standard varies considerably both in terms of what is taken into account in the calculations and the clarity and ease of use of the calculators. It is important that the tool should make the carbon footprinting process as simple as possible for the people being surveyed. This means ensuring that questions are worded as simply and clearly as possible and avoiding words which may be not be understood. It also means ensuring that questions are as simple as possible to answer, for example by avoiding the need for the respondent to sit down with a map and calculator to work out how many miles they travel by bus per year.

Most online tools are often designed for an individual person or household and do not have the capability to store multiple household's results and to analyse the data on a community scale. Other tools that have this capability may require an expensive licence payment.

Although these tools often make suggestions about steps that can be taken to reduce the individual's carbon footprint, such as installing a more efficient boiler or low energy lighting, there is no carbon footprinting tool which can also analyse the effect on the footprint of installing community heating systems. There is no existing mechanism that can be used to analyse the impact that different heating systems would have on fuel poverty levels. This thesis will explore the need for and develop a new tool which can both calculate the current carbon footprint of an individual and also estimate the effect that upgrading heating systems will have on the carbon footprint and spending on energy.

The work will be based on a case study of West Whitlawburn Housing Co-operative (WWHC) which finds itself with a housing stock which has been extensively refurbished to a high thermal standard but still uses electric heating. Although the tool will be designed with the particular situation at WWHC in mind it is also designed to be a flexible tool which could be used by other housing associations or communities which are investigating the potential benefits of district heating systems.

1.1 Objectives

- Development of a carbon footprinting tool which will
    - assess the current footprint of individuals and analyse the data for the whole community
    - assess the current fuel poverty levels
    - make projections about the future carbon footprint of individuals and the community based on the installation of district heating systems
    - make predictions about how upgrades to the heating system would impact fuel poverty levels in the area
- Develop a tool that will be as simple to understand and use as possible, keeping in mind the target audience of the tool
- Carry out an assessment on WWHC to test the tool

1.2 Methodology

The main steps taken to achieve the objectives outlined above are:

- Research the causes, effects implications and definition of fuel poverty.
- Conduct research and a review of issues around carbon footprinting and settle on a clear framework and definition of what is meant by a carbon footprint in this project.
- Review existing carbon footprint calculators, analysing their strengths and weaknesses, learning lessons from them and assess the need to develop a new tool.
- Research and assess the current and potential heating options for WWHC and comparing the advantages and disadvantages of each one.

- Model the potential heating systems, including looking at energy supply and demand matching and heat loss from district heating and analyze their potential impact on both CO_2e emissions and fuel poverty levels.
- Design and make a carbon footprinting tool and discussing the steps taken.
- Test the tool in West Whitlawburn to assess both the success of the tool in meeting the objectives and also the potential effects of new heating systems in WWHC.

2 West Whitlawburn Housing Co-operative

West Whitlawburn is located in Cambuslang in South East Glasgow and has a population of around 1700. The area suffers from multiple deprivations and is ranked as one of the most deprived areas in Scotland. Table 1 shows employment statistics for the Whitlawburn area compared to the averages for South Lanarkshire and Scotland and it can be seen that the area has significantly higher levels of unemployment and income deprivation than the average for the broader area.

Table 1 Whitlawburn area employment statistics

	Whitlawburn	South Lanarkshire Council	Scotland
Job Seeker Allowance claimants	7.9%	2.3%	2.4%
Percentage of working age residents who are employment deprived	30.8%	12.1%	11.6%
Percentage of total population who are income deprived	58.2	16.8	17.1

Source: (Scottish Government 2010)

Figure 1 shows the area of investigation for this study encircled by a red line.

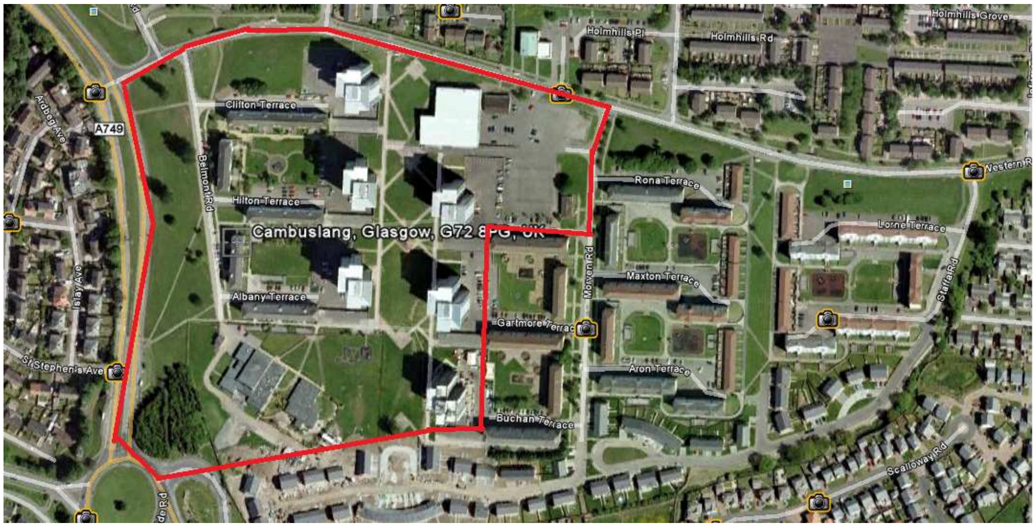


Figure 1 West Whitlawburn Housing Co-operative

In the 1980s the area had become seriously run down, with poor quality housing and a lack of repairs as well as a high crime rate and serious social problems. West Whitlawburn Housing Co-operative (WWHC) was formed in 1989 when the residents decided that something had to change and that their only option was to take control and form a housing co-operative (West Whitlawburn Housing Co-operative 2010).

> *"We really had no choice, either continuing to live in unacceptable and deteriorating conditions or take control, seek housing grants from Scottish Homes and set about regenerating West Whitlawburn as an attractive, peaceful and high quality place to live." Phil Welsh MBE*

All of the properties within the WWHC boundary are owned by the Co-operative and the breakdown of residents in the properties is shown in Table 2.

Table 2 Whitlawburn Households (2001)

Households	%Whitlawburn	% South Lanarkshire Council	% Scotland
Lone Pensioner households	9.4%	22.9%	23.5%
Households with dependent children	7.1%	14.4%	15.0%
Lone adults with dependent children	33.7%	30.8%	28.2%
Children in lone adult households	22.0%	7.3%	6.9%
Children in workless households	63.5%	24.6%	25.1%

Source: (Scottish Government 2010)

2.1 Housing stock

In the two decades since WWHC was formed significant progress has been made in turning around the area with refurbishments carried out on the co-operative's building stock to upgrade the fabric, windows and services of the buildings. There are six high rise blocks and five low rise blocks and all flats are owned by the Housing Co-operative.

The buildings have been upgraded to a high standard, with the new U-values outlined in Table 3, however the heating system in the buildings remain unchanged. All of the buildings investigated in this study have electric heating. This results in very high energy bills for the residents, with an energy consultant finding the average spending on energy to be £1854.40 per flat in 2009 (RSP Consulting Engineers 2009).

Table 3 U-Values at West Whitlawburn Housing Co-operative

Section	U-value (w/m^{2}k)
External Walls	0.27
Roof	0.16
Windows	2.0
Floor	0.7

2.2 Energy consumption

The energy consumption of WWHC was estimated by a 2009 consultants report (RSP Consulting Engineers 2009) and are outlined in

Table 4. The peak load heat demand for the system, based on both heating and domestic hot water was calculated by the consultants to be 1572kW.

Table 4 Electricity consumption of the site

	Dwellings (MWh/annum)		Landlord services (MWh/annum)	Total for the site (MWh/annum)
	Per household	Total		
Heating and hot water	12	6528	450	6978
Power	4	2176	1981	4157
Total	16	8704	2431	11135

Source: (RSP Consulting Engineers 2009)

2.3 Heating systems

WWHC currently has electric heating in its buildings and the Housing Co-operative would like to upgrade this to a more efficient, cost effective and environmentally friendly system. In 2009 they commissioned a firm of consultant engineers to assess the various possibilities for upgrades. The Housing Co-operative set out a number of requirements for any new heating system, these were that it should:

- reduce fuel costs
- be controllable by the tenants, and simple to understand,
- not take up additional space within the homes
- allow each dwelling to be metered and billed separately
- not require a gas based system in each dwelling, as due to the building construction this would not be allowed

(West Whitlawburn Housing Co-operative 2010)

The heating systems and the recommendations are considered in further depth in Chapter 6.

3 Fuel poverty

This section looks aims to establish a clear definition of fuel poverty for use throughout the thesis as well as discussing the causes and effects of fuel poverty.

3.1 Definition

Fuel poverty is widely understood to relate to the amount of money spent on fuel in the home, and this was reflected in the surveys carried out in West Whitlawburn, where typical responses to the question about the meaning of fuel poverty included "not having enough money for heating". It is important for this thesis that a clear definition is adopted and stuck to and in this case the Scottish Government definition has been used, which states that:

> *"A household is in fuel poverty if, in order to maintain a satisfactory heating regime, it would be required to spend more than 10% of its income (including Housing Benefit or Income Support for Mortgage Interest) on all household fuel use." (The Scottish Government 2002)*

The "satisfactory heating regime" in this definition has been defined such that should be able to maintain their living room at 21°C and other rooms at 18°C for 9 hours in every 24 hours and 16 hours in every 24 at the weekend. (The Scottish Government 2002)

It is important to note that fuel poverty is not a measure of how much a household actually spends on energy, but of the amount that they would have to spend to maintain their home at the satisfactory heating level. It is logical that fuel poverty has been defined in this way, as it removes the possibility that someone can be defined in fuel poverty simply because they are very wasteful with their energy use but it could also distort the real situation in some instances. Certain groups of people are likely to spend more time at home than others, such as parents of young children or households where someone is unemployed, may not officially be in fuel poverty if their household income is above the threshold but could in reality end up spending far more than 10% of their income on energy.

Household income has been defined as including housing costs and this has the potential to distort fuel poverty statistics. For a single person living on Job Seekers Allowance of £65.45 per week and with a rent of £56.22 per week, which is covered by housing benefit the fuel poverty threshold would be £13.33 per week. If their rent was to go up, and this increase was met by housing benefit, it is possible that they could be technically lifted out of fuel poverty even though their actual disposable income had not changed at all. With this definition the most effective way for a housing association to technically reduce fuel poverty levels could actually be to increase the rent in their flats! Glasgow City Council was one of a number of organisations which made this point during the Scottish Government consultations on the definition but this was not taken into account. (Glasgow City Council 2005)

It was decided that this definition should be used despite its short comings as this is the official definition used in Scotland.

3.2 Causes of fuel poverty

There are three main factors which affect fuel poverty levels; household income, fuel prices and the energy efficiency of the home. Any one of these factors could be enough to put a household into fuel poverty but it is often the case that these factors are interrelated all three factors combine to leave a household in very severe fuel poverty. These factors are discussed below.

Income

Households with a low income are likely to spend a higher proportion of their income on energy than those on higher incomes and this increases the chance of them being in fuel poverty. People on the lowest incomes can also often have unreliable incomes which could change from week to week if they are in temporary or agency employment, working shifts or doing unreliable seasonal work. This could mean that despite earning enough over a full year there may be weeks when they simply do not have any money left to pay for heating and if they are on a pre-payment meter they could be left in a cold house

Energy prices

Clearly the price of fuels is an important factor and this can vary significantly over time and between different fuels. Those on lower incomes are more vulnerable to rises in energy prices as this represents a higher proportion of their income. Those on lower incomes are also more likely to be in rented accommodation and will often have little choice over where they live or the type of heating system they have. This can often result in the poorest households being stuck with the most expensive heating systems.

Energy Efficiency

Energy efficiency, either in terms of the efficiency of a heating system or the quality of the building can have a significant impact on fuel poverty levels. Again, those on lower incomes often have little choice about where they live and can often be forced to live in poorly insulated homes with old and inefficient heating systems.(Department for Energy and Climate Change 2001)

3.3 Effects of fuel poverty

Fuel poverty can have serious effects on both the health and quality of life of individuals or households. A cold home can exacerbate medical conditions such as influenza, strokes and heart diseases and promote the growth of fungi and mites which can lead to asthma (Department for Energy and Climate Change 2001). Fuel poverty can also lead to a household having to cut back on other things such as food or clothes as so much of their income goes on energy. It could also lead to social isolation as there may not be enough money left after paying for fuel bills for social activities or to travel to visit friends or relatives. The elderly, disabled and children are the most vulnerable to the effects of a cold home and are also the groups who are most likely to spend the largest proportion of time in the home, thus exacerbating the effects of fuel poverty.

3.4 Typical incomes

Table 5 shows estimated income and fuel poverty thresholds, which represents the minimum spend required on energy to maintain a satisfactory heating regime, for households in a number of possible situations, such as a household with one person working full time on the minimum wage, a household with no employment or a household with one person earning the median wage for Glasgow. These numbers can be used to put energy costs into perspective and to estimate how likely a heating system would be to eradicate fuel poverty in West Whitlawburn.

Table 5 Typical household incomes

	Total weekly income	Annual income	Fuel poverty threshold
An unemployed couple with no children	£159	£8,268	£827
An unemployed single person	£122	£6,327	£633
One person working full time on the minimum wage	£218	£11,310	£1,131
One person on median income for Glasgow	£388	£20,150	£2,015
Two people working full time minimum wage	£435	£22,620	£2,262
Single pensioner on basic state pension	£130	£6,760	£676

4 Carbon Footprint

The term ‘carbon footprint’ is now widely used but there is a significant lack of consensus about what it actually means. While it is generally accepted that a carbon footprint refers to an amount of gas released into the atmosphere which will contribute to climate change this is where the consensus stops.(Minx & Wiedmann 2008) A carbon footprint could be associated with an individual product or the lifestyle of a person or group of people over a fixed period of time. There is no consensus on whether a carbon footprint should take into account exclusively carbon dioxide or also include other gasses which contribute to global warming, such as methane. There is also disagreement over whether the definition should include only ‘direct emissions’ such as those from petrol burnt in a car or also include ‘indirect emissions’ such as the emissions associated with the manufacture and distribution of the car itself. (Minx & Wiedmann 2008)

The Oxford Dictionary describes a carbon footprint as:

> *"the amount of carbon dioxide released into the atmosphere as a result of the activities of a particular individual, organization, or community"*(Oxford Dictionaries 2010)

Whist this definition is technically correct, the fact that a carbon footprint is generally discussed in the context of anthropogenic global warming means that this definition is rather misleading. There are a number of other gases such as methane or nitrous oxide that have also contributed to global warming, so only measuring the emissions of carbon dioxide would underestimate the impact of a product or activity (Peters 2010). Some people have suggested that an alternative name should be sought, but with the term 'carbon footprint' now becoming widely recognised, if not clearly defined, and it would be confusing for the general public if a new terminology was adopted. The best option would perhaps be to quote the carbon footprint in either kgs or tonnes of carbon dioxide equivalent (CO2e). This would represent the mass of carbon dioxide gas that would have the equivalent global warming potential of all of the greenhouse gases released due to that activity or product. For example, the global warming potential of methane is 56, which implies that 1kg of methane is equivalent to 56kg of carbon dioxide (Intergovernmental Panel on Climate Change. 1996).

4.1 Direct emissions

A series of emissions factors are produced by the UK Government which show the amount of CO_2e released per unit of fuel used or pound spent on an item. This makes it relatively easy to calculate the emissions related to direct energy use, such as heating a home, use of electricity or driving a car as it simply requires knowledge of the quantity of fuel used, such as natural gas or petrol, and the emissions factor for that fuel. Where energy use is not known it can be fairly accurately estimated; the amount of fuel used by a car for example can be estimated from the engine size, distance travelled and fuel type. The green house gas emissions factor for petrol is 2.3307kg CO_2e per litre therefore if 1000 litres of petrol were used by an individual in one year the carbon footprint associated with it would be 2.3 tonnes CO_2e.

4.2 Indirect emissions

It is not quite as simple or clear how to calculate the 'supply chain' or 'indirect' emissions which are embodied in products or services that we buy. Embodied emissions refer to all the emissions released in the process of designing, manufacturing, marketing and selling a product such as a car. The implication of these embodied emissions is that the more goods and services that are consumed, the higher the carbon footprint will be. This is perhaps an uncomfortable truth in a society which is based on ever increasing economic growth which is reliant on the continual augmentation of consumption. These indirect emissions are not explicitly comparable with the direct emissions associated with burning fuel, but they must nevertheless be included in any carbon footprint estimate if it is to give a good representation of the impact that an individuals lifestyle has on the environment. Sometimes these emissions are simply ignored, such as in the UK Government's Act On CO_2 calculator discussed in Chapter 5.2 but this merely produces a carbon footprint which is both misleading and not directly comparable with footprints calculated using different tools.

4.3 Ecological footprint

The term 'carbon footprint' has its roots in the idea of the ecological footprint which was first conceived by Mathis Wackernagel and William Rees in 1990 (Global Footprint Network 2009a). The ecological footprint is a far broader concept than the carbon footprint as it measures the total environmental burden that humans place on one planet and calculates the amount of land that is required to support a particular lifestyle or activity (WWF & Sustainable Scotland Network 2009). The ecological footprint takes into account both the amount of land required to produce the food or materials required as well as to absorb the emissions produced by a lifestyle or activity and maintain a sustainable biodiversity. The Global Footprint Network defines the ecological footprint as:

> *"A measure of how much biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates using prevailing technology and resource management practices. The Ecological Footprint is usually measured in global hectares."(Global Footprint Network 2009b)*

The ecological footprint thus gives a more complete picture of the impact that human lifestyles have on the planet, taking into account factors such as resource consumption and depletion and land use, whether it is built up, crop or forested land. The results of an ecological footprint are often presented along with a statement informing the user how many times over the estimated sustainable limit they are, such as "*It would require 3.2 planets to support your lifestyle.*" This helps to put the result in context and makes it far more understandable than the result of a carbon footprint analysis that is quoted simply as a number of tonnes of CO_2 or CO_2e which does not mean very much to most people.

However, whilst the ecological footprint has a number of advantages over the carbon footprint it is also a more difficult concept to quantify. The result of a carbon footprint can be calculated relatively easily in kg or tonnes of gas released, but it takes a further conversion and numerous assumptions to convert that into an area of land required. This increases the uncertainty of the result and the likelihood of errors being made in the calculation (Minx & Wiedmann 2008). Taking into account the many pros and cons of the ecological footprint, it was decided that the carbon footprint will be used in this study as it offers a more accurate and reliable result.

4.4 Recommendations

Following the review of literature surrounding carbon footprints it was decided that the definition of a carbon footprint in this thesis should:

- Be a carbon footprint rather than an ecological footprint as it produces a simpler, more reliable result that is more widely accepted and recognised.
- Be measured in terms of carbon dioxide equivalent emissions to ensure that the results are a full representation of the impact of an activity.
- Include both direct and indirect emissions to ensure that the footprint reflects all activities of an individual

4.5 Definition of a carbon footprint used in this thesis

All of these considerations are represented in the following definition of a carbon footprint outlined by the British Standards Institution:

> *"Absolute sum of all emissions of greenhouse gases caused directly and indirectly by a subject either over a defined period or in relation to a specified unit of product or instance of service and calculated in accordance with a recognized methodology" (British Standards Institution 2010)*

In this study, the carbon footprint will be of an individual or the extrapolated footprint for the community, over a period of one year. All calculations in this study are based on the 2009 UK emissions factors published by the Department of Energy and Climate Change which take into account emissions of the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) and are expressed in kg or tonnes of carbon dioxide equivalent (CO_2e).

5 A review of existing carbon footprint tools

A review was conducted of currently available carbon footprint tools, noting the strengths and weaknesses of each. The way a carbon footprint calculator is designed obviously depends on the definition of a carbon footprint which is used by its developer and as there is no fixed definition of a carbon footprint there will inevitably be different methodologies for developing the calculators. There are numerous carbon footprinting tools available, with many free web based tools as well as those for which a license must be purchased. Of the various tools investigated it was found that they had significant differences between them in terms of the way questions were asked, how the footprint was calculated and how the results were presented. Some look only at direct emissions whilst others include indirect emissions from consumption. Some calculate only the emissions of carbon dioxide whilst others calculate the equivalent mass of carbon dioxide for the total green house gas emissions and others include both a carbon footprint and an ecological footprint.

A number of tools were looked at and the following tools have been chosen for a detailed discussion as they are representative of the numerous tools available: Reap Petite, www.myfootprint.org, ACT ON CO2 and www.carbonfootprint.com.
Each tool has been investigated from the following aspects:

- What aspects of the footprint does it look at?

- How easy is it to use and is the language that is used clear?
- How easy are they to answer? Could users be expected to know the information required?
- How visually appealing are they?
- How easy is it to track changes in the footprint over time?

5.1 Reap Petite

Reap Petite is a program that can be downloaded as a free trial but requires a license in order to save results. The program calculates the total emissions over a period of one year in tonnes CO_2 equivalent, as well as an ecological footprint in global hectares. The program has the option to record the data for an unlimited number of individuals and use this to analyse the results of the whole community.

The Reap Petite program is divided up into 8 sections: ‘initial information’, ‘your heat and power’, ‘your travel’, ‘your shopping’, ‘your activities’, ‘your recycling’ and ‘your water’. In the heat and power section there is the option to either enter energy consumption from energy bills, or to answer a number of questions about the respondent’s home, its thermal efficiency, the type of appliances used and their behaviour and the program will estimate their energy usage. This is a useful option as it is likely that many people will not have a whole year’s worth of energy bills to hand so this offers a useful backup option.

Unlike some other programs, Reap Petite does not ask for exact amounts spent on items or activities, but presents the average spent by a household of that size in that particular region and asks if the user to select how much they spend from a series of options such as ‘nothing’, ‘less than this’, ‘about this amount’ or ‘more than this’. An example can be seen in Figure 2, which shows a screen shot from the ‘your activities’ section of the program and each question has a series of appropriate answers to choose from. This method doesn’t offer the flexibility or potential greater accuracy offered by allowing the user to enter the exact amount spent but it is also perhaps unrealistic to expect people to know exactly what they spend on different items. It is possible that this method could actually lead to greater accuracy for some individuals as it gives them some guidance where otherwise they may have simply plucked a number from thin air. This style also makes it very easy to answer the questions, however it does make it rather more difficult to track any changes in the carbon footprint over time. If, for example, a user has previously answered that they spend ‘about double’ the average monthly spend on clothing then they would have to bring their consumption down by a whole category, for example to ‘about this amount’ before the calculator registered any change in the footprint. This does not pose a problem if the aim is merely to calculate a one off footprint, but if the aim is to track the footprint over time then this method is not ideal.

Overall Reap Petite is a very good tool but a licence is required for the tool and this expense significantly reduces it’s accessibility.

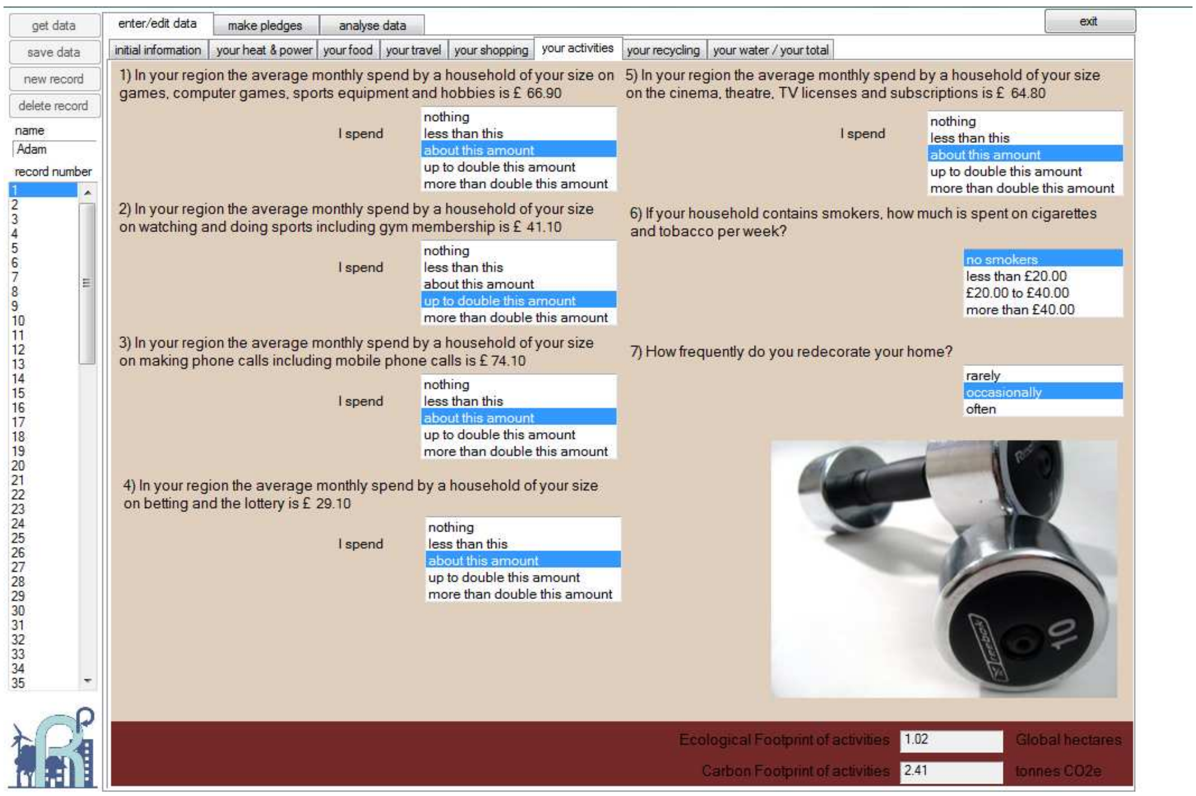


Figure 2 Reap Petite

5.2 Act On CO_2

The UK Government’s carbon calculator, Act On CO_2, is a well made and attractive calculator. It has high quality graphics and animations which make it more interesting and engaging than many other calculators and the questions are asked in an accessible way. This is a free, web based calculator which calculates an individual's carbon footprint.

As with Reap Petite, this calculator also gives the user the possibility to enter details about their energy consumption or to estimate it from their answers to questions about their home and behaviour. The calculator goes into considerable depth with questions about the type of appliances and gadgets, their age and energy efficiency rating and how often appliances are left on standby. These responses are also used at the end of the survey to give specific advice on what the user can do to reduce their footprint, such as buying draft proofing or unplugging mobile phone chargers, and gives an estimate of how big an impact that would make for the specific user.

The section on travel also goes into more depth than most other calculators. It asks the user questions about their driving style, how regularly they check if their tyres are properly inflated, if they use air conditioning in the car and if they regularly drive alone or with other people in the car. These questions certainly allow for a more accurate carbon footprint though it is possible that some people would be put off by the length of time that it takes to carry out the survey. The section on public transport, shown in Figure 3 is simple but effective, allowing multiple journeys to be added and allowing the user to select if it is a single or return journey, the number of times they make the journey, whether that is per day, per week, per month or per year and how many passengers make the trip.

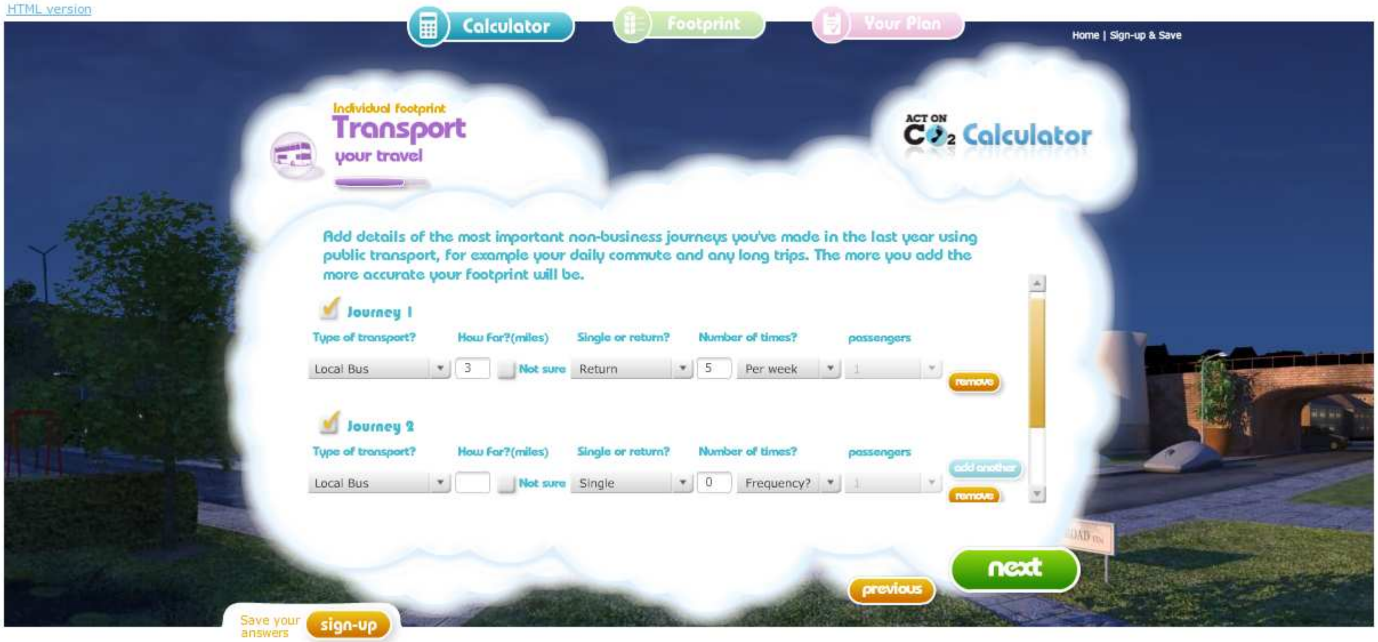


Figure 3 Act On CO_2 public transport calculation

The section on flights also includes more detail than most calculators. It asks the user to select the exact departure and arrival airports as well as asking if it was economy, business or first class. This allows for a more accurate calculation than most calculators which often simply ask how many flights were taken, without even requiring a specific distance to be entered. These are also relatively easy questions for most people to answer as it is likely that you would remember which airport you had flown to and if it was an economy class flight or higher.

The Act On CO_2 calculator does not include a section on consumption of goods and services. As discussed in Chapter 4, the method for calculating the indirect emissions from consumption of food, goods and services is different to that for direct emissions such as from the use of gas to heat your home and are not directly comparable. It is also more difficult to be confident that the indirect emissions calculated are an accurate representation, but it is entirely misleading to simply disregard this whole section of emissions from the calculation. There is no obvious explanation on the Act On CO_2 website as to why this has been excluded, so for the general public who are unlikely to have sampled a selection of different footprinting tools, it may not be obvious that there is a whole section missing from this calculation. This could give users the false impression that their consumption habits and lifestyle have no impact on the environment and that it is possible for them to 'go green' whilst continuing a highly consumerist lifestyle. The lack of a section on consumption also means that the results of this tool are not comparable with those of most other tools. Users that compare their results from this calculator with a national average produced by a different method could be falsely led to believe that their footprint is considerably lower than the national average.

Overall this is a good tool for individuals and is very accessible due to its graphical interface but is not suitable for communities and is seriously let down by the lack of a section on consumption of goods and services.

5.3 www.myfootprint.org

This online calculator developed by the Center for Sustainable Economy calculates an ecological footprint and presents the results in global hectares, yet calls it a carbon footprint. The tool calculates an average footprint for the given country of residence using publically available data from sources such as the United Nations and World Bank and then adjusts the results for the individual according to the answers given (Center for Sustainable Economy 2010). The tool only calculates the footprint of individuals, it doesn't have the capacity to look at communities.

Many of the questions are rather vague and it does not include a section where details on home consumption can be entered, instead it estimates it from answers about the size of house and type of appliances used. The language is not always clear and terms such as 'compact fluorescent bulbs' or 'water saving fixtures' are employed which may be confusing to many users. One question asks the user which 'energy saving features' they have and or if they have 'energy efficient appliances'. The terms are not clearly explained and it is likely that many people will not understand them. For those that do understand it is quite possible that they have a mixture of appliances, some of which are energy saving and some which are not however this possibility is not catered for.

There is only one question about vehicle use, and this simply asks the user to enter the total number of kilometres travelled by each form of transport in a year. This is clearly very difficult to answer and requires the user to carry out some calculations outside the program to estimate how far they travel over a whole year. It is unlikely that many users would be able to easily estimate the number of kilometres travelled by aeroplane per year without searching for a tool to help them to calculate it and there is no advice on the best way to do this.

This tool offers some important lessons on how to present questions in a clear and easy to answer manner.

5.4 carbonfootprint.com

This calculator is a web based tool which calculates an individual's carbon footprint in tonnes of CO_2 equivalent and allows the user to specify the time period over which they wish to measure their carbon footprint. The tool is a relatively simple design and uses few words or explanations but it is clear and easy to use.

The calculator looks at both direct and indirect emissions, but calls them primary and secondary emissions. Whilst the direct emissions calculations are based on the emissions factors supplied by the Department for Environment, Food and Rural Affairs, the indirect emissions are based on estimates made by the company (Carbon Footprint Ltd 2010).

The section on indirect emission is relatively short and basic compared to some other calculators and as shown in Figure 4 has sections such as 'Fashion' with a number of possible responses such as 'I regularly shop to have the latest fashions', 'I buy new clothes when I need them' and 'I only buy second hand clothes'. This approach makes it very easy for the user to answer, as they simply have to choose which response is most appropriate, rather than trying to estimate how much they spend on each item however it is clearly not a very accurate measure. The website openly states that the footprint from indirect emissions may not be very accurate but should be thought of more as a indication (Carbon Footprint Ltd 2010) but this method makes it extremely difficult to track any reduction in the indirect emissions over time unless the user makes a significant change in their behaviour, such as changing from 'I buy new clothes when I need them' to 'I only buy second hand clothes'.

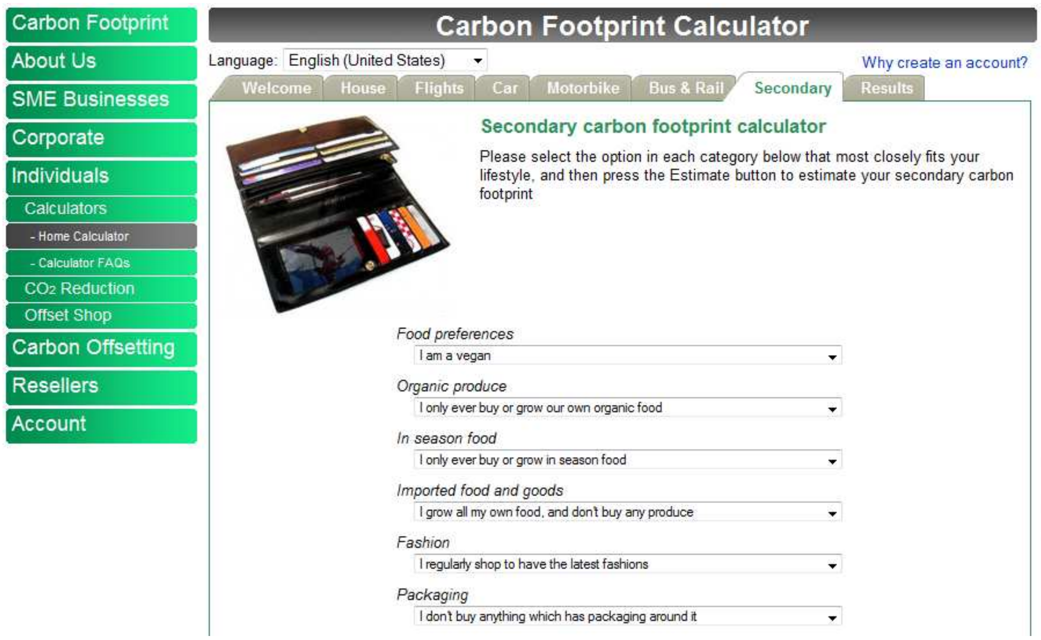


Figure 4 Carbonfootprint.com

The section for home energy use allows the user to enter data either about how much energy is used (for example in KWh) or the amount of money spent on energy. This is a useful option as even if the user does not have their bills to hand, they may remember approximately how much they spend on electricity or gas. This section does not include the possibility to estimate the energy consumption based on the type of home, appliances and behaviour so this calculator is only of use for people who have some information about their energy use or spending.

The section for public transport is also somewhat limited, requiring the user to simply enter the number of miles travelled over the year on different forms of transport. This method requires the user to do some calculations of their own to estimate their total distance travelled over the year and is likely to put some people off or result in them making very vague estimates which may not closely reflect reality.

5.5 WWF Footprint calculator

The online calculator from the World Wildlife Fund (World Wildlife Fund 2010) is a well designed online calculator that asks clear and simple questions and is easy to use. Again it is designed to calculate the footprint of individuals rather than communities.

The section on travel takes a different approach to some other tools by asking the respondent how much time they spend in different types of vehicles per week. This information can be used to estimate the distance travelled and the amount of fuel used. Although this method can only ever give a fairly vague estimate of the actual amount of fuel used, it is a much easier question for the respondent to answer than one that is based on distance travelled. It is more likely that someone will know that they travel 30 minutes per day on a bus than it is that they would know how far they actually travel. This method requires a large amount of statistical analysis in the development of the tool.

In the section about energy use in the home the calculator asks a number of simple questions about the type of building such as; a flat or house, how many people live there and then a number of questions about the user's behaviour. These include the approximate temperature of the home, if they tend to leave lights or appliances on standby or if they use low energy light bulbs. Again, these questions can only provide a very approximate estimate of the carbon footprint, however they are very quick and easy for the respondent to answer and this is more likely to encourage people to complete the survey than if they have to spend a long time answering dozens of questions and working out the answers. It is also the case that many people will not have access to their energy bills and could not be relied on to provide accurate estimates of their spending on energy, so in some cases this technique could actually calculate a more accurate footprint than more detailed calculators where the respondent is forced to estimate many answers because they either don't know or can't remember the answer.

The section on 'stuff' is again very simple and easy to answer, with six questions such as how much do you spend on DIY tools, gadgets, appliances and jewellery. The user is asked to select one of the spending brackets such as £0-100 or £200-300, which again makes the question quite easy to answer as it doesn't require too much thought about exact spending.

The tool calculates both the carbon footprint and the ecological footprint and presents the results in an easy to understand format that shows graphically the number of planets required to sustain your lifestyle, as shown in Figure 5.

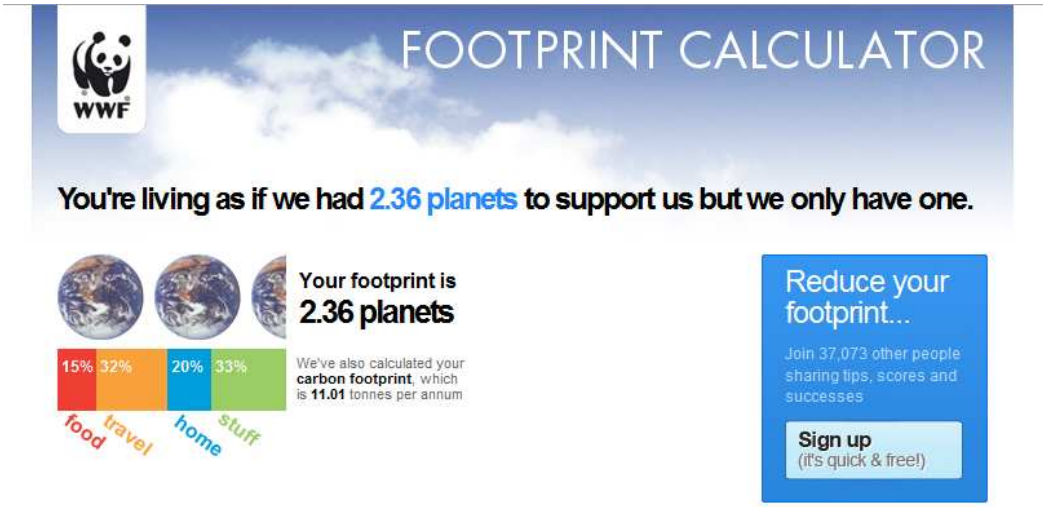


Figure 5 WWF Footprint Calculator

5.6 Discussion

Although there are a many different carbon footprint calculators available, each with their own strengths and weaknesses there is not one tool which stands out above all others as superior. The most appropriate tool for a given situation would depend on both the requirements of the tool and the target user group. If a very accurate and detailed carbon footprint is required and the target audience are motivated and have the time to answer questions then a more detailed tool could be used. In other situations a more straight forward and less time consuming calculator might be required to perform quick and simple footprint surveys before the audience get bored or give up.

It is important for this project that the calculator can handle data from a number of different users and collate the responses. Of all the tools reviewed, only Reap Petite has this capability but a licence must be purchased before the tool can be used and this is likely to be prohibiting to small housing associations or community groups. There is a lack of freely available tools which can be used to calculate community carbon footprints.

From an analysis of the variety of methods that have been incorporated by different tools to estimate consumption levels, it appears that the most accurate method would be for the respondent to enter the amount spent on various items which can then be converted directly into emissions. The disadvantage of this method is that it relies on the accuracy of the estimate or, in many cases, the guess of the respondent. An important criteria for this project is that the tool should be capable of tracking the carbon footprint of individuals and the community over time to show any change in the footprint. To accurately track the footprint of an individual over time it is important that the tool is based on the entry of exact data, rather than those such as Reap Petite which ask the user to select from different categories.

To make it simpler for the respondent they should be given the option to choose the timescale over which they answer, for example they may have an idea how much they spend on food per week, but they may only buy one to two pairs of shoes per year so it would be easier to answer how much they spend per year.

A number of tools calculate both ecological footprint and carbon footprint, whilst others choose one or the other and whilst some tools calculate carbon dioxide emissions, others calculate carbon dioxide equivalent. These differences are not often clearly explained to the respondent and this makes it difficult to compare the results of different tools.

5.7 Development of a tool

It is also important that the tool looks at more than the baseline carbon footprint of an individual or community. An integrated tool is required which can look at both the current carbon footprint and the fuel poverty status of individuals and communities and assess the impact that changes to the heating systems could have on both the carbon footprint and fuel poverty levels. It is important that all of these functionalities are combined into one tool as it makes the process of analysing the situation in a community of housing association much more straightforward.

None of the tools reviewed here have the multiple functionalities required and although detailed modelling packages exist which could be used by a qualified engineer to conduct an in depth analysis of the site, there is a lack of a simple yet effective tool which can be used by non-expert users for whom this tool is mostly aimed at.

The development of a new tool also provides the opportunity build on the strengths of the various different carbon footprinting tools available, combining the best ideas of the various tools into one new design. A number of recommendations are made based on the lessons learnt from the existing carbon calculator tools and these are listed in Chapter 5.7.1.

5.7.1 Recommendations

Following the review of existing carbon footprint calculators there are a number of recommendations that can be made about how the new tool should be developed, taking into account the various strengths and weaknesses of the different tools. These are the following:

- As defined by the carbon footprint definition adopted in Chapter 4, the tool should calculate the carbon footprint in tonnes of CO_2e.
- The tool should store data for a number of users to allow averages over a community to be calculated.
- A back up option for estimating the emissions from energy use in the home should be included in case the individual does not know their energy consumption.
- The tool should be flexible and give respondents various ways to answer questions where possible as is the case with the ActOnCO_2 calculator. This could include:
    - selecting from different time periods such as per week, per month, per quarter or per year
    - entering energy consumption in either the number kWh used or the amount of money spent on fuel
    - entering car travel either by the amount of fuel used in litres, the amount of money spent on fuel or the distance travelled
- The public transport section should be based on the methodology used by ActOnCO_2 where a number of trips can be entered for each form of transport and it can be specified if this is return or single and how often the trip is made. An example could be a 10 mile bus journey, once per month, plus the return trip as well as a 2 mile bus journey five times per week to get to work, plus the return

journey. The calculator should then calculate the annual emissions associated with these journeys.

- Individuals should be asked to enter consumption and energy use in exact amounts rather than selecting a category as it is important that the footprint can be re-calculated in the future and improvements tracked.
- The section for emissions from air travel should require the respondent to specify the distance flown rather than simply the number of flights taken.
- A link should be provided to a website which estimates the distance between airports to allow users of the tool to work out the distance of their flight.
- The tool should avoid using technical or ambiguous words which the general public may not understand as this could either lead to them wasting time trying to understand the meaning of the question, not answering the question or incorrectly understanding the question and answering inaccurately. Technical or overly complicated wording could also have the effect of turning people off the survey, especially given the specific target demographic of this tool.

6 Scope and methodology of the tool

Following the analysis conducted in Chapter 5 it was decided that a carbon footprint tool would be developed, building on the strengths of existing tools and adding the required functionality to analyse the fuel poverty levels and effects of alternative heating systems.

A number of methods of developing the tool were considered, including adding the functionality to the existing Edem tool, which is a tool for modelling the carbon emissions and energy consumption associated with buildings. Finally it was decided that the most appropriate method would be to develop an excel based tool. This allows the tool to be developed relatively quickly and still leaves the possibility that the functionality could be added to Edem at a later date, once the methodology has been clearly established and tested.

This chapter outlines the decisions made about the requirements of the tool, what should be included in it, and how the footprint should be calculated.

6.1 Requirements of the tool

The carbon footprint tool will build on the recommendations in Chapter 5.7.1 and should be based on the following requirements.

- The carbon footprint should be based on the definition outlined in Chapter 4.5. It should be measured in tonnes CO_2e and should be as complete as possible, taking into account:
    - Energy use in the home.
    - Travel, including by car, public transport and air.
    - Consumption of all goods and services.
- The tool should calculate the fuel poverty threshold income for each household.
- Model potential new heating systems to analyse how the footprint and fuel poverty threshold would be affected by installation of new heating systems.
    - User input cells should be included to allow this section to be fully customisable for use at different sites.
- Allow data for multiple people to be stored so that results can be analysed over the whole community.

6.1.1 Target users of the tool

The tool will be designed primarily to be used by housing associations, community groups or others who are looking to assess the impact of community heating schemes and who have some knowledge of current energy demands of the site but is flexible enough to be used in a variety of contexts.

For this project the tool is designed to analyse the heating systems at WWHC but includes user input cells which ensure that the tool can be fully customised for use at other sites. The aim is for the tool to be flexible enough for an expert with detailed knowledge of the requirements of a particular site to customise the design of the heating systems. A function will also be included that will allow users with less technical knowledge to scale the data up or down to give rough estimates for other sites.

6.1.2 Printable survey

The excel tool is aimed at members of staff but to facilitate the surveying of tenants a printable version should be produced. The answers from these surveys could then be fed into the calculator to calculate the carbon footprint.

The survey will ask the same questions as the carbon calculator but allow more flexibility in the way that questions are answered. There may be questions where the respondent may not know the full answer but may be able to provide the necessary information for the answer to be calculated. An example of this would be with travel, where the respondent may know that they travel by bus from West Whitlawburn to Glasgow but not know the distance. The questionnaire provides the space to write these details which can be used to calculate the distance later.

The full text of the questionnaire can be seen in Appendix 2.

6.1.3 Outputs of the tool

The main outputs of the carbon calculator are shown in Table 6. Some of the outputs are relevant to both existing and potential heating systems while others are relevant to only certain systems.

Table 6 Outputs from the carbon footprint calculator

With current heating system	**With alternative heating systems**
Carbon footprint of the individual	Carbon footprint of the individual
Average carbon footprint of the community	Average carbon footprint of the community
The individual's spending on energy	The individual's spending on energy
Fuel poverty threshold of the household	Fuel poverty threshold of the household
Fuel poverty status of the	Fuel poverty status of the

individual	individual
	Cost per unit of heat

6.2 Information about the respondent

The tool should start with a number of questions about the respondent which do not necessarily contribute to the carbon footprint calculations but which can be used either for analysis of the data or to provide information to the Housing Co-operative, such as the tenants opinions on the existing heating system or on fuel poverty in the neighbourhood.

A number of these questions will provide information that can be used to analyse the data and split it up into socio-economic groups, such as by age, income, family size etc. It is anticipated that certain groups will have higher carbon footprints than others, for example people who are retired, unemployed or have young families are likely to be at home more often so are likely to use more energy in the home which would contribute to a higher carbon footprint. It is also possible that households with higher incomes will consume or travel more, which could also lead to a higher carbon footprint. These questions will allow analysis of the data by these sub-groups and confirm if these assumptions are correct.

6.3 Methodology to calculate the carbon footprint

The carbon footprint calculations are based on the UK Government's greenhouse gas emissions factors published in 2009 (AEA 2009). This is an extensive list of emissions factors for both direct and indirect emissions. The emissions factors can be used to convert data about an activity, such as the number of miles travelled in a particular vehicle or the number of kWh of electricity used into kilograms of CO_2e produced.

All of the emissions factors used are for kg of carbon dioxide equivalent (CO_2e) and take into account carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). The emissions factors of each gas are weighted according to their Global Warming Potential relative to carbon dioxide according to the UK Greenhouse Gas Inventory.

The Global Warming Potential of nitrous oxide is 310 and for methane it is 21 (Intergovernmental Panel on Climate Change. 1996).

6.3.1 Grid electricity

The emissions factor used for electricity is 0.50238kg CO_2e/kWh which represents the average emissions of electricity from the national grid. This is based on the current generation mix and is independent of which company the electricity is bought from. Some carbon calculators give credit to individuals who purchase their electricity from companies such as Green Energy that produce electricity from only renewable sources but this can be misleading. The electricity produced by companies such as Green Energy has already been taken into account in the grid average so should not be double counted by reducing the footprint of the individual who buys it. It could be argued that this is unfair to those who make the effort to purchase their electricity from a supplier which uses a high proportion of renewable energy, but to take this into account it would be necessary to use a specific emissions factor for each energy supplier depending on their generation mix.

The emissions factor takes into account transmission and distribution losses of electricity but only includes the direct emissions from fuel burnt in power stations, ignoring the emissions associated with producing and transporting the fuel to the power station.

6.3.2 Direct emissions

Emissions from burning natural gas for heating or hot water are given in kg CO_2e per kWh of gas used.

For travel in private vehicles the emissions factors are available both in terms of emissions per litre of fuel used, or per mile travelled in different types and sizes of vehicle.

Emissions factors for public transport are for the kg CO_2e released per passenger km travelled.

6.3.3 Emissions from Air travel

The emissions factors used for air travel give the number of kg of CO_2e per passenger km travelled and are split into three categories, domestic, short haul and long haul flights. This is because during take off the engines are at full thrust and use a large amount of fuel. On short flights the fuel used at take off represents a larger proportion of the total fuel used and means that the fuel efficiency per mile flown is lower than on longer flights, where the fuel used at take off can be spread over a greater distance (Kollmuss & Bowell 2006). To help the user decide which category their flight comes under they have been named in the calculator as domestic flights, European flights and long haul flights.

The 2009 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting (AEA 2009) suggest multiplying all distances by an 'uplift factor' of 9% to take account of the fact that often planes can often be delayed or asked to circle before landing so the distance is often greater than expected. This should be done automatically by the carbon calculator.

The emissions factors are for the direct emissions of CH_4, N_2O and CO_2 from the fuel used for the flight based on average aeroplane occupancy levels however the actual impact that flying has on the climate are more complex than that. Aircraft generally fly at altitudes between 9000m and 13000m and at these altitudes the warming effects of the greenhouse gases are different and more complex to calculate than at ground level. The concept of radiative forcing is used to take into account these effects. Whilst there is still a great deal of disagreement on the issue, to take account of the effects of altitude as well as the effects of emissions such as water vapour and NOx it is currently recommended that a multiplication factor 1.9 is used (AEA 2009). The government emissions factors do not automatically include this multiplication factor as there is still no clear consensus on this factor. Despite the uncertainty it was felt that it would be misleading to only take into account the direct emissions as this would certainly underestimate the effect of flying so this multiplication factor has been used.

6.3.4 Indirect emissions

The emissions associated with consumption are an estimate of the emissions produced by other organisations in the provision of the relevant goods and services. These emissions factors represent the kg CO_2e produced per £ spent on the particular product.

The emissions factors are developed with input-output tables for the UK economy which record all interactions between different industrial sectors. These tables demonstrate the way that one particular sector of industry uses the goods and services produced by other sectors to produce their own product (AEA 2009). The input-output tables are combined with data about the direct emissions from each industrial sector and reallocated as indirect emissions as indirect supply chain emissions for end products. For example, the supply chain emissions of a newspaper would take into account all of the direct emissions produced by the companies which supply the paper, ink, printing presses as well as other companies which supply services such as hospitality or travel services. The emissions factors give the kg of CO_2 released per pound spent on a product (Dawkins et al. 2010).

The emissions factors are based on the price of a product in Pounds Stirling, excluding VAT. It is unrealistic to expect individual users to do the calculation themselves to remove VAT from the amount spent, so this will be done automatically by the carbon calculator. Most food is exempt from VAT and although there are a number of exceptions, mostly snacks such as crisps and ice cream, it would be too complicated to ask users to enter separately the amount spent on specific types of food for which VAT is applicable so it has been assumed for these calculations that food is VAT free. VAT has not been taken into account newspapers and books or for leisure activities as these are generally exempt from VAT.

7 Heating systems

7.1 Heating solutions for West Whitlawburn Housing Co-operative

In this section the options for upgrading the heating systems in West Whitlawburn will be discussed and compared. The reasoning behind the choices of heating system is based on the consultants' report into heating systems in WWHC (RSP Consulting Engineers 2009) which considered heat pumps, solar thermal and modular CHP in each building but due to the specific requirements of the site they were discounted as possibilities. These systems are discussed briefly, outlining why they are unsuitable before a more in depth discussion of the two favoured technologies; biomass district heating and gas powered combined heat and power district heating. The Housing Co-operative have already narrowed their choices down to these two options so these are the ones which will be investigated in this project.

Heat pumps

Both ground and air source heat pumps were seen as a potentially effective method of reducing both heating costs and CO_2 emissions however they were discounted as an option for WWHC as they do not meet the essential criteria that each dwelling should be individually billed. There is not the space available on site for individual heatpumps for each household and the consultants suggested that it would not be viable to individually meter households from a shared heat pump. Individual billing is seen as an essential criterion of the new heating system by the Housing Co-operative as they believe that this will encourage tenants not to be wasteful with their energy use.

Solar water heating

It was felt that solar thermal could make an important contribution to hot water requirements however with the roof space available it would not be capable of meeting the entire demand of the development. This system would also require a secondary heating system to further heat the water to the required temperature for central heating as well as to provide back-up when it can not meet demand. This was discounted as an option as it is felt that the entire heating and domestic hot water system requires replacing and this system is not capable of fulfilling that requirement.

Combined heat and power (per building)

Individual CHP units for each building were discounted as there is not sufficient space available to install a unit in the existing buildings.

Recommendations

The consultants recommended a district heating system powered by either a biomass boiler or gas CHP unit. The following sections look first at district heating in general and then at the specifics of both biomass and gas CHP heating.

7.2 District heating

A district heating scheme provides heat to a number of separate buildings or dwellings by pumping hot water through a heat distribution network of insulated pipes. A district heating network could supply an individual tower block or a whole housing development, an industrial unit or a site such as a hospital but they are most effective when supplying a combination of different types of buildings with different heat demand profiles which balance out to give a more constant demand for heat. District heating is especially effective in densely built up areas as it reduces the size of the heat network required, reducing both installation costs and distribution heat losses. Due to the high installation costs, which involve constructing an underground network of pipes between buildings, district heating is most cost effective when it replaces existing electric heating systems. This makes district heating very attractive for areas with a high density of high rise tower blocks, which are most likely to use electric heating.

The main elements of a district heating system are:

A central heat source

The water for a district heating system can be heated by any means, from burning fossil fuels in a conventional boiler, using a biomass boiler, a heat pump or a combined heat and power unit.

A heat distribution network

Heat is transferred from the source to the user via a network of insulated pipes. This can be a very simple pipe network for a district heating system which serves only one building or a much larger network that serves a whole town. There are different types of pipe which can be used but the simplest method is to use pre-insulated flexible pipes which can be laid directly in the ground and can also be curved around corners without requiring additional joints (RAUTHERMEX 2005). This is important as it is often at a pipe join where the largest heat losses occur if it is not well installed.

Equipment in individual homes

A district heating system can use conventional radiators for domestic heating, so for dwellings which already have radiators installed they can often be left inplace, thus reducing the installation costs. Where a heat pump is used to supply the heat, larger radiators would be required due to the lower water temperature achieved using heat pumps. Where electric bar or fan heaters had previously been used a new radiator system would need to be installed in the building.

If dwellings are individually billed, as would be the case in WWHC, then it is also necessary to install heat meters in each home to track the amount of heat used.

7.2.1 Benefits of district heating

The main benefit of a district heating system is that it allows the heating systems to be upgraded to a more efficient heating method. It is not possible to install individual gas boilers in the WWHC buildings and in many others like them around the country so there are limited options available for upgrading the old electric heating systems.

The actual benefits of the system depend on the method used to generate the heat, and the two options for WWHC are discussed in more detail in the following sections. Where a district heating system is used to replace existing electric heating, as would be the case in West Whitlawburn, the benefits, both economic and in terms of CO_2 emissions can be significant irrespective of whether the heating system is based on gas CHP or a biomass boiler.

Once a heat network has been installed it is relatively simple and cost effective to change the heating method in the future without having to change all of the equipment in individual homes. For example if a gas CHP system is installed now, it could be upgraded to a biomass CHP system relatively easily in the future when the technology has become more cost effective and better established.

7.2.2 Disadvantages of district heating

Despite advances in the thermal insulation of water pipes, there are still significant heat losses associated with transporting hot water over long distances in pipes. These losses need to be taken into account when assessing the quality and cost of fuel, as well as the size of heat generation system required. The heat losses are discussed in more detail and modelled in Chapter 8.2.

Another problem with district heating is that the system must be ‘always on’. This implies that hot water must be flowing through the pipes at all times, even if only one household needs heat. This increases the heat loss from pipes and is taken into account in the heat loss calculations mentioned above. If a large accumulator tank is used to store the hot water then the heat generator does not necessarily have to run at all times as water can be taken from the accumulator tank. The pumps do need to be running at all times however and electricity required for this must be taken into account.

There will be administrative costs associated with managing the system and billing the tenants and these costs must be covered by the heat cost charge to tenants. These costs are discussed for West Whitlawburn in Chapter 8.3.5.

7.3 Biomass

Biomass is material made up of living, or recently living organisms, usually from plant based material. There are three main types of biomass suitable for energy generation:

- **Wood** Either from coppiced forest, prunings from parkland and gardens, sawmill by-products or waste wood. Willow is often used for coppicing due to its speed of growth and has a high calorific value.
- **Energy crops** These are crops such as miscanthus which are grown specifically for energy generation as they have a high yield and high calorific value.
- **Waste and industrial bi-products and agricultural residues** These can be either from municipal waste collected from households, waste or by products from industry, such as spent grain from the brewing process or agricultural residues such as straw.

(Biomass Energy Centre 2009)

7.3.1 Woody biomass

Given the large resource of wood available in Scotland, wood is the most realistic biomass fuel type for this site. Wood is generally available in one of three forms, woodchips, pellets or logs and these are discussed below.

Logs

Logs are generally suitable for small scale or domestic heating systems up to around 50kW and have not been considered as a suitable fuel for this system (Forestry Commission Scotland 2010).

Pellets

Pellets are made of compressed woodshavings and sawdust. The major advantage of pellets is that because the wood is compressed they have a higher calorific value than normal wood and therefore require less storage space. As the manufacturing process is more intensive and requires more energy than that of woodchips their cost is also considerably higher, at around £150 per tonne (Forestry Commission Scotland 2010).

Woodchips

Woodchips are made by shredding branches and trees in a machine to produce small chips of wood which can be easily handled and automatically fed into a biomass boiler. There is a large resource of wood in Scotland and although this is not currently very developed, as biomass energy generation becomes increasingly common it is likely that woodchips will become more readily available.

Woodchips are a relatively bulky fuel and require considerable storage space, however they are very cost effective at around £80 per tonne for wood with a 30% moisture content (Forestry Commission Scotland 2010). As space is not an issue at West Whitlawburn and cost is perhaps the most important factor, woodchips are recommended as the most suitable biomass fuel for WWHC.

Figure 6 shows how the energy content of wood varies with moisture content as calculated by Equation 1. Whilst biomass boilers are available which can handle woodchips with a wide range of moisture contents it is generally advisable to use chips with a moisture content of below 35%. At a moisture content of 30% wood has a calorific value of 11.66GJ/tonne. All calculations in this thesis are based on wood with a moisture content of 30%.

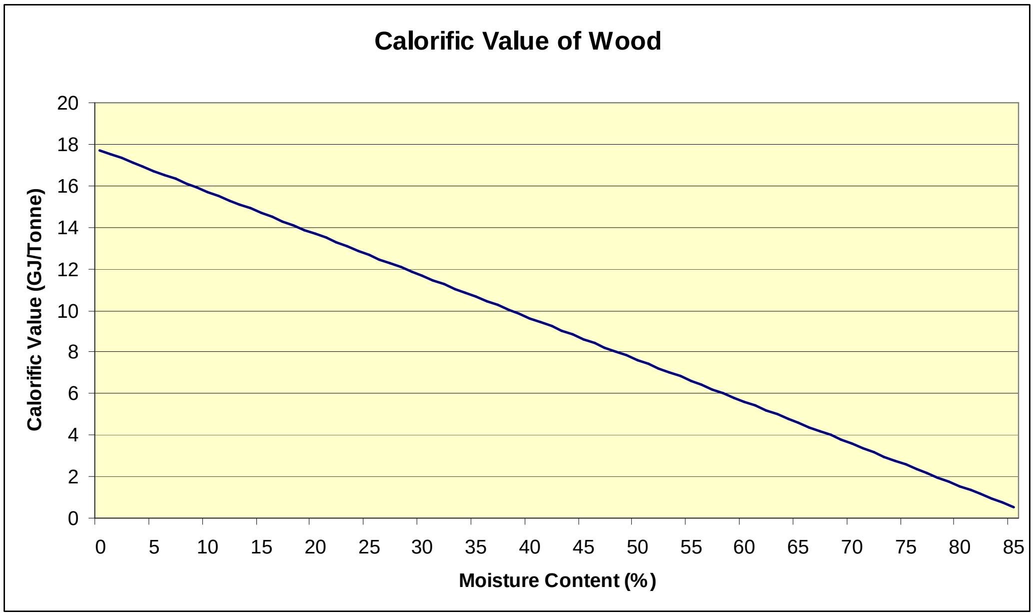


Figure 6 Calorific Value of wood

Equation 1

$$Calorific\ Value\ of\ Wood = 17.7283 - (0.2021 \times Moisture\ Content)$$

Source: (Forestry Commission Scotland 2010)

7.3.2 Biomass heating

Biomass can be converted into either electrical or thermal energy. The simplest is to produce heat by simply burning the biomass, either on its own or co-firing it with other fuels such as coal. Figure 7 shows how the heat can be extracted from a biomass boiler by passing water through a heat exchanger (The Royal Commission on Environmental Pollution 2004).

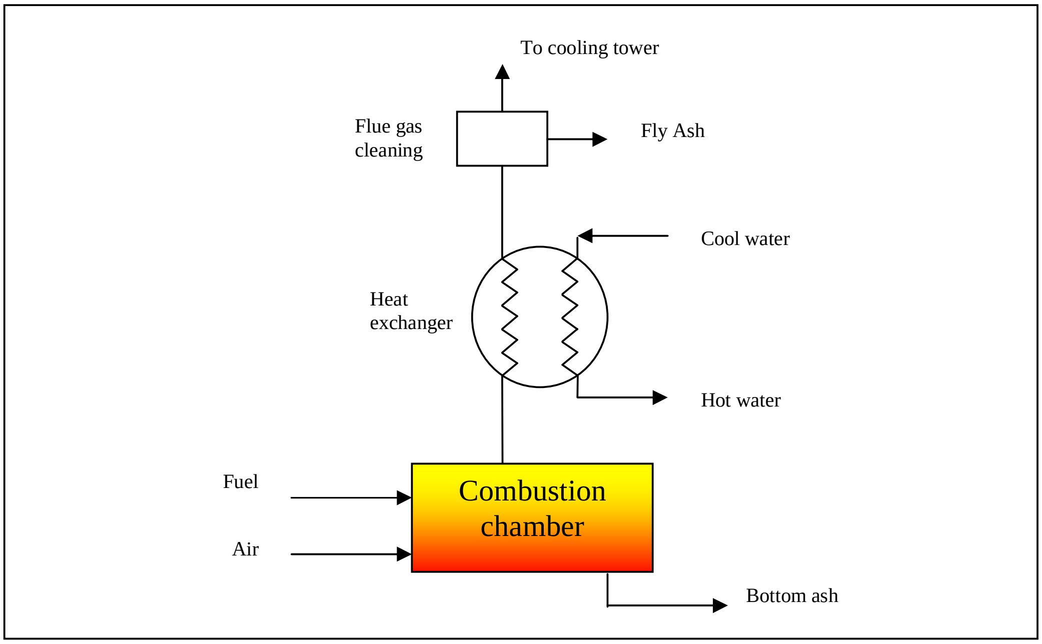


Figure 7 Biomass boiler

Source: (The Royal Commission on Environmental Pollution 2004).

A biomass boiler can be around 90% efficient and is most efficient when working at a full load. To ensure that the boiler is run at maximum efficiency an insulated accumulator or buffer tank is generally used. When the heat demand is below the peak output of the boiler, the water is stored in the tank until it is required. When the tank is full the boiler can be switched off and the heat supplied by the water stored in the tank. This allows the boiler to be run efficiently at full load until the buffer tank is full and then switched off until the buffer tank runs down to a predefined level.

7.3.3 CO_2 impact of biomass

Biomass is often considered to be 'carbon neutral' as the carbon dioxide emissions that are released when it is burnt were absorbed during its growth. If biomass is taken from a sustainable source then more trees will be grown to replace the ones that have been burnt and ensure that the carbon cycle continues. Despite this carbon cycle it is false to assume that biomass is carbon neutral as there are further CO_2 emissions associated with the growth, harvest and transport of the fuel which must also be taken into account. The Department for Energy and Climate Change suggest a carbon emissions factor of 0.01579kgCO_2e/kWh for woodchips to take into account these factors. This still represents and enormous saving over most other fuels, with natural gas having an emissions factor of 0.204 kg CO_2e/kWh and electricity 0.544kg CO_2e/kWh respectively (BRE 2009). Gas boilers are generally used as back up and to meet the peak demand, so the emissions from this must also be accounted for.

7.3.4 Economics of biomass

Using woodchips, biomass can be a very cost effective heating method. At a cost of £80 per tonne of wood chips with a 30% moisture content this gives a cost of 2.7p/kWh, which compares very favourably with the cost of electricity and is similar to that of natural gas. The cost of woodchips is likely to vary by region as well as supplier and the value of £80 which has been used in these represents a high estimate. Even using this upper estimate value, this would still represent a significant saving over the cost of the current electric heating systems in WWHC.

It is also important to take into account the capital costs of the system and this is especially important for district heating due to the high cost of the heat distribution network. This cost can has a very significant effect on the cost per unit of heat which must be charged to the tenants.

Renewable Heat Incentive

The UK is due to launch the Renewable Heat Incentive in April 2011 which will pay a fee for every kWh of heat produced by the specified heat generation methods. This is based on the Feed In Tariff which already exists for electricity generated by renewable methods and is designed to encourage and promote the uptake of renewable energy systems for heat generation such as heat pumps or biomass boilers. The tariff paid will depend on the size of the generation unit and for biomass boilers is split into three different categories of small, medium and large and the tariff for each size are show in Table 7.

Table 7 Renewable heat incentive sizes and tariffs

Size	Scale	Tariff (pence/kWh)
Small	0-45kW	9
Medium	45-kW-500kW	6.5
Large	500kW+	1.6-2.5

The Renewable Heat Incentive will not be included in the cost benefit calculations as it has not started yet and doubts remain over whether or not it will definitely go ahead as planned but it is worth ensuring that the system qualifies for the best tariff possible. There is a significant difference between the tariffs paid for the three boiler sizes and this would become a very important factor in the design of a heating system as a boiler that falls into one of the lower categories would be much more financially viable than a slightly bigger boiler earning a lower tariff.

7.4 Gas combined heat and power

Combined heat and power is a process that simultaneously generates electricity and useful heat from the same source. Conventional electricity generation typically ranges from 30% efficiency for a coal fired power station to around 50% for the best gas fired turbine, with the remaining 50-70% of the energy wasted, mostly as heat. With combined heat and power systems this heat is captured and used for domestic heating and hot water or for industrial processes. A typical CHP system might have an electrical efficiency of 30% and a thermal efficiency of 45%, giving a total efficiency of 75%.

It is possible to use a variety of fuels ranging from biomass to natural gas or even coal in a CHP system. Where a solid fuel is used a conventional steam turbine would be used to power the generator, however this is only economically feasible for systems with an output of over 1MWe, which would not be the case in West Whitlawburn. For smaller scale systems a gas generator is a more appropriate. It is possible to convert biomass fuels such as wood chips for use in a gas generator using a gasification process where air is blown through the fuel to create a combustible gas. This gas, which is mostly made up of carbon monoxide and hydrogen, can then be used as the fuel in the same way as natural gas to produce both electricity and heat (The Royal Commission on Environmental Pollution 2004). This process has not been considered in this case as it is still relatively new and commercially untested technology in the UK. Housing Associations are not generally in the position to invest large amounts of money in untested technologies as it would represent a significant risk and would not be easy to find funding for.

7.4.1 CO_2 impact

Natural gas remains the most appropriate fuel for smaller scale CHP systems such as the one envisioned for WWHC. Whilst gas powered CHP is neither a renewable energy source or a low carbon technology like biomass it can still offer significant carbon dioxide savings over many other methods of generating electricity and heat. In the case of WWHC a gas powered CHP system has the potential to produce significant CO_2 savings as it would be replacing an old and inefficient electric heating system. The actual CO_2 savings from a CHP system that can be associated with an individual household depend on how the electricity produced by the unit is used. Three possible scenarios are outlined below:

- If the electricity is exported to the grid then only the savings associated with the heat can be attributed to the individual household and the emissions associated with the electricity will be taken into account in the carbon intensity of the national grid.
- If the electricity is used for the landlord services, the emissions savings would be attributed to the Housing Co-operative but not directly to the individual households.
- The third option is that the electricity is sold directly to the households, in which case the emissions savings could be attributed to the households. For this to work it would be necessary to have a direct connection to the households so that the electricity would not have to pass through the National Grid to get to them, otherwise the savings would have to be incorporated into the grid intensity.

7.4.2 Economics

The potential financial savings depend on the type of system that is being replaced. In the case of West Whitlawburn where electric heating is currently used, the savings could be considerable.

The real financial benefits of a CHP system are associated with the electricity. The ideal situation is where all electricity is be used on site, in which case the price of the grid electricity that it replaces can be offset against the fuel costs of the whole system, making the heat very inexpensive.

7.4.3 Case study – Stockethill Combined Heat and Power

This case study shows how CHP has the potential to make a large impact on energy costs and CO_2 emissions when replacing electric heating in tower blocks similar to those in WWHC.

In 2002 Aberdeen City carried out a study to investigate the possibilities for replacing the existing electric storage heating in their blocks of flats. The three main requirements of a new heating system where that it must:

- reduce the building's carbon footprint
- be affordable to install
- reduce fuel bills for the tenants and as a result reduce fuel poverty levels

(Energy Saving Trust 2008)

The recommendation of the report was to install a number of combined heat and power (CHP) units, each of which would supply district heating to a number of blocks of flats. To administer the CHP units the council set up a not-for-profit energy service company (ESCO) called Aberdeen Heat and Power Co Ltd (The Scottish Government 2009)

A CHP system was installed in Stockethill supplying a group of four blocks of flats containing a total of 288 flats, of which 98% were owned by the council. The flats had originally been heated by electric storage heating (Energy Saving Trust 2008) and tenants would pay up to £15 per week for heating and an average of £3.48 per week for power (The Scottish Government 2009) which left 70% of the tenants living in fuel poverty (Energy Saving Trust 2008).

A 210kWe gas fired reciprocating engine CHP unit was installed, along with two 700kWth gas fired boilers to provide back up to the system and to meet the peak load. An underground heat distribution network of pre-insulated pipes was installed to deliver the heat to the four blocks of flats and the tenants were also given the option to buy their electricity from Aberdeen Heat and Power, with the any excess exported to the National Grid (The Scottish Government 2009).

With the new system installed, tenants paid a flat rate of £4.75 per week for heat and hot water for 48 weeks per year and for tenants who bought their electricity from Aberdeen Heat and Power paid £3.06 on average for power (The Scottish Government 2009).

The CHP system achieved the three objectives by significantly reducing the CO_2 emissions whilst lifting all tenants out of fuel poverty. The system was affordable, with a total capital cost of £1.84million, with 40% of the cost met by a grant from the Energy Saving Trust (The Scottish Government 2009).

7.5 Impact on fuel poverty and carbon footprint

A district heating system powered by either gas CHP or a biomass boiler is likely to be considerably lower cost and have lower emissions than the current electric heating but it is necessary to model the systems in detail to determine which will be the most suitable system for this development. This is carried out in Chapter 8.

8 Design of the heating systems

The biomass district heating and gas CHP systems discussed in Chapter 7 are modelled automatically by the carbon calculator tool, with the user required to enter a few pieces of data and this chapter details the equations and methodology behind this section of the tool.

The first step is to model the different sized flats in WWHC to calculate the energy consumption required for each one to maintain an satisfactory heating regime as outlined in the definition of fuel poverty.

After that the heat loss from the heat distribution network and storage systems can be modelled by calculating the pipe sizes required and carrying out heat loss calculations for these pipes. This is followed by an analysis of the two heating systems; a biomass boiler and gas CHP district heating.

8.1 Modelling of dwellings

As fuel poverty levels are based on a theoretical spending on energy requires to maintain a satisfactory heating level it is necessary to model the dwellings to determine what this theoretical energy consumption would be. The dwellings in WWHC were modelled using the Edem tool developed by the University of Strathclyde (Energy Systems Research Unit 2008). The flats were modelled based on three different sizes, outlined in Table 8.

Table 8 Floor area of flats

Lat type	Floor area (m^2)
1 bedroom	54.4
2 bedroom	76.5
3 bedroom	82.3

The U-values used in the modelling process are listed in Table 9 and are based on data supplied by the WWHC.

Table 9 U-values of flats

	U-value (W/m^2K)
Glazing	2.00
Roof	0.16
Floor	0.70
Wall	0.27

Further data used in the modelling is shown below:

Ceiling height 2.5m

No wall cavity

Climate: UK standard

HT demand: Scottish standard

HW demand: Scottish standard

Appliances: Standard

Table 10 shows the occupancy levels that Edem bases it's calculations on and work out as 9 hours in every 24 hours during the week and 16 hours every 24 hours during the weekend. These occupancy levels correspond to the definition of fuel poverty outlined in Chapter 3.1. The program will model the energy required to maintain a temperature of 21°C in the living room and 18°C in other rooms during these hours, even if this may not correspond to the actual temperature or hours of occupation in the real flats in WWHC.

Table 10 Occupancy levels

Day	Occupied between
Weekday	7am-9am and 4pm-11pm
Weekend	7am-11pm

The results of the modelling are shown in Table 11, Table 12 and Table 13 for the three different sizes of flats.

Table 11 Energy consumption of a one bedroom flat

	kWh/annum
Heating	3975.5
Hot water	1765.8
Electricity (lighting and appliances)	1566.7

Table 12 Energy consumption of a two bedroom flat

	kWh/annum
Heating	5584
Hot water	2119
Electricity (lighting and appliances)	2203

Table 13 Energy consumption of a three bedroom flat

	kWh/annum
Heating	6005
Hot water	2205
Electricity (lighting and appliances)	2369

8.2 District heating network

8.2.1 Heating network layout

The district heating network will supply the six tower blocks and five low rise blocks. The pipework has been divided into three pipe types; the main pipework underground connecting each building to the heat source and smaller indoor pipes in each building connecting each flat to the main heating network.

Underground pipes

The design of the underground network is shown in Figure 8. The network was split into six sections to estimate the total length of pipework required and these lengths were estimated using the measurement tool on Google Earth (Google Inc. 2010). The separate sections are numbered in Figure 8 and the Table 14 lists the length of each section. This length is then doubled to take into account the return pipe.

Figure 8 District heating network

Table 14 Underground pipe lengths

Section	Length (m)
1	170
2	190
3	130
4	20
5	120
6	50
Total	680
Total pipe length including return pipe	1360

Indoor pipes

The indoor pipework for each tower block is estimated based on a vertical pipe running up the centre of the building, with three metres of horizontal pipe to connect each individual flat to the main pipe. The district heating pipework does not take into account any pipework with in the household as this is already installed and any heat loss from pipework within the household is already taken into account in the heat load calculations. As shown in Table 15, each tower block is 13 stories high with 72 flats per tower, each tower will require 250m of pipework.

Table 15 Indoor pipework in tower blocks

	Length of vertical pipe (m)	Length of horizontal pipes (m)	Total pipe length (m)
Per tower block	34	216	250
Total for six blocks	204	1296	1500

The low-rise blocks are based on a different design, two flats per stairwell on each floor and, depending on the size of the block there are between two and four stairwells per block. The pipe length is based on a vertical pipe in each stairwell and four metres of pipework on each floor to connect to each pair of flats. Table 16 shows the required lengths of the indoor pipework for the lowrise buildings in more detail. To simplify the calculations the horizontal and vertical pipe sections are treated identically in the heat loss calculations.

Table 16 Indoor pipe work in low-rise blocks

	Length of building	Number or vertical pipes (m)	Length of vertical pipe (m)	Length horizontal pipes (m)	Total (m)
Belmont Road a	40m long	2	21	32	53
Belmont Road b	40m long	2	21	32	53

Clifton Terrace	80m long	4	42	64	106
Hilton Terrace	60m long	3	31.5	48	79.5
Albany Terrace	60m long	3	31.5	48	79.5
Total pipe length			147	224	371

8.2.2 Pipe diameter

The carbon calculator can be used to calculate the pipe diameter required for the district heating network. The calculator is based on the following calculations and requires the user to enter the peak heating load, the water flow temperature and the water return temperature. The density and specific heat capacity are entered as a default for water at 50°C. These two values can be changed by the user however it will not significantly affect the result if they are left at the default value as they do not vary significantly within the likely range of water temperatures used for district heating.

To calculate the required pipe diameter Equation 2 is first used to calculate the mass flow rate of water required to meet the peak heat flow rate.

Equation 2

$$q = \frac{h}{c_p \rho dt}$$

Where:
q=volumetric flow rate
h=heat flow rate
c_p=specific heat capacity
ρ=density
dt=temperature difference
(The Engineering Toolbox 2005a)

The peak heat demand was estimated to be 1572kW by the consultants report (RSP Consulting Engineers 2009). At the average water temperature of 50°C the density, ρ, of water is 988.14kg/m^3 and the specific heat capacity, $c_{p,}$ of water is 4.182kJ/kgK (Rogers & Mayhew 2002).

The temperature, dt, is the difference between the water flow temperature, 60°C and the water return temperature, 40°C, and is therefore equal to 20°C. Using these values in Equation 2 gives:

$$q = \frac{1572}{4.182 \times 988.14 \times 20}$$

$$q = 0.01902 m^3 / s$$

At a density of 988.14kg/m^3 and with 1kg of water equal to 1 litre, this is equivalent to 18.79l/s. The engineering toolbox (The Engineering Toolbox 2005b) recommends a water velocity of around 1.5m/s in water pipes.

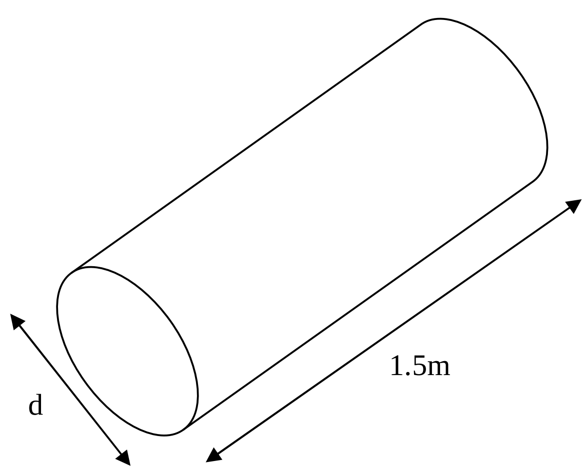


Figure 9 Calculating the pipe diameter

To calculate the required pipe diameter the first step is to calculate the volume of pipe required to hold 18.79l/s for one second if it is travelling at a velocity of 1.5m/s. Figure 9 shows the pipe volume required and this can be used, along with Equation 3 to calculate the required pipe diameter.

Equation 3

$$\textit{Enclosed volume of pipe} = \pi r^2 L$$

Entering the relevant data into Equation 3 gives:

$$0.01902 = \pi r^2 \times 1.5$$
$$r = \sqrt{\frac{0.01902}{1.5\pi}}$$
$$d = 0.127m$$

This shows that a pipe diameter of 127mm will be required for this flow rate. The pipes used in this modelling exercise are supplied by Rauthermex and once the required pipe size has been calculated the most appropriate pipe can be selected from their catalogue (RAUTHERMEX 2005). In this case the closest match is the 125/182 pipe from the 'UNO pipes, pipe series 1, SDR 11' series which has diameter of 125mm.

Smaller pipes can be used inside the buildings as they do not need to carry the same quantity of water. The required pipe size was estimated by calculating the average heat demand per flat at peak heating load of 1572kW. With 544 households this works out as an average of 2.80kW per flat. As the pipes in the Tower blocks will feed 72 flats each, the peak heat demand per towerblock can be estimated at 207.3kW. In the low rise buildings each pipe will only be required to feed 8 flats, which works out to a peak heating load of 23.0kW. Using the method outlined above the pipes chosen for the tower blocks are the UNO 40/91 pipes, with a carrier pipe diameter of 40mm, while the UNO 25/91 pipes, with an pipe diameter of 25mm were chosen for the low rise buildings.

The various pipe dimensions are outlined in Table 17.

Table 17 Pipe dimensions

Pipe section	Pipe length (m)	Pipe diameter (mm)
Underground	1360	125
Low rise	742	25
High rise	3000	40

These calculations will be done automatically in the carbon calculator tool, with the user required to input relevant data and the tool would output the required pipe length for example a number will output a required diameter of 127mm for this pipe. A database of actual pipes manufactured by Rauthermex (RAUTHERMEX 2005) is included and the user can then refer to this data to find the corresponding pipe.

8.2.3 Distribution losses

The heat losses from the pipe network can be calculated by applying Fourier's Law, shown in Equation 4, to the cylinder of the pipe. Using this with the cylinder shown in Figure 10 gives Equation 5.

Equation 4

$$Q = -kA\frac{\partial T}{\partial x}$$

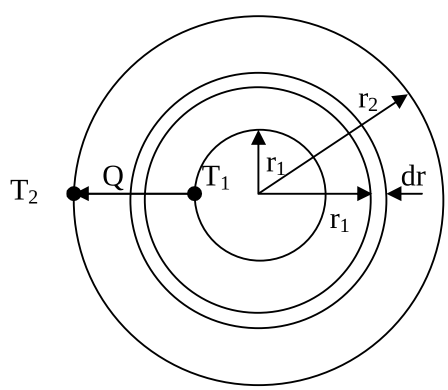


Figure 10 A simple cylinder

Equation 5

$$Q = \frac{2\pi k_a L(T_1 - T_2)}{\ln \frac{r_2}{r_1}}$$

8.2.4 Composite cylinder

The pipes used for district heating are pre-insulated and more complex than the simple pipe shown in the previous section. Figure 10 shows the layout of a composite cylinder with r_1 representing the inner radius of the pipe, r_2 the outer radius of the pipe and r_3 the outer radius of the insulation. As the heat transfer rate, Q, is constant through each layer,

Equation 5 can be applied to each layer in turn which, for the composite cylinder shown in Figure 11 would give The heat loss through the pipe layer is calculated with Equation 6.

Equation 6 and Equation 7 for the inner pipe and the insulation respectively.

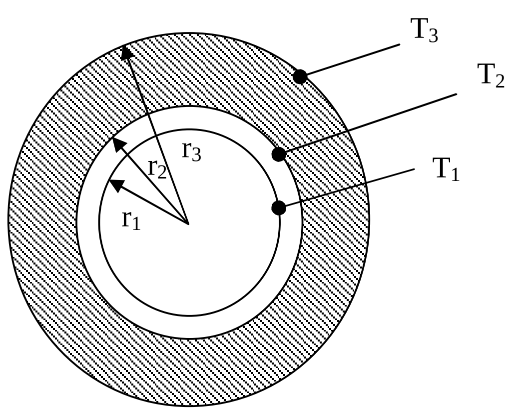


Figure 11 Composite cylinder

The heat loss through the pipe layer is calculated with Equation 6.

Equation 6

$$Q = \frac{2\pi k_a L(T_1 - T_2)}{\ln \frac{r_2}{r_1}}$$

The heat loss through the insulation layer is calculated with Equation 7.

Equation 7

$$Q = \frac{2\pi k_b L(T_2 - T_3)}{\ln \frac{r_3}{r_2}}$$

T_2 can be eliminated from the calculation by adding The heat loss through the pipe layer is calculated with Equation 6.

Equation 6 and Equation 7 together to give Equation 8, which shows the full heat transfer through the two layers.

Equation 8

$$Q = \frac{T_1 - T_3}{\frac{\ln \frac{r_2}{r_1}}{2\pi k_a L} + \frac{\ln \frac{r_3}{r_2}}{2\pi k_b L}}$$

T_1 is the temperature of the inside of the pipe and this is assumed to be the same as the water temperature in the pipe. Whilst the ambient temperature around the pipe mat be known, this is not the same as T_3, the temperature of the outside of the pipe. The ambient temperature is likely to be lower than the temperature of the outside of the insulation, T_3, so the total heat transfer coefficient must also take into account the heat transfer from the outside of the insulation to its surroundings. There are two different scenarios to be considered, the first is for underground pipes which are in direct contact with the surrounding soil so will also face conductive heat losses through the soil. This is discussed in Chapter 8.2.5. The second scenario is the indoor pipes which are surrounded by air and will be subject to convective and radiative losses to the air, which is discussed in Chapter 8.2.6.

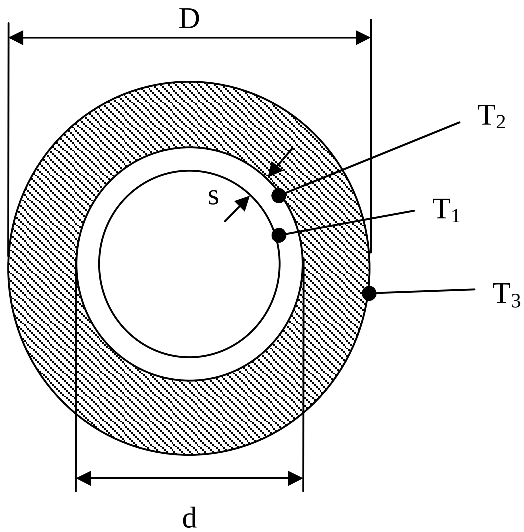


Figure 12 Pipe diameter

The following assumptions are made in the calculations of heat loss from the pipes:

- The calculations are based on the manufacturer's data. This data will represent the best case scenario from laboratory tests and the actual performance is likely to be inferior.
- Pipe lengths are based on the estimated lengths outlined in Chapter 8.2.1 and may differ from the final design of the heat network.
- The calculations are based on a straight line pipe which will be reflect the actual situation in most cases. The calculations are based on a 'flexi-pipe' which can be bent around corners which means that pipe joins will not be required at corners.
- Although the heat loss of curved sections of the pipe would not be identical to that of straight pipes, it would be impossible to model this without a detailed pipe network designed so it has been assumed that heat loss is uniform along the entire length of the pipe.
- The calculations treat the system as a 'full flow' system, where hot water is flowing in the pipes at all times. In reality the water flow will vary with demand and there may not be water flowing in all pipes at all time during the summer, however it would add an unnecessary level of complication to the calculations to take this into account.
- To take into account the potential for higher heat losses through pipe joints as well as the fact that the manufacturer's data represents a best case scenario, the total

heat loss has been increased by a factor of 15% to ensure that heat losses are not underestimated.

- The estimated pipe length has been doubled for all sections take into account the need for a return pipe.

8.2.5 Underground pipes

The underground pipes are designed to be buried 60cm below the ground. The ambient temperature of the soil is assumed to be 10°C with a thermal conductivity of 1.2W/mK (RAUTHERMEX 2005). The temperature of the soil close to the pipe will be slightly raised by the heat from the pipe so to resolve this a layer of soil is treated as a further layer of insulation with a thickness of 0.6m, as shown in Figure 13, with temperature T_4 at the outside of this layer of soil assumed to have a temperature of 10°C, the same as the ambient soil temperature. This means that an extra layer must be added to the total heat transfer calculation, which gives Equation 9.

Equation 9

$$Q = \frac{T_1 - T_4}{\frac{\ln\frac{r_2}{r_1}}{2\pi k_a L} + \frac{\ln\frac{r_3}{r_2}}{2\pi k_b L} + \frac{\ln\frac{r_4}{r_3}}{2\pi k_c L}}$$

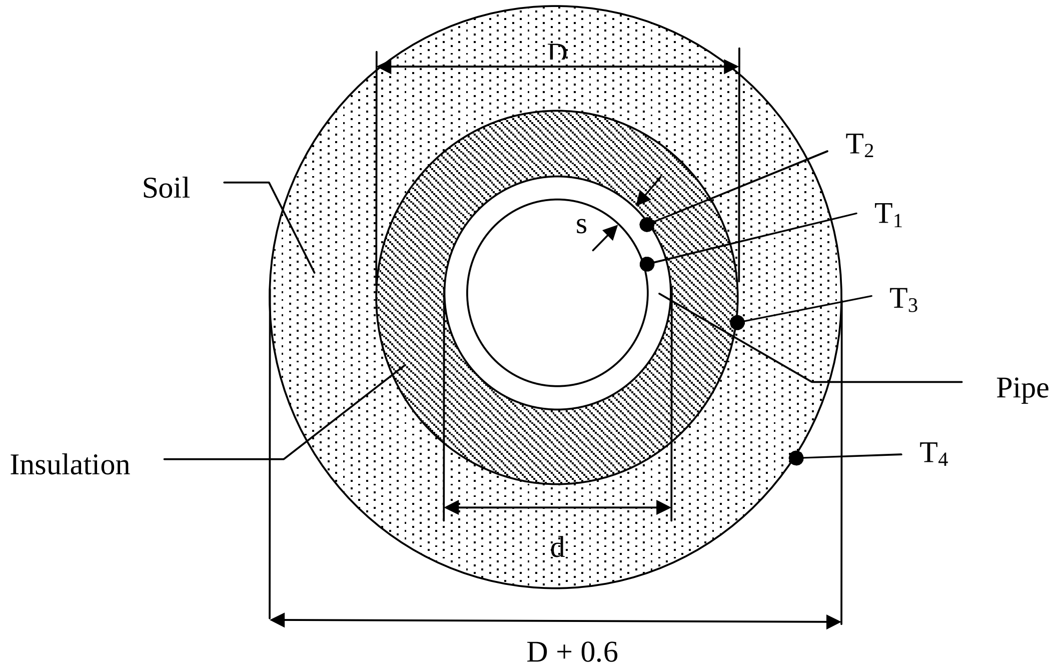


Figure 13 Underground pipes

Table 18 shows the values that were entered into Equation 9 and used to calculate the heat loss from the underground pipes. The result was a heat loss through these pipe sections of 270MWh per year.

Table 18 Values used in calculations of heat loss from underground pipes

Symbol	Value
T_1	50°C
T_2	10°C
R_1	102.2mm
R_2	125mm
R_3	184mm
R_4	784mm
L	1360m

k_a	0.38W/m^{2}k
k_b	0.032W/m^{2}k
k_c	1.2W/m^{2}k

8.2.6 Indoor pipes

To calculate the total heat transfer coefficient the convection and radiation heat transfer coefficients from the outside of the pipe to the ambient air must be taken into account. This is shown in Equation 10. In reality the radiation heat transfer coefficient, h_{R2}, can be ignored as it is very small at these temperatures.

Equation 10

$$Q = \frac{T_1 - T_4}{\frac{\ln \frac{r_2}{r_1}}{2\pi k_a L} + \frac{\ln \frac{r_3}{r_2}}{2\pi k_b L} + \frac{1}{(h_2 + h_{R2})A_o}}$$

The convective heat transfer coefficient h_2 was estimated using the Passive House Planning Package (Feist 2007), which estimates a value of 6.23W/m^{2}k for the low rise pipes and a value of 6.50W/m^{2}k for the tower block pipes. To simplify the calculations a value of 6.5W/m^{2}k was used for both pipes. A sensitivity study was carried out on the value of h_2 to ensure that using this estimated value will not affect the results adversely. Table 19 shows the results of the sensitivity study based on the heat loss from the indoor pipes in the tower blocks and demonstrates that increasing h_2 makes little impact on the annual heat loss. Even increasing the value of h_2 to 1000W/m^{2}k only increases the annual heat loss from theses pipes by 12.5%. Reducing h_2 has a more significant effect on the annual heat loss, for example when h2 is equal to 2W/m^{2}k the annual heat loss is reduced to 177.9MWh. Using a value of 6.5W/m^{2}k is an acceptable approximation for this model as it is considerably more likely to over estimate than an underestimate the heat losses.

Table 20 shows the values used to calculate the heat loss from the indoor pipes. The calculations are based on an ambient temperature of 15°C, which reflects the fact that the pipes are inside, but may be located in a stairwell or lobby so will be lower than the 21°C temperature inside homes. Based on these values, the total annual heat loss from the pipes in the low rise buildings is 41MWh and in the tower blocks it is 250MWh.

Table 19 Convective heat transfer coefficient sensitivity study

Convective heat transfer coefficient (W/m^2k)	Total heat transfer coefficient (W/m^2k)	Total annual heat loss (MWh)
1	0.1312	138.0
2	0.1693	177.9
3	0.1873	196.9
4	0.1979	208.1
5	0.2049	215.3
6	0.2098	220.5
6.5	0.2117	222.5
7	0.2134	224.3
8	0.2162	227.3
9	0.2185	229.7
10	0.2203	231.6
100	0.2363	248.4
1000	0.2381	250.3

Table 20 Calculation data for indoor pipes

Symbol	Values for tower block pipes	Values for low rise pipes
T_1	50°C	50°C
T_2	15°C	15°C
R_1	32.6mm	20.4mm
R_2	40mm	25mm
R_3	93mm	93mm
L	3000m	742m

k_a	0.38W/m^{2}k	0.38W/m^{2}k
k_b	0.032W/m^{2}k	0.032W/m^{2}k
h_2	6.5W/m^{2}k	6.5W/m^{2}k

8.2.7 Total heat loss from pipes

Table 21 shows the total heat loss from the distribution network, with the total increased by a factor of 15% to ensure that the losses have not been underestimated.

Table 21 Total heat loss from pipes

Pipe section	Annual heat loss (MWh)
Tower blocks	250
Low rise	41
Underground	271
Total including 15% extra	646

The total heat loss of 646MWh per year represents 10% of the total heat demand of the site which fits exactly with the recommendation in SAP 2009 (BRE 2009) to assume a heat loss from the heat distribution network or 10% of the total heat demand.

8.2.8 Further losses

Storage losses

The storage losses from the accumulator tank are estimated using the heat loss factor of 0.0152kWh/litre/day recommended in SAP 2009 (BRE 2009). This is based on an accumulator tank of 60000 litres and assuming that the tank is full at all times. During times when the tank is not full this will be an over estimate of the losses however this is preferable to underestimating the potential losses.

The total annual losses from the accumulator tank for this system are calculated to be 194MWh.

Energy from pumping

Whilst not technically a loss, the electricity required for pumping the water around the district heating network must also be taken into account. SAP 2009 (BRE 2009) estimates that electricity used for pumping is equal to 1% of the energy required for heating and hot water. This estimate has been used and in this case this requires 63MWh of electricity.

8.3 CHP

8.3.1 Design

As discussed in Chapter 7.4, the size of a CHP unit is limited by the heat demand at the site. It is usually recommended that a CHP system powers buildings with a variety of uses, such as a combination of residential and industrial buildings to ensure that the heat demand is relatively constant. In the case the system will be linked only to residential buildings and the relatively small heat demand from the landlord services so is important that the unit is not oversized or heat will be wasted during summer.

The design of the CHP system should be based on carefully monitored energy consumption profiles of the whole development to ensure that it is the appropriate size for the site. In this study such detailed data was not available so the analysis is based on energy demand profiles provided by modelling programs. The system is designed to meet 50% of the annual heat demand, which would require a 358kWthermal system. The Jenbacher J208 GS gas engine is recommended in this case. It can be run with an electrical power of 294kWe and thermal power of 395kWth or, most appropriately for this development, with an electrical power of 330kWe and a thermal output of 358kWth.

The system is designed to run at full load throughout the year. Electricity generated by the unit will be used for the landlord services with any surplus exported to the National Grid.

By running the system on full load all year it is likely that some heat will have to be wasted during the summer months when the heat demand is reduced, but it is likely that it would still be beneficial to run the unit at full load at these times to benefit from the lower cost and less carbon intensive electricity that can be generated.

8.3.2 Modelling the system

The CHP system was modelled using the Merit program which is a supply matching program developed by the University of Strathclyde. The program which can be used to match the energy supplied by renewable energy systems with the demand profile of buildings or groups of buildings. Merit includes a number of predefined energy profiles of various types of UK buildings such as dwellings, offices and industry. It is possible to adjust the profiles by entering the required total energy consumption over the period and the program will use this to scale the magnitude of the energy demand profile.

Merit was used to model the CHP unit described above against the thermal energy demand profile of both the flats and the landlord services. The profiles used are for the typical heat demand of a dwelling, with the annual consumption adjusted to match that of WWHC. A typical profile of an office was used to represent the profile of the landlord services and scaled to match the total energy consumption of landlord services of 405MWh.

Whilst these are not likely to match exactly with the energy demand profile they will provide an acceptable estimation of the supply and demand match of the development and the CHP unit. The CHP unit was modelled based on full load operation throughout the year. The unit is modelled with a $60m^3$ accumulator tank which is designed to hold two hours worth of hot water at average consumption, but during periods of low consumption would last much longer.

Results

The thermal energy supply and demand profiles can be seen in Figure 15, with the red line representing the demand and the green line representing supply. The effects of using the $60m^3$ accumulator tank can clearly be seen from the graph as there are times when heat is supplied significantly above the rated output of the unit of 358kW. Table 22 shows the results of the analysis and it can be see that the system meets 50% of the heat demand as anticipated. Although there is some heat wasted during the summer months this is only 322MWh which represents 10% of the output of the system and this loss is compensated for by the electricity generated by the unit. As the emissions factor for the electricity generated by the unit is lower than the grid intensity it is also environmentally beneficial to use the unit when there is little heat demand as this would still produce less CO_2 emissions than importing the equivalent electricity from the National Grid.

When electricity from the unit can be used onsite large savings can be made compared to importing electricity from the National Grid however the electricity exported to the grid is less profitable. If a further detailed study of the energy profile of West Whitlawburn revealed that there are periods during the summer where both heat demand is low an electricity demand from landlord services is also low then it would be worthwhile considering modulating the CHP unit at these times. It is not financially beneficial to run the unit when there is both a low heat demand and a low electricity demand onsite as the income from exporting the electricity to the grid would not cover the running costs. In these situations it would be better to use heat stored in the accumulator tank or from the back up boilers to meet any heat demand and import electricity from the national grid.

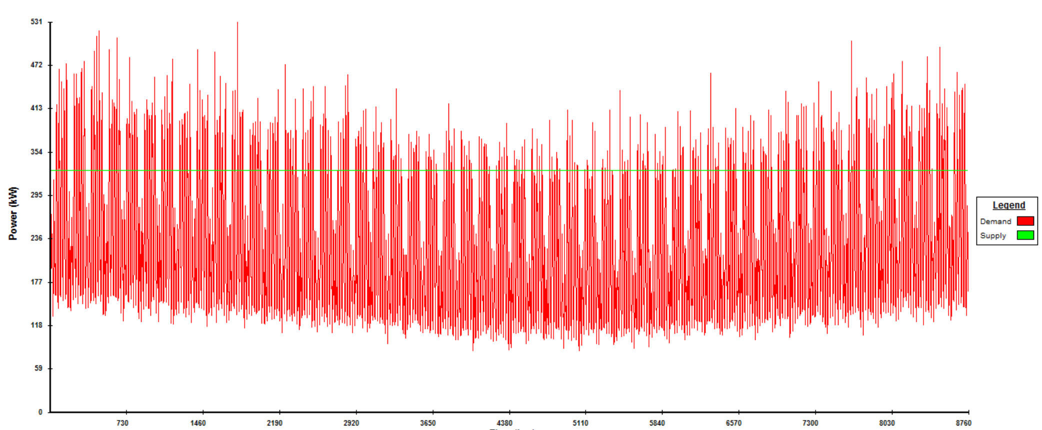


Figure 14 CHP electricity demand matching

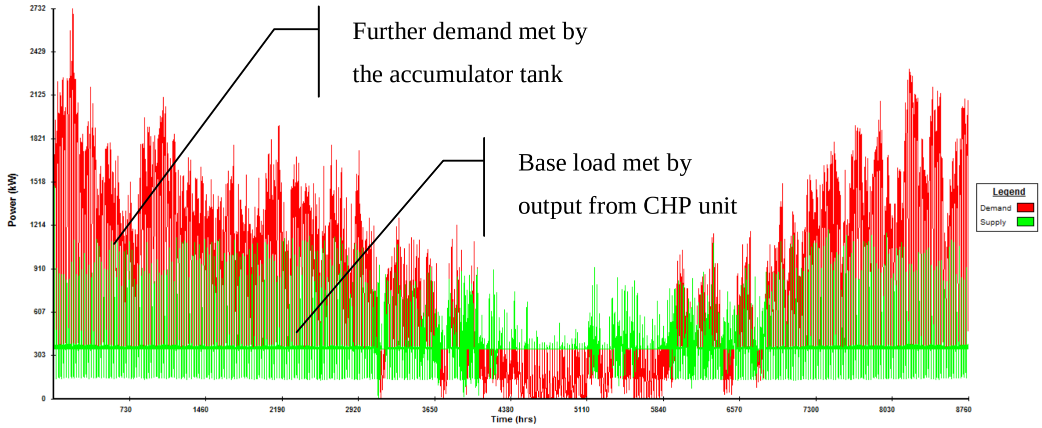


Figure 15 CHP heat demand matching

Table 22 Output from CHP system

	Electrical energy	Thermal energy
Energy demand (GWh)	1.98	6.28
Energy supply (GWh)	2.89	3.20
Energy used (GWh)	1.92	2.88
Energy surplus (MWh)	967.30	322
Energy deficit (MWh)	57.92	3.39
Match rate	76.23%	50.23%

8.3.3 Fuel

With a total efficiency of 80.7% the CHP unit will require an input of 3.54GWh of natural gas per year. There will be a further requirement of 4.7GWh of natural gas per year to supply the backup gas boilers and to make up for the distribution losses calculated in Chapter 8.2 which gives a total of 12.15GWh of natural gas per year.

8.3.4 CO_2 emissions

The emissions savings associated with the CHP unit must be split between the heat and electricity generated. The UK government guidelines (AEA 2009) recommend using the formulas outlined in Equation 11 and Equation 12 to calculate the emissions factors of the heat and electricity generated by the CHP unit. Although the actual emissions breakdown would depend on the specific system, the equations provide an acceptable approximation which will be applicable to other systems and is the guidance given by the UK government for reporting emissions.

Equation 11

$$\text{Emissions per kWh electricity} = \frac{2 \times \text{total emissions}}{(2 \times \text{total electricity produced}) + \text{total heat produced}}$$

Equation 12

$$\text{Emissions per kWh heat} = \frac{\text{total emissions}}{(2 \times \text{total electricity produced}) + \text{total heat produced}}$$

Emissions from electricity

Using Equation 11 the emissions factor for electricity produced by the system was calculated to be 0.362kg CO_2e/kWh generated. If 1.92GWh of electricity is used from the CHP system for landlord services as was estimated in the modelling exercise this would equate to a total saving of 349tonnes CO_2e when compared to Grid electricity. All of this saving would be attributed to the Housing Co-operative.

Emissions from heat

Using Equation 12, the emissions factor for heat generated from the CHP unit was calculated to be 0.181kgCO_2e/kWh. A further emissions factor was calculated for the heat generated by the backup gas boilers which was found to be 0.324kgCO_2/kWh which gives and average emissions factor for a unit of heat from the district heating system of 0.262kgCO_2/kWh. This compares very favourably with the emissions factor for grid electricity of 0.544kgCO_2/kWh which is currently used for heating in the flats.

In a flat with a current electricity consumption for heating and hot water of 12000kWh this would equate to a saving of 3.7 tonnesCO_2e per annum, or a reduction of 57%.

Over the whole site the CO_2 savings from domestic heat and hot water and landlord services heat, hot water and electricity would equate to a saving of 2500 tonnesCO_2e per annum. This is the saving based on energy used onsite and does not take into account the additional savings associated with the electricity exported to the National Grid.

8.3.5 Costs

At the scale required the cost of natural gas is 1.94p/kWh (Department of Energy and Climate Change 2010) which equates to a total spending on gas of £235,760 per year. There is also a cost of £7536 for electricity for running the pumping systems.

A cost of £40,000 was included for operation and maintenance of the system. This takes into account the cost of staff to run the system, and to handle the billing of tenants as well as maintenance of the system.

The consultants report estimated a capital cost of £1m to install a gas fired CHP system with district heating for this site however this cost has been increased to £1.5m for these calculations to add a good margin for error and ensure that the cost is not underestimated.

It has been assumed that a loan will be taken out to cover the capital costs an the annual repayment required is calculated using Equation 13 where:
C=Capital cost
r=rate of interest
n= repayment period in years

Equation 13

$$Annual\ \ repayment = \frac{Cr(1+r)^n}{(1+r)^n - 1}$$

The calculations are based on an interest rate of 7% and a repayment period of 15 years. This gives a total annual repayment of £164,692.

Table 22 shows that 1.92GWh of electricity from landlord services will be offset by electricity generated in the CHP system. At an average cost of 12p/kWh for grid electricity this works out as a saving of £230,000 per year on electricity that would otherwise have been imported from the grid. There is a further 859MWh of electricity which would be exported to the national grid each year at an export tariff or 3p/kWh, providing an income of £26,000 per year.

The results of the cost benefit analysis are that 2.75p/kWh would need to be charged to tenants for their heat to cover costs and repayment of the capital loan.

8.3.6 Fuel poverty

Table 23 shows the effects that the CHP system would have on the energy costs of tenants. It is anticipated that the system would lift almost all households out of fuel poverty as the highest theoretical spending on energy is estimated to be £631 for a large, three bedroom flat. Comparing this with the typical incomes in Table 5 where the lowest annual income is £6327 suggests that all households could be expected to be lifted out of fuel poverty with this system.

Table 23 Energy costs with CHP

	Current cost (£/annum)	Future cost per annum (£/annum)			
		Current average consumption	Theoretical consumption of a small flat	Theoretical consumption of a medium flat	Theoretical consumption of a large flat
Heating	1500	297	158	212	226
Power	500	500	196	275	296
Standing charge for electricity	109.5	110	110	110	110
Total	2109.5	906	463	596	631

8.4 Biomass boiler

A biomass boiler is not suitable for all sites as it requires a large amount of space for the boiler and wood storage as well as access for large truck to deliver the fuel. This is not an issue in West Whitlawburn as there is a large amount of space available on the site, as shown by Figure 16. There is also good road links so access for trucks would not be a problem.

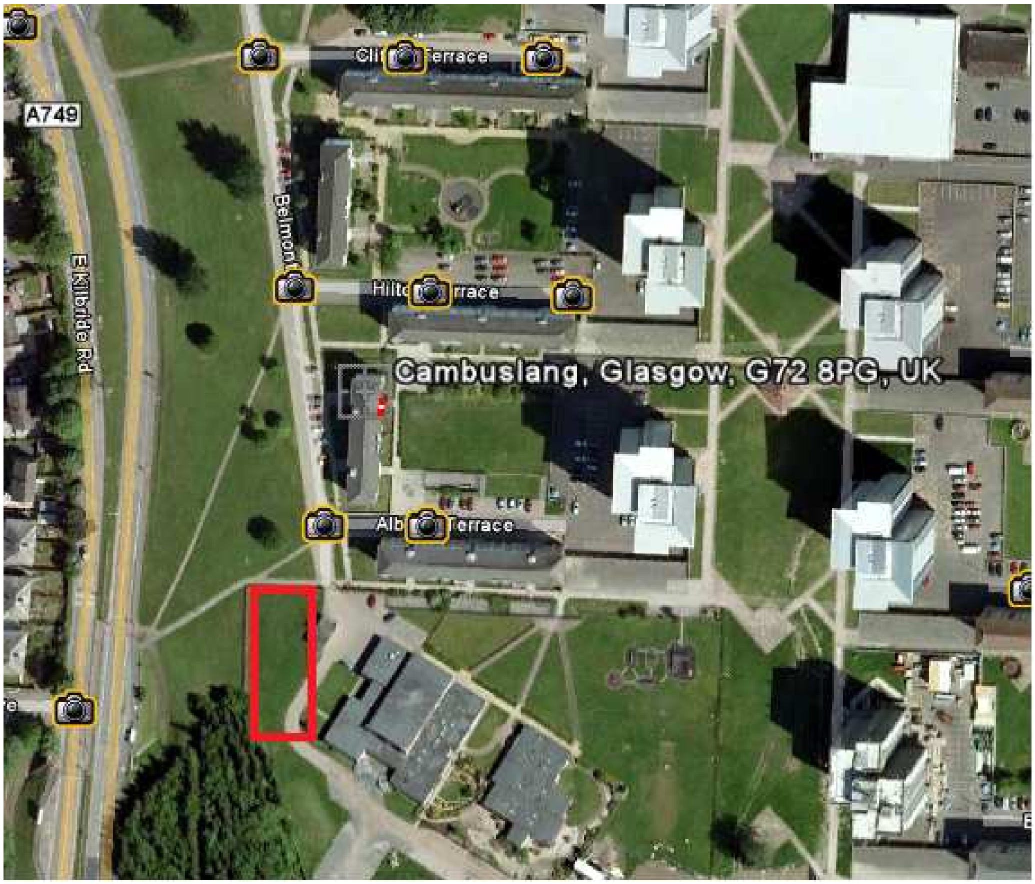


Figure 16 Location of the biomass boiler and wood store

8.4.1 Design

It is generally recommended that a biomass boiler is designed to meet 70% of the annual heat demand of the site (Ward & Holley 2003). In this case, with an annual heating load of the site of 6280 MWh/year a 560kW boiler would be required to meet 70% of the demand. The consultants report recommended installing two 280kW boilers to allow the boilers to match the variable heat demand profile better than would be possible with just one 560kW boiler.

As discussed in the previous chapter, the Renewable Heat Incentive will not be taken into account in the calculations as there are still doubts that it will go ahead. Even so, it is worth ensuring that the boiler qualifies for the best tariff pssible in the even that it does come in. As a 560kW boiler would be just outside the limit to qualify for the medium tariff of 6.5p/kWh tariff it is worth designing the boiler to be under 500kW as this would make a very significant impact on the financial viability of the system. For this reason it is recommended that two 240kW Hoval Forester UFS wood chip boiler (Hoval Ltd 2009) are installed.

One boiler would be used year round to provide a base load with the second boiler used at times of higher demand. As with the CHP system, a 60000 litre accumulator tank is recommended to help to match supply and demand more accurately. The biomass boilers would be backed up by a 1572kW gas boiler to meet peak demand as well as provide back up for when the biomass boilers undergo maintenance.

8.4.2 Modelling the boiler

Boiler 1 is designed to run at full load throughout the year, meeting the base load heat requirement of the site. Boiler 2 also runs at full load for most of the year whilst in the summer it is switched off for period when it is not required. The system was modelled using Merit to match the supply from the boilers to the heat demand from the dwellings and landlord services. It was found that boiler 2 would be required to run for 6625 hours per year. Table 24 shows the number of hours which each boiler will be required to run for. Boiler 1 is scheduled not to run for 10 days per year which will allow for maintenance to be carried out on the boiler. This should be scheduled for the summer months when demand for heat will be low so as to limit the amount of time that the the gas boilers would be required.

Table 24 Running times of biomass boilers

Boiler	Running time (hrs)	Energy delivered (GWh)
1	8520	2.04
2	6625	1.59

The system would be backed up by gas boilers which would be expected to supply around 3.49GWh of heat per year

8.4.3 Fuel

The recommended fuel in this case is woodchips as one of the main requirements of the system is to reduce energy costs for tenants. As discussed in Chapter 7.3, woodchips are more cost effective than pellets and are more practical for a large scale system than logs.

The calculations are based on the use of woodchips with 30% moisture content, which have a calorific value of 11.66GJ/t (Forestry Commission Scotland 2010). Based on running the two boilers for the times outlined in Table 24 a total input of 1247 tonnes of woodchips would be required per year. Table 25 shows the quantities of each type of fuel required and the cost of the fuel.

Woodchips generally have a density of 200-250kg/m^3 (COFORD WoodEnergy 2010), which based on the lower estimate would require approximately 33 tonnes of woodchips per week. To store a week's supply of woodchips would require a storage space of 166m^3. This could easily fit on the site and a storage unit of this size would allow delivery from large 20 tonne trucks and would require less than two deliveries per week. The site has sufficient access for trucks of this size, with an existing road leading directly to the proposed location of the boiler.

Table 25 Fuel use with biomass district heating

Fuel	Total fuel used (GWh)	Cost
Woodchips	4.04	£99,754
Natural Gas	3.78	£73,376
Total	7,820	£173,130

8.4.4 CO_2 emissions

The CO_2 emissions from the biomass boiler are calculated using a carbon emissions factor or 0.0158kg CO_2/kWh (AEA 2010). These are added to the emissions from the gas back up boilers to give an average emissions factor 0.138kg CO_2e/kWh of heat.

Table 26 CO_2 emissions from the biomass boiler

	Energy used (GWh)	Carbon footprint (tonnes)
Woodchips	4.04	36.3
Natural gas	3.78	771.8
Emissions from electricity for pumping	0.0628	34.2
Total for biomass boiler	7,820	842

Table 26 shows that very large savings in CO_2 are possible with a biomass boiler backed up by natural gas, with an estimated 78% saving expected.

8.4.5 Costs

As WWHC hope to secure grant funding for a biomass district heating system the economics of the biomass district heating system have been evaluated from two perspectives, one taking into account the capital costs of the system and including loan repayments in the annual costs and the other assuming that grant funding can be secured for the project so loan repayments are not required.

Running costs of the system were evaluated based on the anticipated cost of fuel, as well as the running cost and maintenance of the system. These costs were used to calculate the cost per unit of heat that would need to be charged to cover the running costs of the system.

The cost of wood chips is assumed to be £80/tonne at 30% moisture content. At the quantity required, natural gas can be purchased at a significantly reduced rate, currently this would be 1.94p/kWh of natural gas (Department of Energy and Climate Change 2010).

As Table 25 shows, based on a cost of £80 per tonne of woodchips (The Sustainable Development Commission Scotland 2005), the total cost of woodchips per year would be around £100,000. It is estimated that 3.78GWh/year of natural gas will be required to top up the biomass boiler which, based on an industrial unit price of 1.94p/kWh

(Department of Energy and Climate Change 2010) would cost approximately £73,000 per year.

A cost of £40,000 was included for operation and maintenance of the system. This takes into account the cost of staff to run the system, and to handle the billing of tenants as well as maintenance of the system.

The annual loan repayment is calculated in the same way as for the CHP system, using Equation 13. The capital cost of the system was estimated by the consultants to be similar to the CHP system at around £1million. The costs are very similar because the main cost is associated with the district heating network rather than the heat generation system. As with the CHP system, a value of £1.5million has actually been used in these calculations as it was felt important to include a large amount of leeway as this type of project can often end up costing considerably more than originally estimated. As with the CHP system, the calculations are based on a 15 year payback period and an interest rate of 7%. This gives an annual loan repayment of £164,692.

The cost per unit of heat with capital costs included is 5.52 p/kWh and just 3.16p/kWh without capital costs included. Clearly the it would be preferable to receive grant funding for the capital cost but even without it the unit cost is still far lower than the cost per unit of electricity. Even without taking into account the capital costs, the cost per unit of heat is still higher than the cost of heat with the gas CHP system.

The cost per unit of heat is considerably higher than the cost with gas CHP, whether a grant can be secured or not.

8.4.6 Fuel poverty

Table 27 shows the energy costs per flat with biomass district heating, including capital costs. The table shows the costs based on the consultants estimated average energy consumption as well as for the modelled energy consumption to maintain a satisfactory heating level for the three different sized flats. The costs are significantly lower than with the current electric heating system but it is likely that a number of households would still be left in fuel poverty. Comparing the costs with the potential incomes of households in shown Table 5 shows that a single unemployed person would be in fuel poverty in all but the small flat and even then it would borderline and an unemployed couple living in a medium or large flat would also be in fuel poverty.

Table 27 Energy costs with biomass boiler with capital costs included

	Current cost (£/annum)	Future cost per annum (£/annum)			
		Current average consumption	Theoretical consumption of a small flat	Theoretical consumption of a medium flat	Theoretical consumption of a large flat
Heating	1500	596	317	425	453
Power	500	500	196	275	296
Standing charge for electricity	109.5	109.5	109.5	109.5	109.5
Total	2109.5	1205	628	859	859

Table 28 shows the same as Table 27 but excludes capital costs from the calculations. The costs are obviously much lower than in Table 27 and it can be seen that the total energy costs could be expected to be more than halved with the installation of the new system and it could be expected that most households would be lifted out of fuel poverty.

Table 28 Energy costs with biomass boiler excluding capital costs

	Current cost (£/annum)	Future cost per annum (£/annum)			
		Current average consumption	Theoretical consumption of a small flat	Theoretical consumption of a medium flat	Theoretical consumption of a large flat
Heating	1500	341	181	243.4	259
Power	500	500	196	275	296

Standing charge for electricity	109.5	109.5	109.5	109.5	109.5
Total	2109.5	951	486.3	628	665

Referring to Table 5 which shows typical incomes of people in WWHC it can be seen that if grant funding could be secured the biomass boiler would be expected to lift the majority of people in the neighbourhood out of fuel poverty as the lowest income, for a single person on Job Seekers Allowance, is £6327 per annum whilst the highest fuel poverty threshold for a three bedroom flat is £665. The majority of flats are two bedroom and it is unlikely that a single person would be living in one of the three bedroom flats on their own. Although most of the residents might be technically out of fuel poverty there are likely to be people who still spend significantly more than 10% of their income on energy in the home. The average energy consumption estimated by the consultants report would cost £951 per annum with the biomass system installed and this would represent 15% of the household income for a single person on job seekers allowance.

8.4.7 Renewable heat incentive

As discussed in Chapter 8.4.1, it is recommended that the size of the boiler is below 500kW to keep it within the medium tariff of 6.5p/kWh. If the two 240kW boilers were run at full load for a year this would equate to an additional income of £273,312. Despite some doubts about whether the renewable heat incentive will finally be introduced or not the calculations show that it would be worthwhile ensuring that the system qualifies for the medium tariff as the ideal design size is likely to be around the borderline between the two tariffs.

If this extra income was secured the system would easily compete with CHP on costs.

8.5 Summary

Although both the biomass and CHP systems represent a big cost saving over electric heating, as it stands biomass can't compete with CHP in terms of the unit cost of heat.

Both systems offer a significant CO_2 saving compared to the current electric heating, though biomass offers a slightly larger saving.

9 Developing the tool

This section builds on the details in the previous chapters, discussing the process and methodology for developing the carbon footprint tool in detail.

As discussed in Chapter 6, it was decided that the tool would be developed with Excel, with a separate worksheet for each section of the tool. The worksheets are protected to prevent users from modifying equations or data tables with only the specified data input cells left editable. The cells which the user is required to edit are left white with a bold black border, with the rest of the sheet coloured so that it is clear to the user which cells they should edit. This can be clearly seen in Figure 17.

There are seven worksheets which are visible to the user and the remaining six sheets containing data are hidden. The design of these sheets is discussed below.

9.1 Introduction worksheet

In this section of the tool the user is asked to answer a number of questions about themselves, their home and their opinions. These questions are designed to provide more information about the respondent and in particular to allow analysis of the results by different categories, such as age groups, incomes etc. They are asked about the number of adults and children who live in their house as well as their ages, their income and the number of days per week which someone is home during the day time.

There is also a question about the number of bedrooms in their flat and this is used to determine the size of their flat and therefore the fuel consumption required to meet the fuel poverty requirements. The worksheet is shown in Figure 17.

There are also a number of questions that are designed to provide more information about the views of tenants on energy and fuel poverty issues. The information provided by these questions is especially useful for the Housing Co-operative and can be used when looking for funding for upgrades to the heating system. These questions are:

- How happy are you with your current heating system?
- Do you feel that you can afford to heat your home to a comfortable temperature in winter?
- What do you understand by the term fuel poverty?
- Do you think that fuel poverty is a problem for people in your neighbourhood?

The carbon footprint will be calculated for an individual but to make it easier the user, they can choose to answer questions in the consumption section based on the spending for their whole household. The user is also asked to select if they are answering on behalf of their whole household or just for themselves using a tick box which is set up to register a ‘1’ in a specific cell in the ‘Data – other’ sheet. If the individual box is checked and register 2 if the household box is checked. The total carbon footprint calculated for consumption will be divided by the number of people in the household if a ‘2’ is found in the relevant data cell.

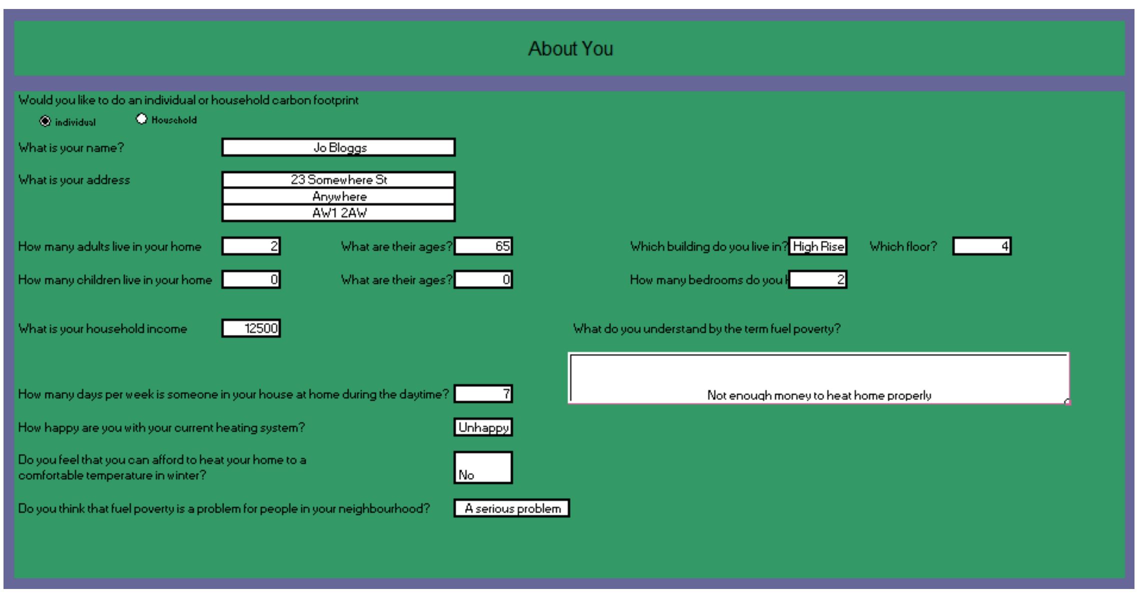


Figure 17 Carbon calculator - About you

9.2 Home worksheet

The tenant should provide details of their energy consumption. In WWHC this will only be electricity, however the calculator will also include the option to enter details of gas consumption to ensure that the tool is transferable to other communities. Where they do not have details of their energy consumption in kWh they will be asked enter how much they spend on electricity. If the tenant does not supply any energy consumption data, it will be estimated by using the energy consumption modelled with Edem for their particular size of flat.

Figure 18 shows a screen shot of the Home sheet of the tool. The top section of the screen is where the user is required to enter the details of their energy use. The first questions are about the energy supplier and the unit and standing charge costs. The user will be asked to bring copies of energy bills where possible so these details can be easily located on the bill however when this is not possible the unit cost and standing charge will be looked up for their supplier.

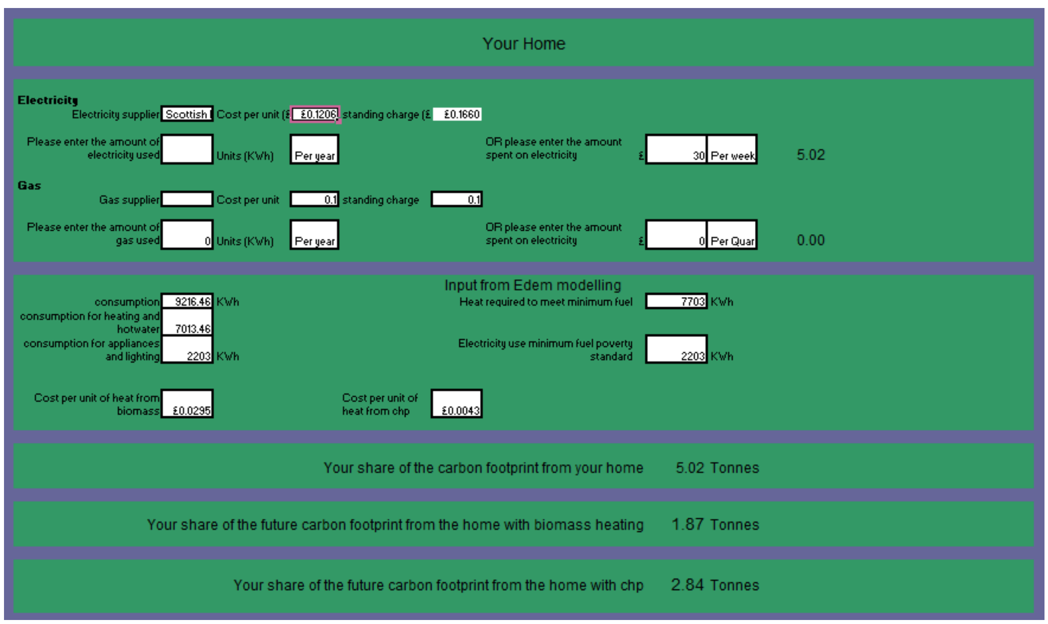


Figure 18 Carbon calculator – Your home

The user is then given the option to either enter the number of units used or the amount spent on fuel. A drop down box can be used to select the period of time that this consumption covers, for example ‘per month’. An excel lookup table is stored in the ‘Data – other’ worksheet which matches up specified time period with a multiplication factor which will convert the data into an annual consumption. For example if the user entered that they use 1000 units of electricity per month, this would be multiplied by a conversion factor of 12 to convert this into an annual consumption of 12000 units. If the user chooses to enter the amount spent there is a further calculation required to calculate the number of units which that corresponds to. Figure 19 shows the excel formula used to calculate the carbon footprint from electricity consumption, which also uses the ‘IF’ function to display an error message if the user attempts to enter values in both the box for the number of units consumed as well as the box for the amount spent on fuel. The formula also divides the footprint by the number of people in the household to calculate the individual’s share of the carbon footprint from energy use.

*=IF(OR(C10>0,J10>0),IF(AND(ISNUMBER(C10),ISNUMBER(J10)),"ERROR",IF(C10>0,((LOOKUP(D10,electricity_units)*C10*LOOKUP(E10,Duration,duration_multiplier))/1000)/(Introduction!C15+Introduction!C17),((LOOKUP(D10,electricity_units)*(J10-(G8*LOOKUP(K10,Duration,duration_multiplier)))/E8*LOOKUP(K10,Duration,duration_multiplier))/1000)/(Introduction!C15+Introduction!C17))),0)*

Figure 19 Excel formula for carbon emissions from electricity consumption

There is an identical section for gas consumption and the combined footprint from gas and electricity is displayed at the bottom of the screen.

The second section of the worksheet displays the current energy consumption and the theoretical energy consumption from the modelling exercise described in Chapter 8.1. The theoretical energy consumption will be used to calculate the fuel poverty threshold of the property. The results of this modelling are stored in a lookup table in the ‘Data – other’ worksheet and the lookup function is used to automatically enter the relevant data in these sections according to the answer given for the number of bedrooms in the household. Figure 20 shows the formula used to lookup the heating requirement for each of the three flat sizes. When a paper questionnaire is used there is the chance that the respondent will not have entered the number of bedrooms, in which case a default value of 2 will be used as the majority of flats have two bedrooms.

=LOOKUP(Introduction!K17,flat_size,heat_required)

Figure 20 Excel formula – heat consumption of flats

This calculation is only appropriate for the particular flats in WWHC and would not be applicable to other flats with different sizes, construction or heating systems. To use this section of the tool accurately for other flats it would be necessary to model them using Edem.

The current consumption of the household is calculated from the answers given. Where the household has both gas and electricity the gas is taken to be used for heating and hot water and the electricity for lighting and appliances. Where only electricity is used, as is the case for West Whitlawburn, it is not possible to tell what proportion of the electricity is used for heating and hot water and what proportion is used for appliances and lighting. In these cases the calculated value from the modelling is used as the consumption for lighting and appliances and it is assumed that the remainder of the electricity consumed is for heating and hot water.

The final sections of the worksheet apply the carbon factors calculated in the 'Heating systems' sheet for both biomass district heating and gas CHP district heating to which ever is highest out of the current and the theoretical heat consumption values. The highest of the two values is used as it is likely that with reduced energy costs the house would be maintained at least at the same temperature or higher. In cases where the household limits its energy use for financial reasons and uses less that the calculated value it is assumed that they would increase their energy consumption if the energy costs were reduced. As it is impossible to know how much they might increase their energy consumption by, so the best estimate is to use the calculated value.

9.3 Travel worksheet

In this sheet data is required for all travel throughout the year. Following the review of existing carbon calculators it was decide that users should be given the possibility to enter their travel details in a number of different ways, to ensure that it is as simple as possible.

Private vehicles

Owners of private vehicles, whether it be a car, motorbike or van can choose to enter either the total number of litres of fuel used, or the amount spent on fuel per week, month or year or provide details about the type of vehicle and the number of miles driven.

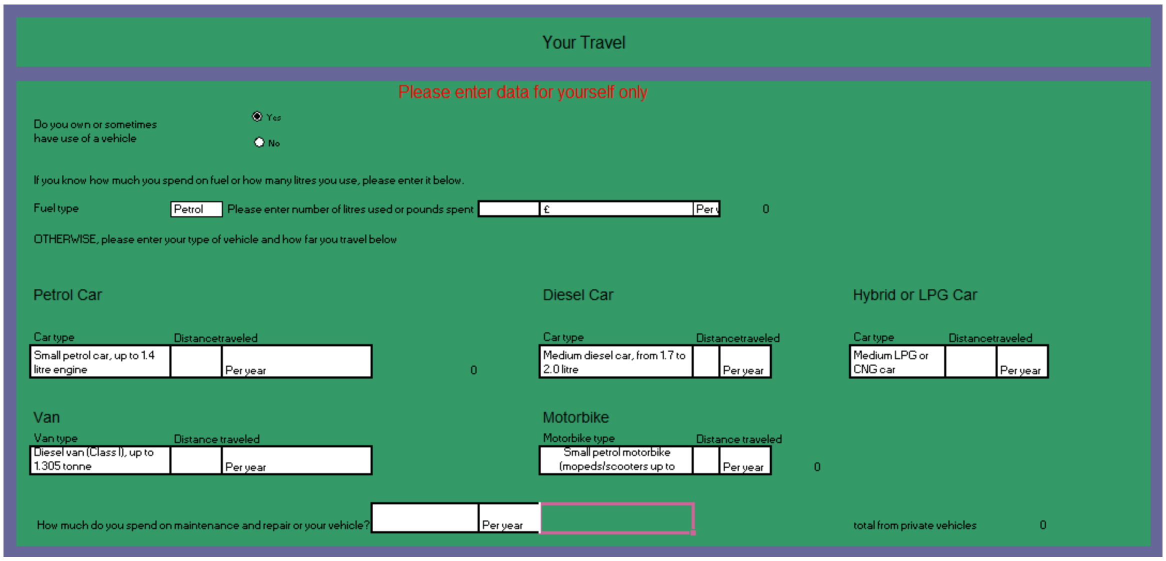


Figure 21 Carbon calculator – Your travel

Figure 21 shows the private transport section of the Transport worksheet. The user is asked if the own or sometimes use a car, van or motorbike. If the 'no' tick box is selected it runs a macro which hides the section of the sheet about private transport and if yes is selected another macro is run which unhides the section.

If the amount of fuel used or the amount spent on fuel is known this should be entered in the first section. There are three drop down boxes which the can be used to specify the fuel type, the units, either in £ or litres, and the time period which the answer applies to. Each drop down box is linked to a lookup table in the 'Data – other' sheet which contains relevant multiplication factors.

The second option is to select the vehicle type and enter the number of miles driven over a certain time period. The vehicles are divided into cars, vans and motorbikes and then further divided by fuel type and size – small, medium, large or average. Drop down boxes are used to select the appropriate vehicle and then the number of miles are entered in the appropriate box and the time period selected from the dropdown box. Figure 22 shows the formula used to calculate the footprint from the use of a petrol car. An IF( ) function is used to set the answer to zero is a value has already been entered in the previous section for the quantity of fuel used of the amount of money spent on fuel so that it is not counted twice.

*=IF(OR(J13="",J13=0),LOOKUP(C19,Petrol_car,petrol_car_intensities)*D19*LOOKUP(E19,Duration,duration_multiplier),0)*

Figure 22 Excel formula - emissions from driving

Public transport

Public transport is divided into the following modes of transport; bus, train, ferry, coach, Eurostar, subway and taxi. Following the review of other carbon calculators it was decided that it is unrealistic to simply ask the user to enter the number of miles travelled per year by each form of transport. This would either result in the user making a wild guess, or having to do quite a number of calculations outside of the tool. Instead, the user will be given the possibility to enter a number of different journeys and the frequency that they make them, for example if they may make a 2 mile return bus journey five days per week the calculator will automatically calculate the annual CO_2 emissions associated with this.

The user will be asked to enter the number of miles travelled by each form of transport, however most people are unlikely to know distances; they may take the bus from West Whitlawburn to Glasgow city centre but not know how far it is. For this reason on the printed paper questionnaire they are given the option to write a journey such as West Whitlawburn to Glasgow city centre and the actual distance will be calculated for them later. The trip distances will be estimated using the directions tool on Google Maps (Google - Imagery 2010) which can be used to calculate the distance to drive from one location to another. Although this will not provide exact distances as bus routes will not always take the most direct route, it is likely to provide at least as good an estimate as asking the user to guess the distance travelled.

Figure 23 shows the public transport section of the ‘Transport’ worksheet. Each section has five lines, which allows up to five different trips to be entered. This allows the flexibility to enter different trips without any separate calculations being carried out, such as a daily 3 mile commute to work by train can be entered along with longer train journeys such as a 200mile trip to visit family that is made 3 times per year. Drop down boxes are included so that the period, such as ‘per week’, can be selected as well as if the trip is one way or return.

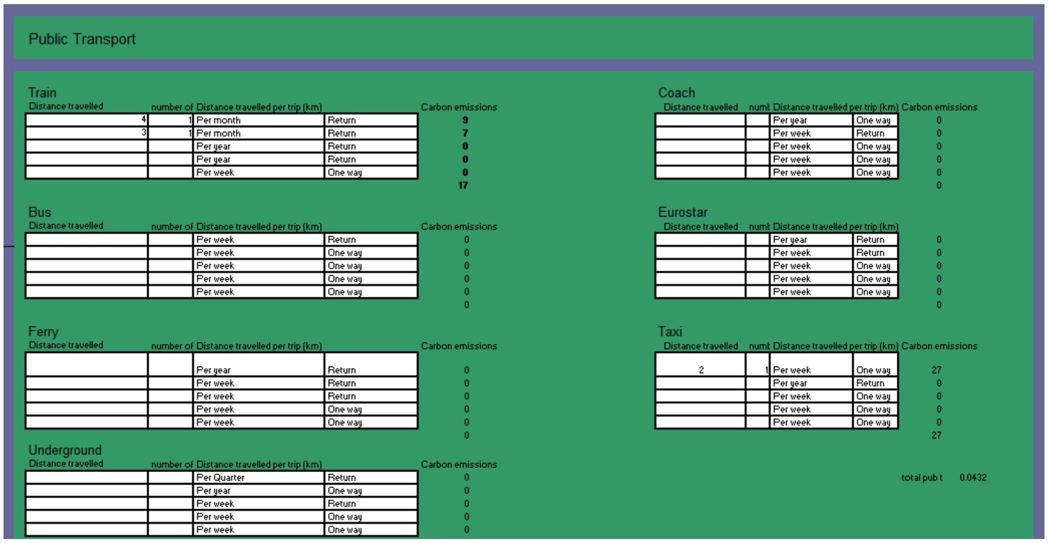


Figure 23 Carbon calculator – Public transport

Air travel

Figure 24 shows the section on air travel. The user is asked to enter the distance flown, and select from drop down boxes whether it was a single or return flight and if it was a domestic, short- haul or long-haul flight, as these each have different emissions factors. To ensure that the distances entered are accurate, a link is included to the website http://www.travelmath.com/flight-distance/ where they can enter the departure and arrival airports and the website will calculate the distance flown. The link is created using an excel button linking to a macro which opens the website.

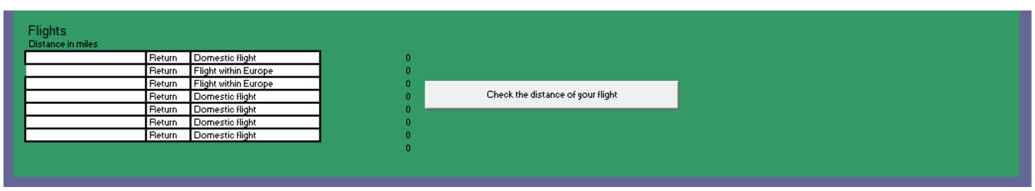


Figure 24 Carbon calculator - Flights

Figure 25 shows the formula used to calculate the emissions from a flight and includes a multiplication factor of 1.9 to take into account radiative forcing effects as well as a conversion factor from miles to kilometres as the input is asked for in miles whilst the emissions factor is for kilometres.

*=C73*1.9*LOOKUP(D73,Flights,flightdist)*LOOKUP(E73,flight_cat,Flight_intensities)*'Data - Travel'!$F$182*'Data - other'!$B$35*

Figure 25 Excel formula – emissions from flying

9.4 Data on consumption

Users are asked to enter data about their consumption in two sections, items which are likely to be bought regularly and other items which may be bought once per year or not at all. If the user has chosen to answer as an individual then the total carbon footprint associated with the consumption will be applied to their total but if they have chosen to answer for their household it will be divided by the number of people in the household. Figure 26 shows the worksheet on consumption.

Regular purchases

This section contains items bought regularly and the user is asked to enter the amount spent on the following items and select the time period that this applies to from a drop down box.

- Food and drink
- Clothes
- Shoes
- Newspapers, books
- Hotels, restaurants and pubs
- Toiletries/makeup
- Cigarettes and tobacco products

One off purchases

This section contains items which are likely to be bought less regularly, if at all, in a given year and the user is asked to enter how much they spent on each item in the last year.

- Electronic gadgets such as TVs, MP3 players or kitchen appliances
- Computer equipment

- Furniture
- Power tools
- Painting and decorating
- A new car
- Jewellery

Activities

The last question in this section is about how much is spent on hobbies and activities such as going to the cinema or attending sports events. Again, there is the option to enter the amount spent per week, per month, per quarter or per year.

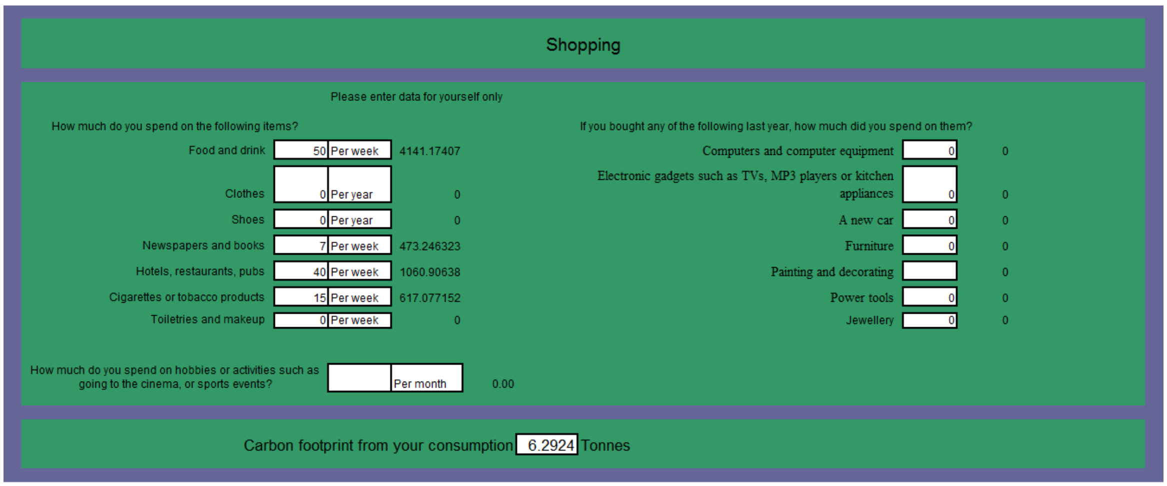


Figure 26 Carbon calculator – Your shopping

9.5 Total

Figure 27 shows the worksheet which displays the results. There are four results sections on this page and there are no user input boxes. The first section shows the current carbon footprint of the individual, divided into the three sections and also the total footprint. It also displays the average footprint of the other people in the neighbourhood who have already taken the survey. When only a few surveys have been carried out the community average could obviously be distorted by an individual with a very high or very low footprint so it is important that this is only looked at when a significant proportion of the neighbourhood have been surveyed.

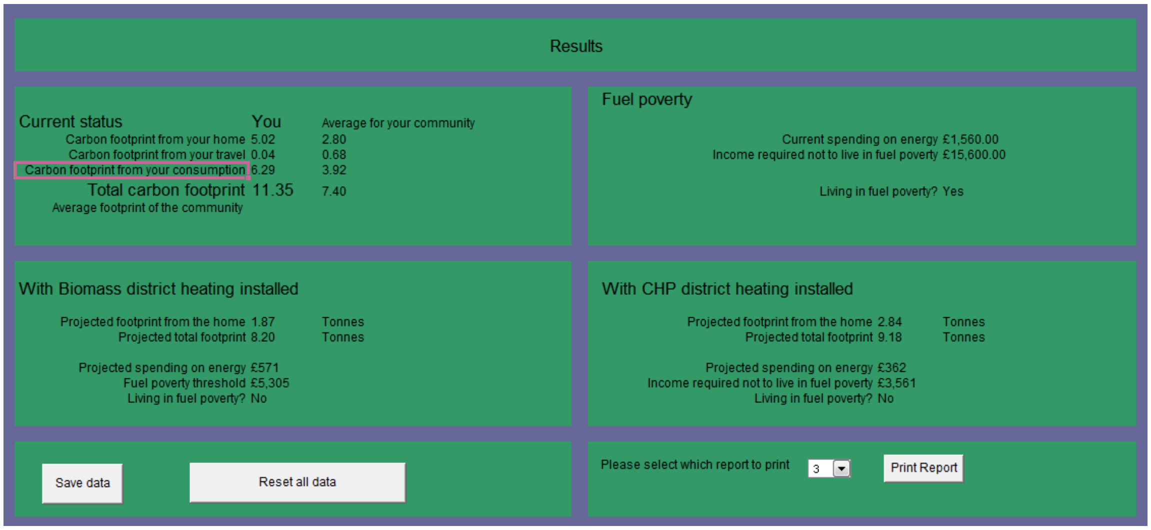


Figure 27 Carbon Calculator - Results

The next section on the worksheet displays the current fuel poverty status of the household. It displays what the current spending on fuel would be to maintain a satisfactory heating regime and the household income required to be above the fuel poverty threshold.

The next two sections show the effects that the proposed new heating systems would have on both the fuel poverty status of the household and carbon footprint of the individual. For each system the projected new carbon footprint from energy used in the home and the new total carbon footprint of the individual are detailed. The costs to maintain a satisfactory heating regime are also detailed along with income required to be above the fuel poverty threshold.

At the bottom of the page are four buttons which are each linked to different macros. The first one is called ‘Save data’ and when activated uses a macro to record the data entered for the individual to the ‘Average’ for later use. There is also a button titled ‘Reset all data’ which uses another macro to reset all data input cells to either blank or the default value.

The third button is for creating a PDF report showing an individual’s carbon footprint and comparing it to the average in the community. The reports are created from the records stored in the Average worksheet and there is a dropdown box which can be used to select the record number required. The macro is designed to print a PDF file using the PDF Writer (BioPDF 2007) tool and this must be installed before a PDF can be created. The fourth button on the page opens a link to the download page for this tool so that users who do not already have it installed can do so easily.

9.6 Heating systems

The 'Heating systems' worksheet is divided into three sections; one on combined heat and power, one on biomass heating and another which contains data relevant to both systems. The worksheet requires a number of inputs from the user then automatically carries out the calculations outlined in Chapters 8.4 and 8.3 and the output from the sheet is the cost per unit of heat in pence/kWh and an emissions factor per unit of heat in kgCO_2e/kWh for both the CHP and biomass systems.

Figure 28 shows the CHP section of the worksheet, which requires 12 inputs from the user. The electrical and thermal power and efficiency should be supplied by the manufacturer of the CHP system to be installed and in the case of WWHC are based on the data for the Jenbacher J208 GS CHP unit (Clarke Energy Ltd 2007). The number of maintenance days and the efficiency of the backup gas boiler are also required.

The next two inputs required are the quantity of electricity used on site and the quantity of heat wasted during the summer months. For accurate inputs into these two boxes it is necessary to model the energy supply and demand and analyse how they match. In this case the modelling was done using the Merit tool as described in Chapter 8.3.2. The values from this modelling exercise are left as default values and could be scaled up or down as appropriate and used when analysing other sites when it is not possible to model the system in more detail.

There is also a cell where the total running and maintenance costs of the system are entered.

The final three inputs are for calculating the annual repayments on the capital loan and are the total capital cost, the interest rate on the loan and the repayment period. The default value of the interest rate is 7% and the repayment period is 15 years but these can easily be changed by the user.

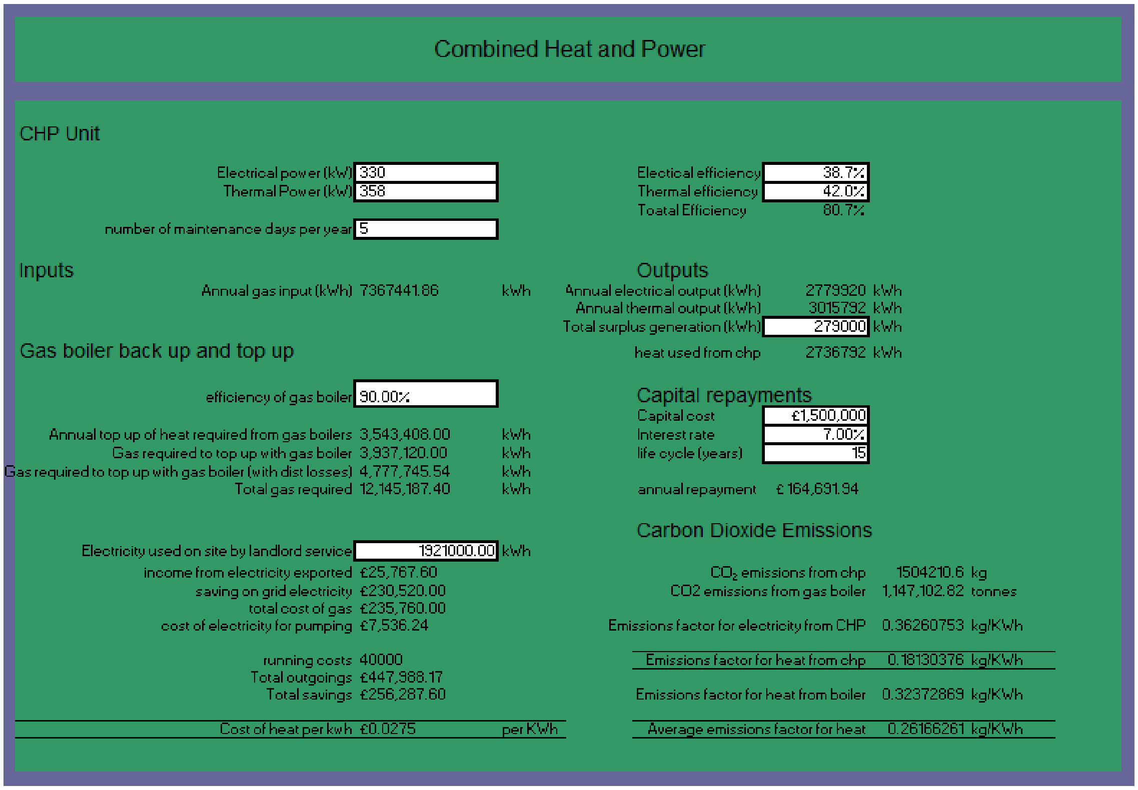


Figure 28 Carbon Calculator - CHP

Figure 29 shows the section on the biomass boiler, which requires 13 user defined inputs. The inputs for the efficiency of the backup gas boilers, the calorific value of the woodchips and the cost of woodchips are all set to default values which can be changed by the user if required.

The thermal power and efficiency of the two biomass boilers should be supplied by the manufacturer, which in this case study is Hoval (Hoval Ltd 2009) and the power and efficiency of both boilers are 240kW and 90% respectively. The next inputs are the hours of operation of each plant and this requires the system to be modelled using a tool such as Merit as discussed in Chapter 8.4. The hours of operation of boiler 1 is set to a default value of 8520 hours which allows for 10 days of maintenance per year while the hours of operation of boiler 2 is determined by the demand profile of the site and in the case of WWHC it is estimated to be 6625 hours per year.

As with the CHP section, there are also inputs relating to the capital cost and loan as well as the running costs of the system.

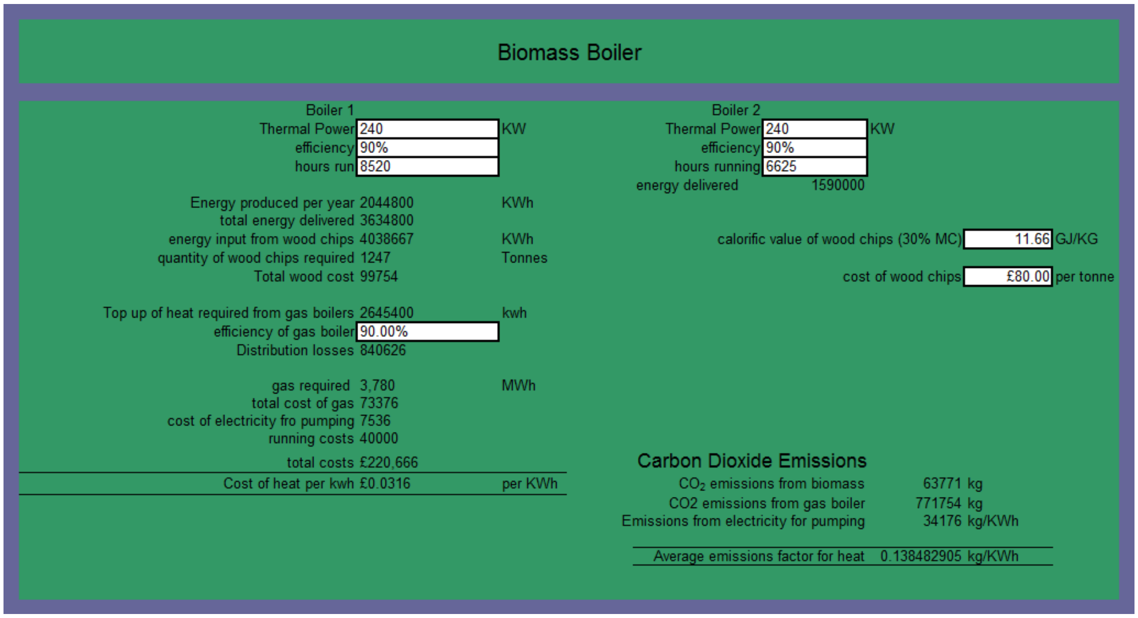


Figure 29 Carbon calculator – biomass boiler

The final section of this worksheet shown in Figure 30 contains data which is used by both the CHP and biomass sections of the sheet. The user is required to input six pieces of data; with the first three related to energy prices: the export tariff for electricity exported to the National Grid, the cost of natural gas bought at industrial quantities and the average price of electricity bought from the National Grid. There is also an input for the number of dwellings connected to the system. The final two inputs are the peak heat consumption of the site and the electricity consumption for heating purposes which is used to calculate the actual heat demand of the site. There are also two further inputs into the system which are calculated in other sections of the tool and these are the distribution and storage losses and electricity required for pumping.

A button is included in this section which scales the data for the heating systems up or down if the user enters an alternative number of dwellings. This is not meant to provide a detailed or accurate representation of different sized systems but just to give a rough estimate in cases where a more detailed analysis is not possible.

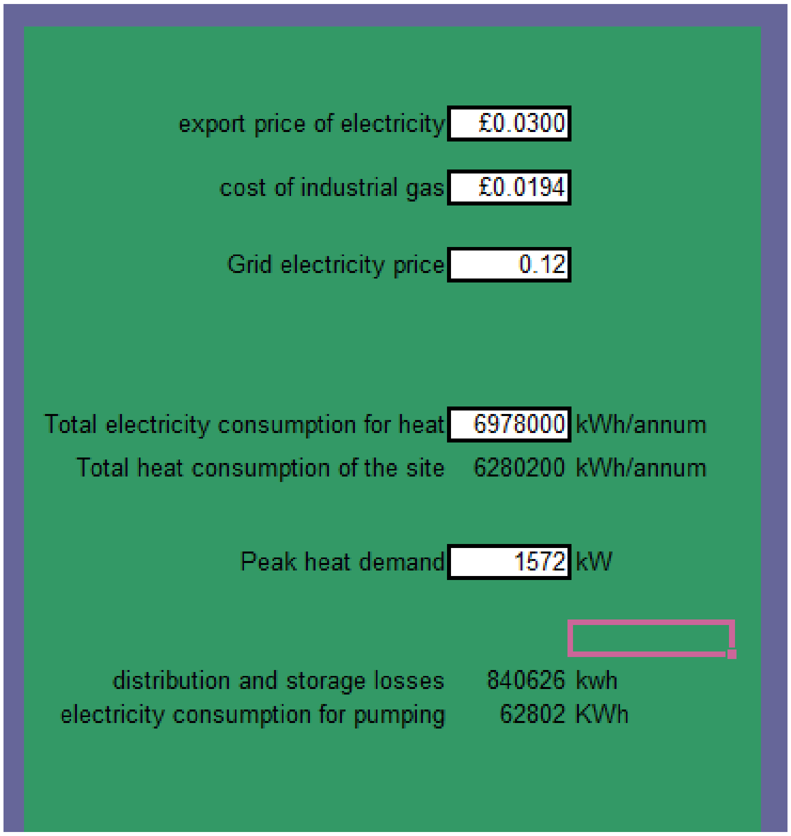


Figure 30 Carbon calculator – heating systems data

9.7 Pipes

Figure 31 shows the distribution and storage losses section of the 'Pipes' worksheet. The calculations are based on the workings in Chapter 8.2 and require a number of inputs with details about the specific district heating system. In this case data is used for the WWHC distribution network but this is easily customisable for other networks. The sheet includes three different pipe sections and has an input box where the user can enter the length of pipework required for each section. The tool will then automatically double the value input to include the return pipe. The other inputs required in this section are the water flow temperature and the water return temperature as well as the average ambient temperature for each section. The total heat transfer coefficient of each section of the pipe is taken automatically from the pipe characteristics section of the sheet which is discussed below. The output of this section is the total heat loss from the heat distribution networlk which, as discussed in Chapter 8.2.7 is also increased by a factor of 15% to take into account extra losses through joints and the fact that the data used is based on ideal conditions.

The storage losses section has inputs for the size of the accumulator tank required and the total heat loss factor for the tank and outputs a total annual heat loss from the tank.

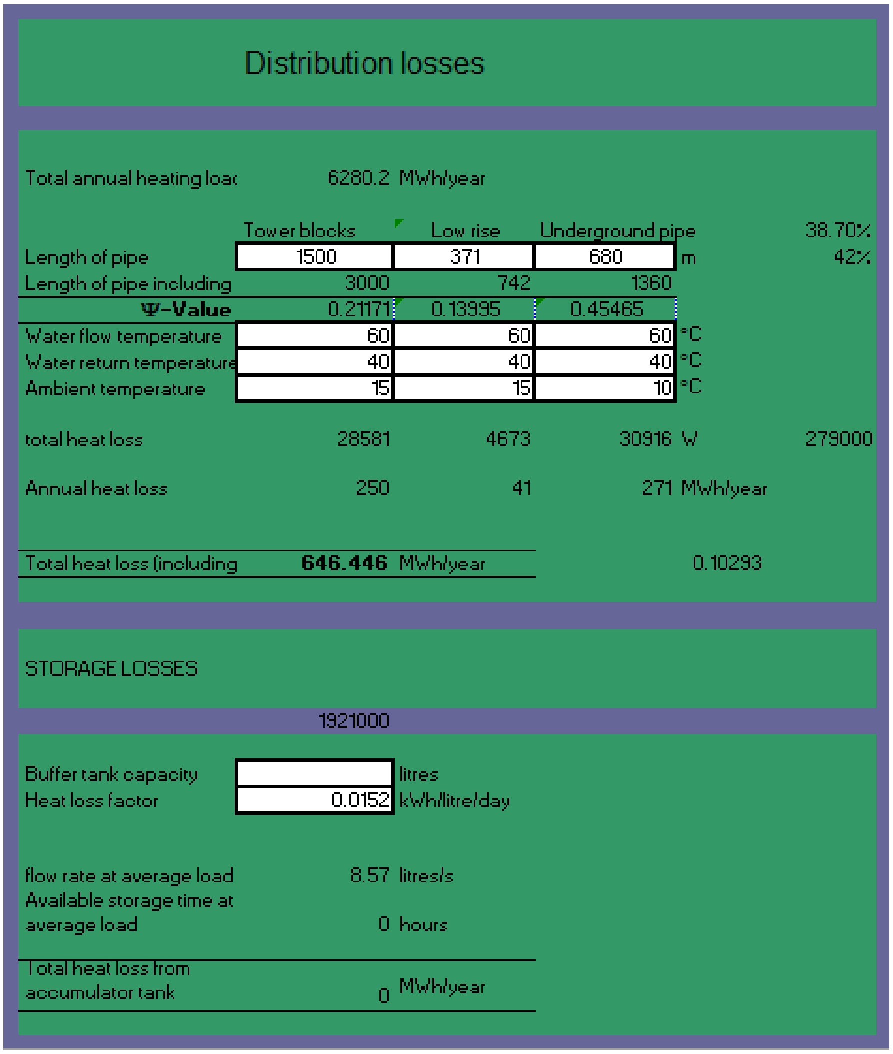


Figure 31 Carbon Calculator – Distribution losses

Figure 32 shows the pipe characteristics section of the 'Pipes' worksheet which is used to calculate the size of pipe required and the heat loss coefficients of the pipes. The section is divided into three parts for each of the three possible pipe sections. In this case the sections are underground pipe, tower blocks and low rise. If a specific distribution network does not require three different sections then it is also possible to leave sections blank.

The first inputs required are related to the water flowing in the pipe and are used to calculate the pipe diameter required. The water velocity, specific heat capacity and density of water are all left with default values but can be changed if required. This data is used along with the peak heat load taken from the heating systems worksheet to calculate a required pipe diameter and then the user is required to manually select the closest match from the data table included in the worksheet. The dimensions of the pipe should then be read off from the table and entered in the relevant box for nominal width, pipe wall thickness and external diameter which correspond to the dimensions d, s and D respectively which are supplied by the pipe manufacturer. These dimensions are automatically converted to the required input dimensions by the tool. The other inputs required are thermal conductivity of the pipe and the thermal conductivity of the insulation and whilst these are set to the default values supplied by the pipe manufacturer (RAUTHERMEX 2005) they can be changed by the user as required. The first pipe section is for modelling underground pipes and also requires the thermal conductivity of the soil and depth at which the pipe is buried, and again default values are entered which can be changed by the user if required. For the indoor pipes the convection heat transfer coefficient is also required and a default value his included, as discussed in Chapter 8.2.3.

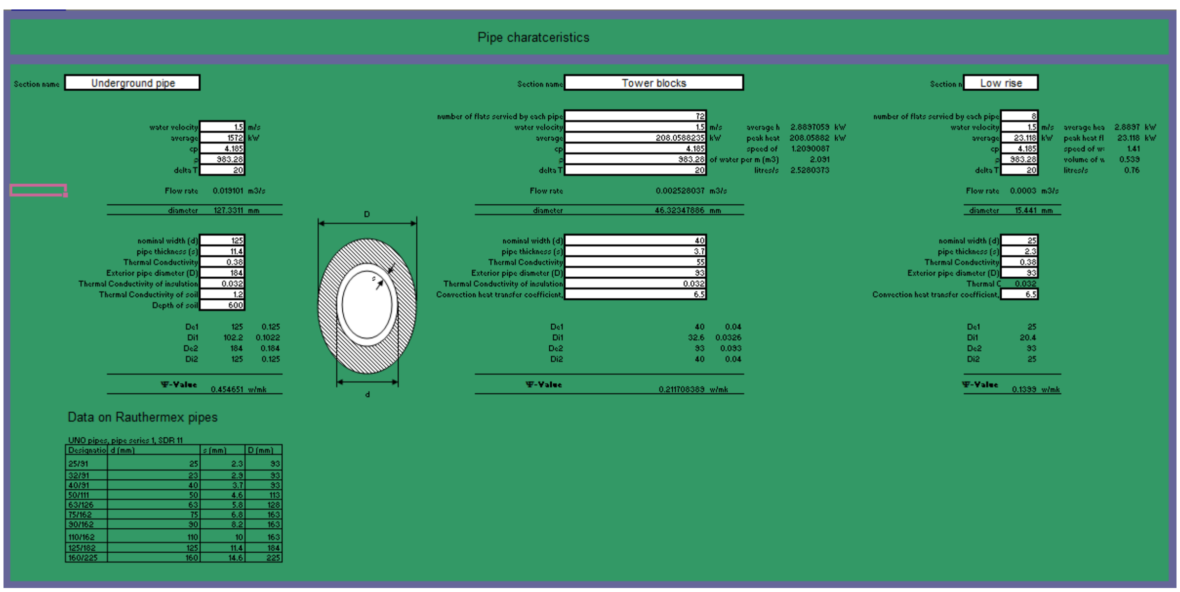


Figure 32 Carbon calculator – pipe characteristics

The output from this section is the total heat transfer coefficient of each section of pipework, which is linked in to the heat loss section of the worksheet.

9.8 Hidden worksheets

There are six hidden worksheets are; Data – fuel, Data – travel, Data – consumption, Data –other, PDF report and Average.

The Data sheets include the relevant data from the UK government emissions factors (AEA 2009) with the exception of Data – other which is used to store lookup tables, inputs into dropdown boxes and outputs from tick boxes.

The Average worksheet is used for storing a record of each individual's survey responses which can be used to analyse the data over a whole community.

The PDF report sheet can be used to create a report from any record stored in the Average worksheet and an example can be seen in

Appendix 1 Example PDF report. The report is created using the buttons in the Total worksheet with is explained in Chapter 9.5.

10 Use of tool in WWHC

The tool was tested in West Whitlawburn and this chapter discusses how it was carried out, issues which arouse, lessons learnt in the process and the results and analysis of the surveys.

10.1 How questionnaire worked

It was felt that a very limited number of responses would be received from sending the survey to each house and asking tenants to fill it in and return it so other possible methods were considered. It was felt that a more successful method would be to go through the questionnaire in person with people however it would be an extremely labour intensive task to knock on doors asking individual tenants if they would be willing to do the survey. For this reason it was decided that a focus group would be the most effective method of conducting the surveys. The focus group was tacked onto an existing residents meeting a number of people would already be attending and this did work, with all tenants attending the meeting filling in the questionnaire.

The questionnaire had been sent to tenants in advance of the meeting so that they knew what information to bring with them and they were asked to bring along and electricity bills that they had. If fact when the tenants arrived at the meeting they had all already filled in the questionnaires and were keen to move on to their regular meeting. This did not allow time to check that all questionnaires had been filled in correctly and as a result there were a number of ambiguous answers. One example was that a respondent had not indicated clearly if they were answering the consumption questions with a weekly, monthly, quarterly or yearly answer. In this case the numbers had been written directly above ‘per week’ and the values were consistent with likely weekly values so it was assumed that these were the amounts spent per week. In the future it would be important to either ensure that the surveys are filled in with supervision or are carefully checked when they are submitted to ensure that they are completed fully.

An number of further surveys were carried out by asking individuals who visited the Housing Co-operate offices to complete the questionnaire. These tenants would not have had previous warning about the survey so would not have been able to check their energy bills and this was reflected in the fact that a number did not enter their energy consumption. Where this was the case the energy consumption for the appropriate size of flat which was modelled with Edem was used. This provides a good estimate and as it turned out the consumption predicted by Edem was quite similar to the actual consumption values supplied by other tenants, but it is obviously to have real data supplied by the tenant.

The experiences of carrying out surveys in these two different methods suggest that the best method in the future would be to hold a number of focus group sessions either in link with existing residents groups or where tenants are invited to attend and offere the incentive of a prize draw for people who take part. Tenants could be asked to bring energy bills with them where possible and the surveys carried out in person with them to ensure that the questions are fully understood and the surveys fully answered.

It is certainly possible that the responses to the survey are either not representative of the overall population, or that an individual's responses do not accurately represent their real situation. One respondent stated that they do not spend any money on toiletries or makeup. It is possible that this is true, or that they spend very little on these items but it seems unlikely for example that they never buy any soap. This would suggest that some questions need to be rephrased to ensure that they are sufficiently clear for everyone. It is likely that the results obtained would be more complete if the surveys were carried out in person as this would allow the surveyor to clarify the meaning of questions or confirm with the respondent that the response is correct if for example, they say that they never spend any money on clothes or shoes.

10.2 Discussion of results

10 carbon footprint surveys were returned in total which represents a sample size of just 2% of the population of 544 flats. Although this small sample size does not allow for detailed statistical analysis of the results it does provide an indication of the energy consumption and carbon footprint of the area. A larger sample size of around

10% or 54 households would be required to give a lower margin of error on the results.

Due to the low number of responses the results were not broken down and analysed by the different socioeconomic groups as had been planned. More surveys would need to be carried out to make an analysis of this type meaningful.

The results of the survey show that the average energy consumption is considerably different to that estimated in the consultant's report (RSP Consulting Engineers 2009) which estimated an average of 12000kWh of electricity for heat and 4000kWh for power per year, giving a total electricity consumption of 16000kWh. This contrasts with an average consumption of just 9639kWh from the surveys carried out. It is not possible from the electricity bills to know how much of this was for heating and hot water and how much was for appliances and lighting, so for the purposes of the calculations it has been assumed that the power consumption is equal to the theoretical power consumption from the modelling exercise in Chapter 8.1 with the remainder of the household's electricity consumption assumed to be for heating and hot water. This method gives an average electricity consumption of 7312kWh for heat and 2327kWh for power. These results are very similar to the results of the modelling which estimated 7703kWh for heating and hot water and 2327kWh for lighting and appliances.

These results will be affected by those respondents who did not fill in the survey fully and who's energy consumption had to be estimated using the theoretical values, but the results of the other respondents also suggest that the consultants have overestimated the energy demand for the site. With such a small sample size it is possible that the results are not representative of the full population but as the highest electricity consumption from any respondent was 11373kWh which is someway short of the estimated average and it suggests that further investigation of the energy demand would be required before a final design of the district heating system was developed.

10.3 Analysis of results

The average carbon footprint of an individual was 6.4 tonnes CO_2e per annum. Figure 33 shows how this is broken down into 2.59 tonnes from home energy use, 0.89 tonnes from travel and 3.21 tonnes from consumption. Whilst it is difficult to compare this to an average produced by a different tool due to the reasons discussed in Chapter 4, this average seems particularly low, with most average UK footprints around 10 tonnes. It is interesting to compare the results to an average footprint published for Scotland by the (West Wales Eco Centre 2010) which states an average footprint of 10 tonnes per person, with 4.3 tonnes attributed to consumption, 2.9 tonnes to domestic energy and 2.1 tonnes to travel. The results for West Whitlawburn are quite similar for domestic energy, which is unsurprising given the electric heating in the site, but significantly lower for both consumption and travel.

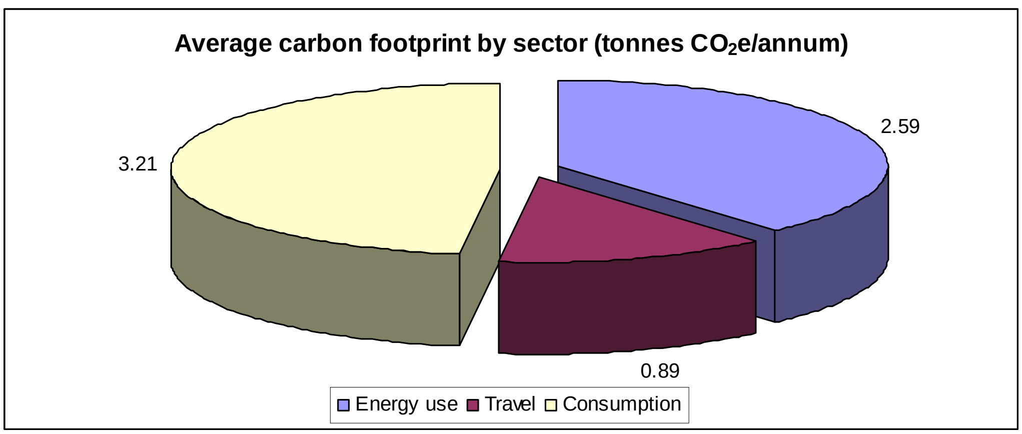


Figure 33 Average carbon footprint

To verify that the results of the calculator are accurate the responses from one of the survey were entered into the carbonfootprint.com calculator and the results compared. As discussed in Chapter 5.4 the carbonfootprint.com section on consumption is quite different in format so it is likely that the results for this section may differ. Table 29 shows the results of the comparison between the two tools, with the results for home and travel almost identical and the results for consumption fairly close. This suggests that the calculator is functioning correctly and that the average footprint from travel and consumption amongst this sample is significantly lower than the national average.

Table 29 Verification of results

	This carbon calculator	carbonfootprint.com
Home	2.51	2.50
Travel	0.06	0.06
Consumption	3.15	3.87
Total	5.72	6.43

There is the possibility that the surveys were not fully or accurately completed and that the level of travel and consumption has been underestimated however it is unsurprising that the results for West Whitlawburn would be lower than the national average in these sections due to the high levels of poverty and deprivation in the area which would limit the inhabitants ability to travel and spend money on goods or services.

10.4 Impact of new heating systems on carbon footprint

Figure 34 shows the average carbon footprint from energy use in the home with the current heating system as well as with biomass or gas CHP district heating installed.

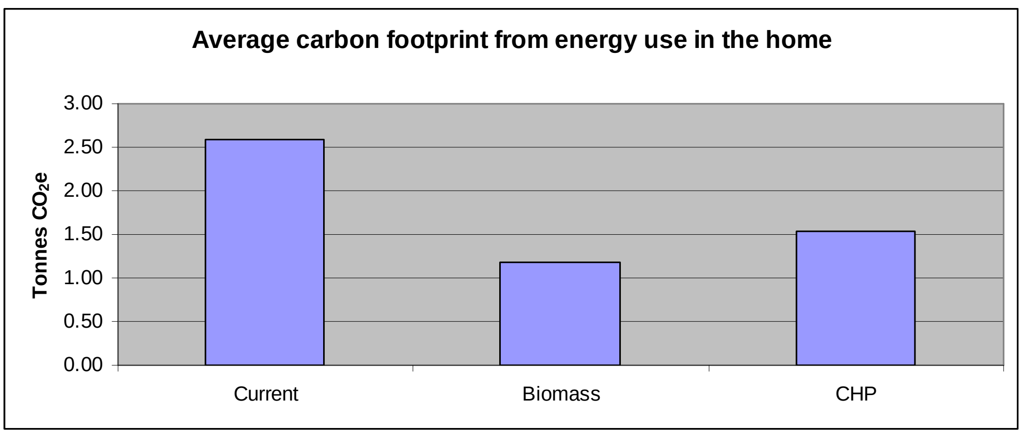


Figure 34 Average carbon footprint from energy use in the home

With biomass district heating installed the average carbon footprint from energy use is more than halved to 1.18 tonnes per year while the average carbon footprint with CHP district heating is also significantly reduced from 2.59 to 1.54 tonnes. It should be noted that this is the carbon footprint for power for appliances and lighting as well as for heating and that the carbon footprint for power consumption will obviously not be affected by the installation of a new heating system. The reduced carbon footprint of the electricity from the CHP system is attributed to the landlord rather than the tenants.

Both proposed systems could have a significant impact on the carbon footprint from energy use in the home, with the biomass boiler the best option in terms of reducing emissions.

It is possible that an improved heating system with significantly lower bills would lead to tenants maintaining their home at a higher temperature, in which case the estimates of CO_2 emissions reductions would be overestimates. This is one of the reasons that the Housing Co-operative set one of the objectives of the system to be that households are individually billed for the amount of heat that they consume. Without this condition it is likely that a large amount of heat would be wasted and whilst it is likely reduced bills will lead to households being maintained at a higher temperature it is less likely that heat will be wasted when households are charged for the amount they use. It is of course the aim of the refurbishments that tenants can afford to heat their homes to a sufficient temperature so it is desirable that those tenants who previously couldn't afford to heat their homes sufficiently would now consume more heat.

10.5 Impact on fuel poverty

Figure 35 shows the fuel cost to maintain a satisfactory heating regime for the current heating system and for biomass and gas CHP district heating. Costs for both systems take into account the capital costs of the system. Both district heating systems are shown to make a significant impact on spending on energy. With the current heating system 8 out of 10 households surveyed were living in fuel poverty with only 3 out of 10 living in fuel poverty with both of the new heating systems. Those households still living in fuel poverty all stated that they have a total household income of below £4999 per year. Table 5 shows that even a single unemployed person would have an income above this level when housing benefit is taken into account and it is possible that the respondents who have stated that they have an income below this level have not included housing benefit in their estimate. It is likely that if housing benefit were included in the calculations then all houses would technically be lifted out of fuel poverty. In future when the survey is carried out it should be specified more clearly that income should take into account housing benefit.

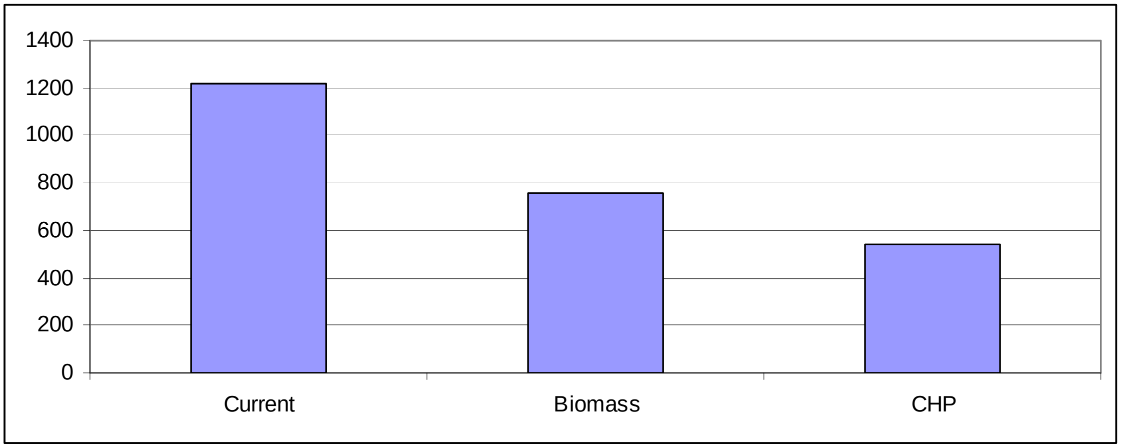


Figure 35 Average spending on energy to meet fuel poverty requirements

Although both systems would leave three out of ten of the households surveyed still living in poverty, the actual costs for the biomass system are considerably higher than for the CHP system. As reductions in energy costs for the tenants are one of the main requirements of the system, it is unlikely that the biomass system could be justified on economic grounds unless some grant funding could be secured or the Renewable Heat Incentive earned. As Table 27 and Table 28, if full grant funding were secured then the economics of biomass becomes competitive with the gas CHP and with the Renewable Heat Incentive it could actually work out cheaper.

11 Future work

11.1 Further work at West Whitlawburn

Although the number of surveys completed from WWHC is currentlylow, the surveys will continue to be conducted and the results will be updated. Once the sample size has reached an acceptable size the results will provide a more meaningful assessment of the carbon footprint of the West Whitlawburn. When a larger number of surveys have been carried out it will be possible to re-evaluate the average energy consumption of the site to see how it fits with the consultants estimates. If the energy consumption is found to be considerably different to the estimate which the design of the heating systems were based on then it would be necessary to change size of the heating systems and heat distribution network. This would be relatively simple to do as it only requires a few inputs into the calculator to be changed and the calculator will automatically change the carbon emissions factors.

11.2 Further use of the tool in other areas

The calculator will be made publically available and can be used by other housing associations, landlords, communities or individuals who wish to calculate the carbon footprint of their community or to asses the impact of installing a district heating system.

11.3 Further developments to the tool

A number of lessons were learnt in the process of carrying out the surveys and these will be reflected in future use of the tool. It will be important that a number of questions are reworded in the survey to ensure that responses are accurate and complete.

The calculator saves the responses of all surveys in the 'Average' worksheet but there is no functionality in the tool to go back into these records to change the data. If the design of the heating systems were to be updated in the future, the only way to change the CO_2 emissions or costs associated with new heating systems in these records of surveys which have already been stored would be to either manually change the data for all of the records in the 'Average' worksheet or to re-enter all of the survey answers for all respondents. In the future it would be worthwhile investigating the possibility of adding a new functionality to the tool which would allow data to be re-called from the average sheet and edited.

A further step for the carbon calculator would be to incorporate the functions into the Edem program. Combining the two tools in this way would allow for a more flexible and complete evaluation of developments. This process would involve adding sections to Edem to calculate the footprint from travel and consumption and also updating some of the existing functions of Edem. Edem currently includes limited options for evaluating the impact of biomass and district heating so it would be important add more detail, including the calculations for heat loss from the pipes as well as more detailed options for configuring the district heating systems such as various different biomass boilers or CHP systems. Edem is already set up to model the theoretical energy consumption but it would also be important to allow the possibility to enter actual energy consumption so that a real carbon footprint can be calculated rather than basing it on the estimates from the model.

Integrating the calculator into Edem would also allow properties with different types of original heating systems to be analysed which would allow for broader potential use of the tool.

12 Conclusions

The objective of developing a carbon footprinting and fuel poverty analysis tool which can analyse the effect that upgrading the heating systems could have on the carbon footprint and fuel poverty levels was achieved. The tool was tested in West Whitlawburn Housing Co-Operative and found to work well. The results of the carbon footprint assessment were verified by entering the same data into another carbon footprint calculator and comparing the two sets of results, which were found to be very similar.

The average carbon footprint of the individuals surveyed in WWHC was found to be considerably lower than the national average for both the travel and consumption sections. This is as would be expected for an area such as West Whitlawburn which suffers from multiple deprivations and has a significantly lower average income than the general population. The majority of the individuals surveyed were living in fuel poverty and for people spending such a large proportion of their already small income on fuel it is not surprising that they have little left to spend on travelling or consumption. The footprint from energy was very close to the national average.

Heat loss

The results for the heat loss calculations show that the heat loss from pipes is significant, representing around 10% of the total heat demand of the site. It is essential to take these losses into account when assessing the feasibility of a potential district heating system however it was shown in the case study of WWHC that these losses are not prohibitive to the scheme. It would be important to take all reasonable measures to ensure that the pipe layout is as direct as possible as this will save money both from heat losses and the installation of the system.

Costs and recommendations

Both proposed heating systems were found to fulfil the objectives of reducing the CO_2 emissions and fuel poverty levels and both would be suitable solutions for West Whitlawburn

The gas CHP system makes the biggest impact on energy costs, reducing the average cost to maintain a satisfactory heating regime from £1263 to £539, compared to £755 for biomass.

Conversely, the biomass system produces the biggest CO_2 saving, reducing the average emissions from energy consumption from the current level of 2.59tonnes per year to 1.18 tonnes. This compares with CHP which is reduced to 1.54 tonnes.

Currently a gas CHP district heating system would be the most appropriate for West Whitlawburn as it has the biggest impact on energy costs, whilst also making a significant reduction in carbon dioxide emissions.

References

AEA, 2009. *2009 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting*, UK: Department of Energy and Climate Change (DECC) and the Department for Environment, Food and Rural Affairs (Defra).

AEA, 2010. *2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting*, UK: Department of Energy and Climate Change (DECC) and the Department for Environment, Food and Rural Affairs (Defra). Available at: http://www.defra.gov.uk/environment/business/reporting/pdf/100805-guidelines-ghg-conversion-factors.pdf.

Biomass Energy Centre, 2009. What is BIOMASS? Available at: http://www.biomassenergycentre.org.uk/portal/page?_pageid=76,15049&_dad=portal&_schema=PORTAL [Accessed August 9, 2010].

BioPDF, 2007. PDF Writer. Available at: http://www.biopdf.com/.

BRE, 2009. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, Garston. Available at: http://www.bre.co.uk/filelibrary/SAP/2009/SAP-2009_9-90.pdf.

British Standards Institution, 2010. *PAS 2060:2010 : Specification for the demonstration of carbon neutrality*, London: BSI British Standards Institution.

Carbon Footprint Ltd, 2010. Carbon Footprint Calculator. Available at: http://www.carbonfootprint.com/calculator.aspx [Accessed June 8, 2010].

CE55 Energy Saving Trust, 2004. *Community heating – a guide*, London: Energy Saving Trust.

Center for Sustainable Economy, 2010. Ecological Footprint Quiz by Center for

Sustainable Economy. Available at: http://www.myfootprint.org/en/visitor_information/ [Accessed June 7, 2010].

Clarke Energy Ltd, 2007. Jenbacher type 2. Available at: http://www.clarke-energy.co.uk/downloads/type2.pdf.

COFORD WoodEnergy, 2010. WoodEnergy.ie. Available at: http://www.woodenergy.ie/iopen24/defaultarticle.php?cArticlePath=51.

Dawkins, E., Roelich, K. & Owen, A., 2010. *A Consumption Approach for Emissions Accounting - the REAP Tool and REAP Data for 2006*, York: Stockholm Environment Institute. Available at: http://www.resource-accounting.org.uk/uploads/Reports/REAP%20Documentation%20April%202010.pdf.

Department for Energy and Climate Change, 2001. *The UK Fuel Poverty Strategy*,

Department of Energy and Climate Change, 2010. Prices of fuels purchased by non-domestic consumers in the United Kingdom excluding/including CCL (QEP 3.4.1 and 3.4.2). Available at: http://www.decc.gov.uk/en/content/cms/statistics/source/prices/prices.aspx.

Energy Saving Trust, 2008. Guidance on meeting the energy efficiency requirements of the Scottish Housing Quality Standard. Available at: http://www.energysavingtrust.org.uk/business/Publication-Download/?oid=396297&aid=1231473.

Energy Systems Research Unit, 2008. *EDEM*, University of Strathclyde: University of Strathclyde.

Feist, W., 2007. *Passive House Planning Package 2007*, Darmstadt: Passiv Haus Institut.

Forestry Commission Scotland, 2010. Energy Content of Wood. *Wood Energy*. Available at: http://www.usewoodfuel.co.uk/EnergyContentofWood.stm.

Glasgow City Council, 2005. *Glasgow's Local Housing Strategy 2003-2008 - Update 2005 - Fuel Poverty Strategy*, Glasgow.

Global Footprint Network, 2009a. Footprint Basics - Overview. *Global Footprint Network*. Available at: http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_basics_overview/.

Global Footprint Network, 2009b. Glossary. *Global Footprint Network*. Available at: http://www.footprintnetwork.org/en/index.php/GFN/page/glossary/ [Accessed August 6, 2010].

Google - Imagery, 2010. Google Maps. Available at: http://maps.google.com/.

Google Inc., 2010. *Google Earth*, Google Inc. Available at: http://earth.google.com/.

Hoval Ltd, 2009. Hoval Forester UFS Wood chip boiler outputs from 180 to 2000kW. Available at: http://www.hoval.co.uk/docs/GB/PDFs/Hoval_Forester_UFS%28180-2000%29_Jan_09.pdf.

Intergovernmental Panel on Climate Change., 1996. *Climate change 1995 : the science of climate change*, Cambridge ;;New York: Cambridge University Press.

Kollmuss, A. & Bowell, B., 2006. *Voluntary Offsets For Air-Travel Carbon Emissions: Evaluations and Recommendations of Thirteen Offset Companies*, Medford, MA, USA: Tufts Climate Initiative, Available at: http://www.tufts.edu/tie/carbonoffsets/TCI_Carbon_Offsets_Paper_April-2-07.pdf.

Minx, J. & Wiedmann, T., 2008. A Definition of 'Carbon Footprint'. In *Ecological economics research trends*. New York: Nova Science Publishers, pp. 1-11. Available at: https://www.novapublishers.com/catalog/product_info.php?products_id=5999.

Oxford Dictionaries, 2010. carbon footprint. In *Oxford Dictionaries*. Oxford University Press. Available at: http://www.oxforddictionaries.com/view/entry/m_en_gb0978170 ER.

Peters, G.P., 2010. Carbon footprints and embodied carbon at multiple scales. *Current Opinion in Environmental Sustainability*, In Press, Corrected Proof. Available at: http://www.sciencedirect.com/science/article/B985C-5088MK2-1/2/30642f548d5de0fc1def7662a060b290.

RAUTHERMEX, 2005. Technical information 817600 EN. Available at: http://www.rehau.co.uk/files/Technical_information_RAUTHERMEX_817600_.pdf.

Rogers, G. & Mayhew, Y., 2002. *Thermodynamic and transport properties of fluids.* 5th ed., Oxford: Blackwell.

RSP Consulting Engineers, 2009. *West Whitlawburn Housing Co-Operative - Renewable Energy Feasibility Study*, Glasgow.

Scottish Government, 2010. Scottish Neighbourhood Statistics Report. *Scottish Neighbourhood Statistics*. Available at: http://www.sns.gov.uk [Accessed July 4, 2010].

The Engineering Toolbox, 2005a. Flow Rates in Heating Systems. *The Engineering Toolbox*. Available at: http://www.engineeringtoolbox.com/flow-velocity-water-pipes-d_385.html [Accessed August 6, 2010].

The Engineering Toolbox, 2005b. Maximum Flow Velocities in Water Systems. *The Engineering Toolbox*. Available at: http://www.engineeringtoolbox.com/flow-velocity-water-pipes-d_385.html [Accessed July 12, 2010].

The Royal Commission on Environmental Pollution, 2004. *Biomass as a renewable energy source*, [London] :: Royal Commission on Environmental Pollution, Available at: http://www.rcep.org.uk/.

The Scottish Government, 2009. Guidance to Local Authorities on Fuel Poverty: Case Studies. Available at: http://www.scotland.gov.uk/Publications/2009/05/28154437/1 [Accessed June 14, 2010].

The Scottish Government, 2002. Scottish Fuel Poverty Statement. *The Scottish Fuel Poverty Statement*. Available at: http://www.scotland.gov.uk/Publications/2002/08/15258/9955 [Accessed June 4, 2010].

The Sustainable Development Commission Scotland, 2005. *Wood fuel for warmth - A report on issues surrounding the use of wood fuel for heat in Scotland*, Edinburgh: The Sustainable Development Commission Scotland. Available at: http://www.sd-commission.org.uk/publications/downloads/050626-SDC-Wood-Fuel-for-Warmth.pdf.

Ward, S. & Holley, M., 2003. *Bristol City Council Biomass Study*, Bristol: Centre for Sustainable Energy. Available at: http://www.cse.org.uk/downloads/file/pub1055.pdf.

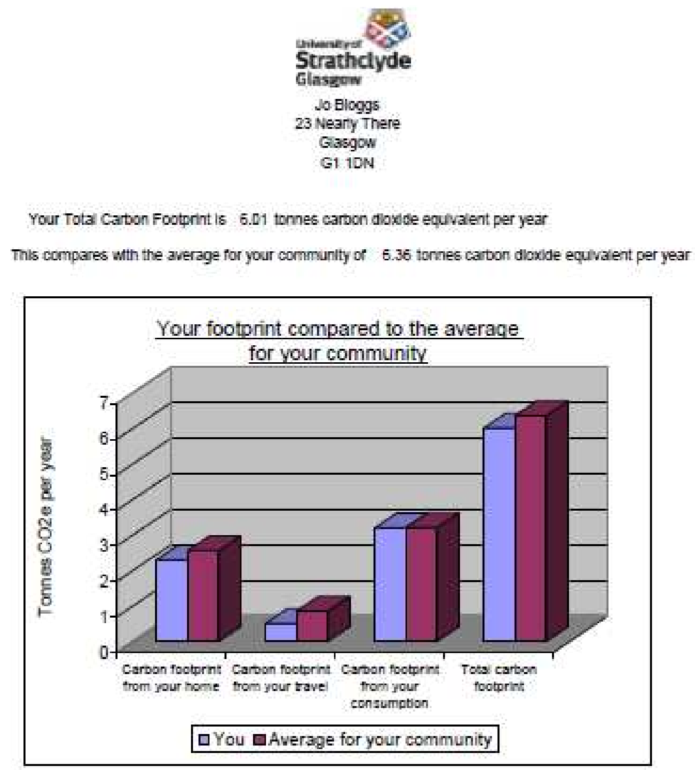
West Wales Eco Centre, 2010. The average carbon footprint per person in the UK - Climate Change Wales. Available at: http://www.climatechangewales.org.uk/public/?id=112.

West Whitlawburn Housing Co-operative, 2010. *West Whitlawburn Climate Challenge Fund Application Form*, Glasgow.

World Wildlife Fund, 2010. WWF Footprint Calculator. *WWF UK - for a living* *planet*. Available at: http://footprint.wwf.org.uk/.

WWF & Sustainable Scotland Network, 2009. *A Footprint Guide for Scottish Local Authorities and Community Planning Partnerships*, UIK. Available at: http://www.localfootprints.org/documents/8477_LFP%20Footprint%20Guide%20FINAL.pdf.

Appendix 1 Example PDF report


University of Strathclyde Glasgow

Jo Bloggs
23 Nearly There
Glasgow
G1 1DN

Your Total Carbon Footprint is 6.01 tonnes carbon dioxide equivalent per year

This compares with the average for your community of 6.36 tonnes carbon dioxide equivalent per year

Appendix 2 Printable survey

Carbon footprint survey

Any information that you provide on this form will be held in the strictest confidence. Your answers will be used to calculate your ‘carbon footprint’ in tonnes of carbon dioxide. Your carbon footprint will be used along with other people’s to estimate the total carbon footprint of your community as part of a study for the University of Strathclyde. Your name will not be used in the study however if you would like to hear feedback on what your carbon footprint is then please enter your name and address below so that it can be delivered to you.

If you wish to receive feedback on your carbon footprint, please enter your name and address below:

Name	
Address	

You can choose to answer questions in the 'Your shopping' section based on what you do or spend as an individual or based on the total for your household – please tick below if you are answering as an individual or a household.

☐ Individual ☐ Household

PLEASE NOTE: Section 2 – 'Your energy' should be answered based on the total energy use for your household.

PLEASE RETURN THIS FORM TO:

WEST WHITLAWBURN HOUSING CO-OPERATIVE RECEPTION

You and your household

1. How many Adults live in your house?		2. What are their ages?	
3. How many children live in your house?		4. What are their ages?	
5. How many bedrooms do you have in your house?			

6. Do you live in ☐ High rise tower or ☐ Low rise building

Please specify the building name and the floor you live on:

7. What is your total household income?

☐ £0-£4,999 ☐ £5,000-£7,499 ☐ £7,500-£9,999

☐ £10,000-£14,999 ☐ £20,000-£29,999 ☐ £50,000-£74,999
☐ £15,000-£19,999 ☐ £30,000-£49,999

8. How many days per week is someone in your house at home during the daytime?

9. How happy are you with your current heating system?

☐ Very happy ☐ Satisfied ☐ Unhappy

10. Do you feel that you can afford to heat your home to a comfortable temperature in winter?

☐ Yes ☐ No

11. What do you understand by the term fuel poverty?

12. Do you think that fuel poverty is a problem for people in your neighbourhood?

☐ Not a problem ☐ A small problem ☐ A serious problem

Your Energy

13. How do you pay for your electricity?

☐ Pre-payment card or key ☐ Monthly bills ☐ Quarterly bills
☐ Other, please specify

Please supply as much detail as possible about your electricity use as possible, preferably for a full year or several months.

14. Which company supplies your electricity?	
15. How much does your electricity cost per unit and for the standing charge? (This should be written on your bill)	Standing charge Per unit (KWh)
16. How many units of electricity does your household use or how much do you spend on electricity?	£/units per week/month/quarter/year (please circle)

Your Travel

17. Do you own or sometimes use a car, van or motorbike?

☐ Yes ☐ No

18. If not please continue to question 21, otherwise:

What type of vehicle do you own?

☐ Car	☐ Small	☐ Petrol
☐ Van	☐ Medium	☐ Diesel
☐ Motorbike	☐ Large	☐ Hybrid
	☐ Average	☐ LPG or CNG

	How many litres of fuel do you use	Or, how much do you spend on fuel	Or, how many miles do you drive
19. How much do you use your vehicle? Please answer one of the following questions:	Litres per week/month/quarter/ year (please circle)	£ per week/month/quarter/ year (please circle)	Miles per week/month/quarter/ year (please circle)

20. How much do you spend on maintenance and repair or your vehicle?

£ per week/month/quarter/year (please circle)

Public Transport

21. Please list the number of miles travelled by each of the following forms of public transport. If you don't know the distance then please list any journeys made (such as from home to Glasgow City Centre) and how often you make this trip.

	Distance travelled or trips made
Bus	Miles per week/month/quarter/year (please circle)
Train	Miles per week/month/quarter/year (please circle)
Ferry	Miles per week/month/quarter/year (please circle)
Coach	Miles per week/month/quarter/year (please circle)
Taxi	Miles per week/month/quarter/year (please circle)
Subway	Miles per week/month/quarter/year (please circle)
Eurostar	Miles per week/month/quarter/year (please circle)

22. Please list any flights that you have taken in the last year (and specify if it was a single or return flight)

Your shopping

23. How much do you spend on the following items?

Food and drink	£ per week/month/quarter/year (please circle)
Clothes	£ per week/month/quarter/year (please circle)
Shoes	£ per week/month/quarter/year (please circle)
Newspapers and books	£ per week/month/quarter/year (please circle)
Hotels, restaurants, pubs	£ per week/month/quarter/year (please circle)
Toiletries and makeup	£ per week/month/quarter/year (please circle)
Cigarettes and tobacco products	£ per week/month/quarter/year (please circle)

24. If you bought any of the following last year, how much did you spend on them?

Electronic gadgets such as TVs, MP3 players or kitchen appliances	£
Computers and computer equipment	£
Furniture	£
Power tools	£
Painting and decorating	£

A new car	£
Jewellery	£

25. How much do you spend on hobbies or activities such as going to the cinema, or sports events?

£ per week/month/quarter/year (please circle)