Department of Mechanical and Aerospace Engineering

Investigating Energy Demand Reduction Potential in an Urban Community

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Signed: Nicholas Major   Date: 25/08/2017

Abstract

The aim of this project was to quantify the energy demand reduction potential for an urban community in Scotland. Through a literature review an understanding of the current work in this area. Some of the papers found followed a process to quantify the demand on a national scale, but there was no defined methodology of how to apply this at a community scale. Energy demand reduction is a vital component of some strategies studied, however plays a significantly smaller role in the most recent Scottish Energy Strategy. The review also highlighted that research in demand reduction in complex and highly interdisciplinary, so it was decided that the scope of the project should only be to quantify the demand reduction potential for the community.

Through a selection process, Govanhill was selected as to community for this study. This was followed by an energy demand audit which quantified the current energy demand of the community in terms of heat, electricity and transport. This found that the majority of demand is in domestic heat, so effort in demand reduction should be focussed here.

The energy demand reduction potential of a range of measures was quantified. This was expressed in terms of the maximum potential reduction for the community (i.e. if measure was installed throughout the community). The results which have been presented could be used as part of the future community energy strategy. The project concluded with a consultation with an industry group and a local community action group.

The calculations aimed to best reflect the community as much as possible. The consultation highlighted that there are many characteristics of the community which are not captured in the data used for the calculations. If this study were to be replicated, it is highly recommended to include physical survey of the community to improve the accuracy of the calculations.

Acknowledgements

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1. INTRODUCTION

Q: What is the greenest unit of energy?

A: The one we don't use.

In recent years, there has been continuous progress towards more sustainable energy systems worldwide. This has been driven primarily by a greater understanding of the impacts of carbon intensive lifestyles and the urgent need for more sustainable energy. There are further challenges to energy beyond carbon intensity, which are described as the energy trilemma:

1. **sustainability** – low carbon, renewable energy

2. **affordability** – energy which is within the budget of all members of a population

3. **security** – sufficient supply to meet demand when required

The challenges faced by the energy industry over the next few decades are huge and there are several different approaches which are being taken to make the changes which are needed.

Scotland has always been a country at the forefront of the sustainable energy transition. This is due to a number of factors, primarily to the plentiful renewable resources available as well as the attitude of the country's government. The Climate Change (Scotland) Act 2009 set a requirement for Scotland's Green House Gas (GHG) emissions in 2050 to be reduced by 80% compared to 1990 levels, in line with the recommendations from the international Paris Agreement. So far, significant progress has been made to reduce emissions which has resulted in the emissions in 2015 being 37.6% lower compared to 1990 as

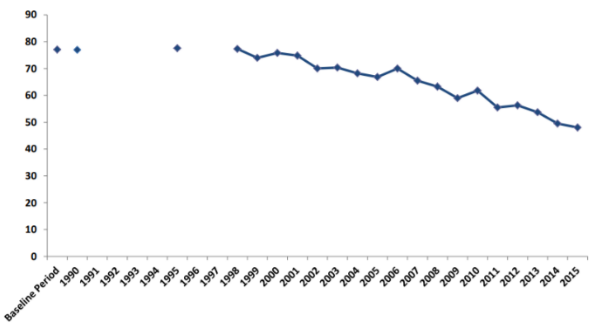

Figure 1 - Historic carbon emissions in Scotland

shown in figure 1. The interim target of the Climate Change Act of 42% reduction by 2020 has been met 6 years early.

The emissions reductions are met by a number of sectors with different approaches being taken for each sector. The majority of emissions reduction so far has come from sharp increases in renewable electricity supply as well as technological advances in the agriculture and waste management sectors. Minimal emission decreases have been achieved in other sectors such as transport and residential housing.

The majority of developments to achieve a more sustainable energy system have been focussed on increasing renewable supply. However, it can be argued that far more is required to achieve the targets set for 2050. One approach is to focus on energy demand reduction, where the end use need for energy is reduced. In the past few years, there has been some progress in reducing energy demand with a 15% reduction in final energy demand from 2005 to 2014, however the further demand reduction should be explored to understand the potential savings which could be achieved. There are two different ways of reducing energy demand: energy efficiency and demand reduction. As an example, car transport has had developments in reduced fuel consumption, which can be described as energy efficiency, but if the car is only used for half of the journeys for that household, that is demand reduction. Both are valid approaches and both are considered in this research project. So far, simple "quick wins" such as cavity wall insulation for dwellings have been implemented, but there are many more opportunities available which should be explored as part of Scotland's future energy strategy.

2. GENERAL AIM OF THE PROJECT

Energy demand reduction can be part of a national strategy for Scotland. However, to allow for an understanding of the impact on a large scale, it is helpful to first look at the implementation on a smaller scale. This project has the general aim to study the demand reduction opportunities in an urban community. Studying an urban community was selected for several reasons. Mainly as the majority of national energy demand will continue to be in an urban environment. In addition, the space available for local renewables can often be a limiting factor.

In order to achieve the general aim, this project will:

1. Consider the current policy position and research practice of demand reduction

2. Quantify the current energy demands for the selected community

3. Investigate the impact of a range of demand reduction techniques on this community energy demand

4. Assess which techniques may have the greatest potential for the selected community

Studying these aspects should provide a good framework to prioritise future development for this community. If the methodology is sound, it may be possible for this same process to be applied to other communities wishing to improve their sustainability. If the measures are also effectively applied to a wider network of communities, further progress towards the targets set by the *Climate Change Act* would be delivered, making energy reduction part of the wider energy strategy for Scotland.

3. METHODOLOGY

Objective:

Assess the demand reduction potential for an urban community in Scotland.

Approach:

To achieve the general aim described above the following stages were followed for this research project:

Stage 1 – Literature review, to understand current research and policy in energy demand reduction

Stage 2 – Select community

Stage 3 – Quantify current energy demand of the community

Stage 4 – Quantify demand reduction potential

Stage 5 – Consult with local organisations to gain opinions of potential measures

Stage 6 – Conclude main findings and recommendations

These stages follow a robust approach which should provide useful insight into the potential of demand reduction in urban communities. If the findings are positive, then there is the opportunity for the same approach to be applied to other communities of a similar type. It may also inform future studies into the wider socio-economic benefits of demand reduction methods.

3.1. Stage 1 – Literature Review

The literature review is a vital step for any research project. The main purpose of this stage in the project is to gain a thorough understanding of the research and development work undertaken thus far in demand reduction. It also allows an understanding of demand reduction's current place in Scottish policy.

3.1.1 Sustainable energy in the UK

The first area of focus was to determine research papers which have studied and quantified energy demand by energy demand type (i.e. heating, electricity, transport, etc.) Most commonly energy demand is expressed in terms of fuel consumption by sector or fuel type, rather than to a higher resolution required for this study. Higher resolution will not only help to achieve greater accuracy when determining the energy demand of the community, but it will also allow an understanding of where energy demand comes from.

Sustainable Energy – Without the Hot Air (SEWTHA) by David JC MacKay aims to determine if the UK is capable of running entirely on renewable energy. The method taken in SEWTHA to achieve this was to quantify the energy demand by type and maximum renewable generation potential by technology type. The results in SEWTHA will inform the process of quantifying the energy demand for the selected community in this project, but also give a wider perspective of the available renewable energy resources which can supply the demand.

The forms of energy demand which are considered in SEWTHA are transport (cars, planes, freight), heating and cooling, lighting, information systems and other gadgets, food and manufacturing. The results of the energy demand calculations carried out are shown in figure 2. The total energy demand for the UK is 195 kWh/person per day. It is useful to express the energy demand in these units as it gives a perspective of the scale of demand. The approach taken for the calculations is well founded, using simple equations which accurately represent the energy demand for each form for the whole of the UK.

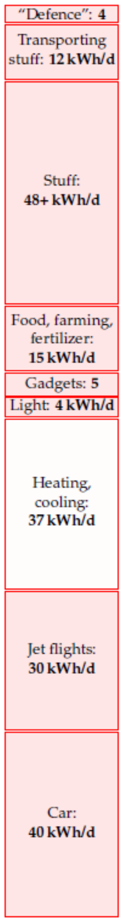

Figure 2 - SEWTHA UK Energy Demand

For this project, a number of the sectors will be of particular interest when calculating the energy demand for the community. These are: car transport, heating and electricity. It is worth noting that while the community will have a demand for all of the sectors defined in SEWTHA, the above three categories have been selected as a focus for this study as they will likely require the most community development to achieve demand reduction. The calculation approach and energy demand for the sectors are shown below.

Car transport:

- Calculated using: energy used per day = distance travelled per day/distance per unit of fuel * energy per unit of fuel

$$Total\ demand = 40\ kWh/day\ (20.5\%\ of\ total)$$

Heating (separated into hot water – including cooking and washing – and space heating):

- Hot water demand based on Power consumption * time in use per day
- Space heating demand estimated assuming that a 1kW electric fan is used per person for half of the year. However, most people use more than they need so demand is doubled

$$Total\ demand\ for\ hot\ water = 12\ kWh/day\ (6.2\%)$$

$$Demand\ for\ space\ heating = 24\ kWh/day\ (12.3\%)$$

Electricity:

- Lighting calculated based on 10 bulbs with a mix of incandescent and low energy bulbs used for an average of 5 hours per day
- Domestic lighting estimated around 5.5 to 2.7 kWh/p/d for a 2-person household
- workplace lighting estimated at 1.3 kWh/p/d, totalling 4 kWh/p/d
- Other electrical appliances roughly estimated to 5 kWh/day

$$Total\ demand\ for\ lighting: 4\ kWh/p/d\ (2.1\%)$$

$$Total\ demand\ for\ other\ electrical\ appliances: 5\ kWh/p/d\ (2.6\%)$$

While the calculation methods and demands will likely be accurate when aggregated over the whole of the UK, the approach relies heavily on rough estimates, which can introduce a high degree of error if the same method is used for a small community. One of the main purposes of focussing on a small community for this project is the benefit of more accurate results in terms of current demand and demand reduction potential.

For the purpose of this study, the calculation used to estimate car transport energy demand in SEWTHA should be used for this project, since the values for distance travelled and efficiency can easily be altered.

For the other energy demands, a more accurate method which takes into account the specific properties of the community should be used where possible. For example, the space heating demand will vary significantly depending on the quality of the local building stock.

As described above, the aim of SEWTHA was to compare current energy demand and renewable generation potential. When calculating the *maximum* renewable generation the total figure is 180 kWh/p/d, very close to the calculated demand of 195 kWh/p/d. The issue here is that to achieve this level of generation, the renewable facilities must be country-sized. For example, the calculation for onshore wind requires an area the size of Wales and for energy crops, 75% of the land area would need to be covered. This approach may be possible, but would come up against severe difficulties, primarily the competition for space as well as public perception of such a large system of renewables. Applying what the public would believe is acceptable for the UK, the author found that the amount of renewable generation would only be around 18 kWh/p/d with the issues reducing the realistic generation shown in Figure 3. From this result, it can be stated that to move towards a more sustainable energy system requires either the majority of the land area being dedicated to renewable generation, or a significantly reduced energy demand, or both. This highlights the need for energy demand reduction and more research and development in this area.

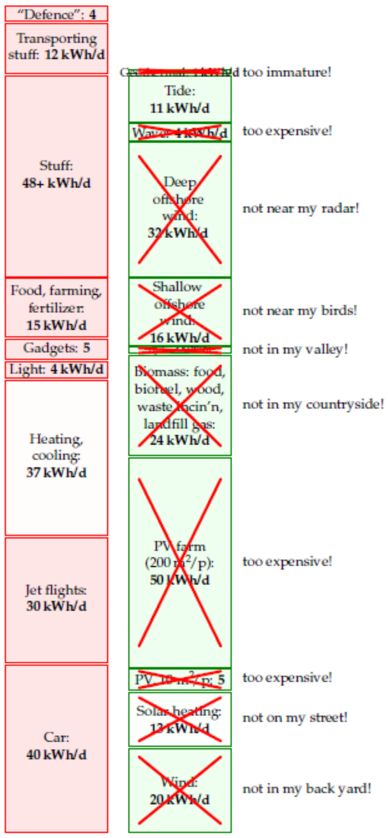

Figure 3 - Impact of public perception on renewable large scale renewable generation

Further on in the paper, the author looks at future developments and ways in which energy consumption can be reduced. The two highlighted methods, which will have the largest difference are:

1. Transport mode shift towards public and active transport and electrification of the transport system
2. Improved heating through increased efficiency of heat generators and reducing heat loss in buildings

The calculated potential demand reduction for transport is 50%, while the saving for heating is 25%. This gives a good indication of the difference which can be made. An outcome of the project is to generate more accurate figures for the potential demand reduction of the selected community for a range of measures.

Throughout the process of this project further energy demand can be identified for the selected urban community.

SEWTHA shows the impact of our daily actions and also highlights the energy demand reduction achieved through changes in lifestyles. These actions are shown in figure 4. For example, moving to a vegetarian diet for all but one day a week reduces energy demand by 10 kWh/d, 25% more than installing solar thermal panels. If possible it would be interesting to highlight the impact of decisions like this for the community, to give a greater perspective of where to focus effort to reduce demand.

Simple action	possible saving
Put on a woolly jumper and turn down your heating's thermostat (to 15 or 17 °C, say). Put individual thermostats on all radiators. Make sure the heating's off when no-one's at home. Do the same at work.	20 kWh/d
Read all your meters (gas, electricity, water) every week, and identify easy changes to reduce consumption (e.g., switching things off). Compare competitively with a friend. Read the meters at your place of work too, creating a perpetual live energy audit.	4 kWh/d
Stop flying.	35 kWh/d
Drive less, drive more slowly, drive more gently, carpool, use an electric car, join a car club, cycle, walk, use trains and buses.	20 kWh/d
Keep using old gadgets (e.g. computers); don't replace them early.	4 kWh/d
Change lights to fluorescent or LED.	4 kWh/d
Don't buy clutter. Avoid packaging.	20 kWh/d
Eat vegetarian, six days out of seven.	10 kWh/d

Major action	possible saving
Eliminate draughts.	5 kWh/d
Double glazing.	10 kWh/d
Improve wall, roof, and floor insulation.	10 kWh/d
Solar hot water panels.	8 kWh/d
Photovoltaic panels.	5 kWh/d
Knock down old building and replace by new.	35 kWh/d
Replace fossil-fuel heating by ground-source or air-source heat pumps.	10 kWh/d

Figure 4 - Potential energy saving of a range of measures

Sustainable Energy – Without the Hot Air will be a valuable resource for this project. The approach to separate the demand calculations into so many different categories is particularly useful. While there are issues in the calculation methods used in SEWTHA, having a detailed range of categories will help with understanding the energy demand results in this project. The main finding which relates to this project is that when considering public acceptance, renewable generation is an order of magnitude smaller than the energy demand, as shown in Figure 3. This shows the requirement for further development in the area of demand reduction, with the examples of transport and heating giving an indication of the potential reductions which can be achieved. The task of this project is to determine the full potential of demand reduction in the context of an urban community.

3.1.2 Demand reduction in Scottish strategy

Following the review of SEWTHA, it was important to find out if similar studies had been carried out in Scotland, to determine to what extent demand reduction should be a part of energy strategy in this context. Ricardo Energy and Environment (RE&E) conducted a technical strategy paper for WWF Scotland: *The Energy of Scotland: Heating, Moving and Powering our Lives from Now to 2030*. RE&E are a consultancy firm specialising in a wide range of energy system modelling and policy advice. Here, they were tasked with developing a scenario which achieves a target of 66% emissions reduction on 1990 levels by 2030 in a cost optimal way. The report details the targets and vision which need to be met as well as the benefits and actions for each of the sectors. The key headlines which describe the scenario are:

- Energy efficiency – 20% lower demand than today
- Heating – 40% of Scotland's heat from renewables
- Electricity – Scotland generates equivalent of 143% of electricity demand
- Transport – half of buses and 1 in 3 cars are electric; 18% of transport coming from renewables

Energy efficiency here is described as the "bedrock of carbon reduction". This confirms the importance of demand reduction and the requirement for it as part of Scotland's energy strategy. In the RE&E report, they anticipate energy efficiency will advance with vehicles, electrical appliances and most of all with buildings. For the built environment, this will be achieved through a major programme to retrofit existing homes and buildings, which will reduce domestic heating demands by 30% by 2030. To add to this, new building regulations will be to a higher standard and more efficient appliances will be common. Improved efficiency in transport and heating systems through electrification will also reduce final energy demand and should be taken into account when performing calculations in this project.

The benefits of reducing building heating demand by 30% were also highlighted. In addition to reducing carbon emissions, retrofitting buildings lowers energy bills and in the RE&E scenario, fuel poverty is eradicated. The improved indoor air quality is estimated to save the NHS £48-£80 million and the process of retrofitting will support economic development, creating 8-9000 jobs. Lowering heating demand will also allow for low temperature heating systems through heat pumps, allowing for zero carbon housing. This highlights the potential socio-economic benefits of demand reduction, particularly in space heating. Following the energy demand results from the RE&E study, it would be of particular interest to determine the socio-economics of the demand reduction measures investigated. This would strengthen the business case and quantify the full benefit to the local communities and government.

To achieve the targets set out, RE&E specify that a clear vision must be shown by the Scottish Government. An energy efficiency programme should be produced to support developments in this area and multi-year funding must be in place to deliver at scale. Uptake should be driven by regulation of minimum standards which will be supported by grants and loans to households. This clear vision and comprehensive programme is of paramount importance for a large-scale demand reduction scheme to deliver on targets.

So how does this scenario developed by RE&E compare to Scottish policy? *The Draft Climate Change Plan (third report)* and the *Scottish Energy Strategy*, both published in January of 2017 have set out the Government's vision to 2032 in anticipation of the 2050 target. By 2032, the aim is to achieve a 66% reduction in greenhouse gas emissions compared to 1990 levels. If this can be achieved, Scotland will be at the forefront of tackling climate change, with the yearly targets shows in Figure 5. Emissions reductions will be achieved mainly in the sectors of electricity, waste, transport, residential housing and services. The main approaches outlined include almost complete decarbonisation of electricity (including carbon capture and storage), 80% of buildings supplied by low carbon heat,

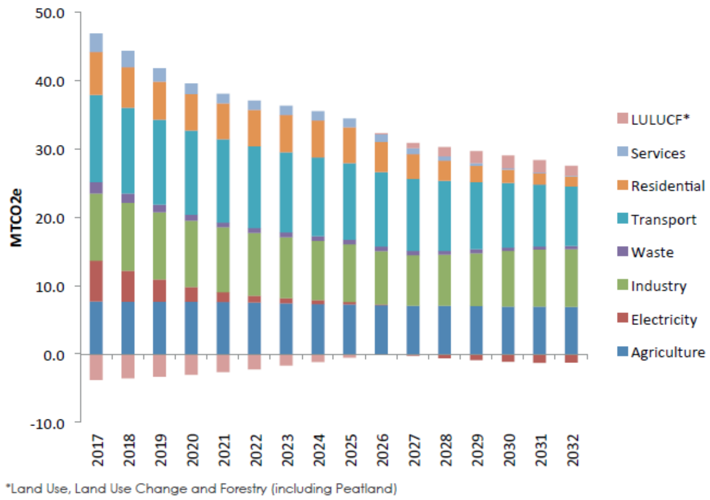

Figure 5 - Scotland emission targets up to 2032

low emission cars and vans being widespread and waste management systems moving towards a circular economy.

The energy demand reduction measures set out by the Scottish Government are of significantly lower priority than those set out in the RE&E strategy. While services (non-domestic sector) will have more of a focus on energy efficiency, the target set for the residential sector is only a 6% reduction in heating demand achieved through moderate increases in cavity and loft insulation. Compare this to a 30% reduction in the RE&E scenario. Energy demand will be decreased through greater use of electrified transport, however there is little in the way of modal shift or reducing the need for travel, which will lead to reduced emissions.

The main findings from the two Scottish Government strategy documents show that demand reduction currently only plays a small role, contradicting the findings from the SEWTHA paper and the scenario from RE&E. There is an overall lack of clarity on how the targets for each sector are going to be achieved, which is essential. For example, the decarbonisation of electricity could take a number of permutations and this isn't described in the strategies. This has been highlighted by Professor Alf Young of Strathclyde University, who states that the energy strategy may be "an ambition too far" due to the lack of clarity. Because the fact that this strategy is looking at a reasonably long timescale it is impossible to predict the exact technologies, but greater clarity is still required. These findings suggest that the Scottish Government believe that further development and demonstration of the benefits of demand reduction is needed if it is to play a more vital role in a national energy strategy. However, it may be the case that support is needed from the government first to support these developments. This could be described as a chicken and egg scenario. If demand reduction techniques are shown to have a significant impact on the sustainability of the community, this could lead to further developments which in turn could lead to higher prioritising from the Scottish Government.

3.1.3 Community energy development

Community energy is one of the key components of Scotland's *Energy Strategy*. Community ownership can have many benefits for the local population and there are a number of organisations and financial incentives which support such developments. The UK Government's *Community Energy Strategy: Full Report* states that "community energy covers aspects of collective action to reduce, purchase, manage and generate energy". In Scotland, the main organisation which supports community energy schemes is Community Energy Scotland. This organisation has helped almost 300 community energy projects throughout Scotland, with the vast majority of these projects focussing on small-scale renewable generation installations. Only a handful of their projects focus on energy efficiency. This is the case with almost all community energy projects, and one of the key reasons is described by Community Energy England who state:

"Energy efficiency and demand reduction has struggled to produce working business models at community level as they don't offer the same guaranteed income streams"

This has tended to be the case with many energy efficiency and demand reduction projects and was one of the key issues with the now defunct Green Deal, which was a financing scheme for improvements to buildings. For any of the measures suggested in this project to be deemed successful, it is essential that the energy demand reduction is achieve as designed. A strong design and monitoring process would be required to achieve this.

Another issue is that the majority of community energy schemes are set up in rural locations. Urban locations would likely provide more of a challenge for the schemes since there is far less space available for most of the systems and the energy demand will be much higher. It is likely that demand reduction is more suitable in the urban than the rural environment. The lack of community demand reduction projects in urban locations suggests that this project will be unique and could hopefully highlight the potential for schemes like this in the future.

3.1.4 The research area of demand reduction

In general, there is limited research looking into energy demand reduction. One paper of particular interest for this project was *A Research Strategy for Reducing Energy Demand* generated by the End Use Energy Demand (EUED) Centres. This is a group of 6 research centres which perform research projects on different aspects of demand reduction with the aim to “reduce the energy required in the UK to achieve sustainable lifestyles”. In the EUED paper, energy efficiency and demand reduction are stated to be “the most promising, fastest, cheapest and safest means to mitigate climate change”. The paper also highlights that on top of the climate change impacts, reducing energy demand can also have several other benefits such as improved health and increased economic activity. The issue of the energy trilemma (as described in the introduction) of sustainable, affordable and secure energy can be made smaller through reduced energy demand, as shown in Figure 6. With a smaller energy demand, the scale of renewable generation and storage technologies could be significantly reduced. It would be interesting to investigate a scenario where there was greater investment in demand reduction to see if this would be more cost effective.

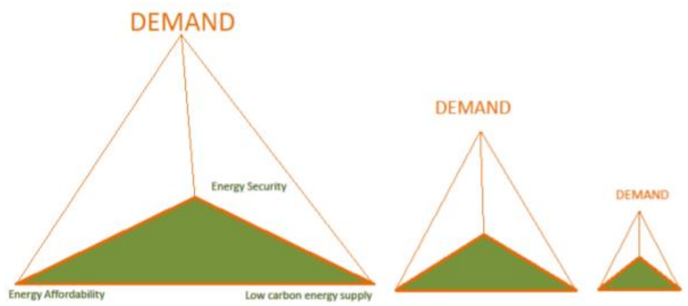

Figure 6 - The energy trilemma with energy demand reduction

While opinion of the EUED paper may be biased, since it is written by a research community which will benefit from further investment in this area, it does lead to the question of why demand reduction isn’t more dominant in Scottish energy policy. Demand reduction is key for a number of energy scenarios which have been generated by many organisations. The EUED paper gives the example of the *New Policies Scenario* from the International Energy Institute for their *2014 World Energy Outlook*. In this scenario, efficiency and demand reduction measures contribute 50% of the additional emissions reductions to 2040, more emission reduction than all energy supply and carbon capture technologies combined.

The main purpose of their paper is to highlight the requirement for a long-term investment strategy into EUED. Since the majority of the “quick win” measures have been realised, more advanced approaches must be taken. The issue discussed in the paper is that this area of research is particularly complex and interdisciplinary. This is particularly true since “people and societies do not use energy as an end in itself but as consequence of enacting certain social practices and ways of life”, stated in the EUED paper. For example, someone who drives a car expends energy to drive to the local supermarket. This decision will be down to a number of factors such as distance, volume of shopping, availability of a car etc. Simply making other more sustainable measures available will not necessarily convince the person to use them. Since the challenge to understand and deploy demand reduction techniques is large, the next ten years will be critical in terms of research support. The EUED paper calls for a number of actions to support research in the following themes:

- Theme A – More for Less
    - How can demand reduction be achieved?
- Theme B – Supply and Demand
    - Demand and technology implications of decarbonizing energy supply
- Theme C – Equity, Social Justice and Securities
    - How and why does energy demand vary between different sections of the population?

The EUED group clearly states that demand reduction will play a vital role in future energy strategies, a position suggested in *Sustainable Energy – Without the Hot Air*. The main message from the EUED paper is that research into this area is particularly complex, more so than the traditional renewable energy generation approach. Whilst it is desirable to develop a complete scenario determining the exact demand of the community and the consequences of reducing the demand, this would not be attainable for just one project, particularly within the limited scope of a 4 month MSc project. The focus for this project is therefore most concerned with Theme A of the research strategy above, looking at how demand reduction can be achieved within a defined community. Further research following this project could be conducted into the other two themes to develop a greater understanding of how demand reduction could realistically be achieved.

3.1.5 Overall findings from the literature review

A literature review forms a vital first step of any research project and a number of interesting findings have been made for this project. Energy efficiency and demand reduction has been shown to be a crucial part of future sustainable energy strategies. *Sustainable Energy – Without the Hot Air* takes an analytical approach to show that the amount of energy consumed must be decreased to move towards an entirely renewable energy system. The Scottish 2030 strategy laid out by Ricardo Energy and Environment also has demand reduction as a key component, with the majority of savings from buildings, setting an ambitious target of 30% heating demand reduction. When this is combined with a renewable energy supply source, a truly low carbon energy system could be realised, moving towards the climate change targets. Unfortunately, the *Energy Strategy* and *Climate Change Strategy* set out by the Scottish Government do not seem to follow the same thought process. These strategies rely heavily on electrification and transport to improve the efficiency of the energy system. As stated above, this lack of demand reduction may be due to lack of evidence of successful pilot schemes. Perhaps further developments and demonstration in the near future may help change strategy.

It is however true that the issue of energy demand reduction is very complex. The challenges of the installation of a wind turbine would mainly be technical, whereas demand reduction is far more interdisciplinary, requiring a greater involvement of the social sciences. The End Use Energy Demand Centres have set out a research strategy, stating the need for a long term commitment to research in this area. The potential benefits from research, development and deployment of a national demand reduction strategy are far greater than just emissions reduction, instead it could tackle all aspects of the energy trilemma. This project will focus on one aspect of EUED research, looking at how energy demand can be decreased.

Throughout the literature review, an in-depth search was made into projects which are similar to this research project. It became apparent that this focus of urban community energy demand reduction measures hasn't been researched before and as such there is not a clear method which can be followed. This is even true for the research conducted so far for the EUED centres. One of the outcomes of this project should therefore be to try to develop a method which can be replicated for other communities. The paper which has a method somewhat similar to this project is SEWTHA. The energy demand audit process taken in SEWTHA is separated by type of energy, which should be followed as a method for this project. Since the paper considers energy demand reduction on a national scale, care must be taken when applying the same approach to a small community. As highlighted earlier in this section the calculations made for some of the demand types are questionable and could introduce a significant amount of error. A more accurate calculation method should be followed in this project wherever possible.

Overall, a substantial amount of research has been completed in this literature review, developing a strong understanding of the role and developments in energy demand reduction.

3.2. Stage 2 – Selecting a Community

In order to have a project which is relevant to a large proportion of Scotland's population, the selection of the study community is crucial. If suitable data sources are available, a similar study could be replicated for other communities. The main requirements for the community of focus in this project are:

1. Represents a significant proportion of the population in Scotland
2. Reliable data sources available
3. Ideally, somewhere in need of regeneration, since this would be more suitable for the more extreme demand reduction measures.

3.2.1 Rural or urban community?

It has been stated throughout this paper that an urban community should be selected. This section will give data and reasoning which supports this decision.

Types of communities are generally separated into two categories: urban or rural. In general, an urban community is more densely packed, however has facilities in much closer proximity to the resident population. The publication *Scottish Government Urban/Rural Classification 2013 – 2014* classifies communities into a 6-fold or an 8-

fold classification system. Selecting the 8-fold system, the classes are shown in Table 1.

Table 1- Rural/urban classification in Scotland

Class	Class Name	Description
1	Large Urban Areas	Settlements of 125,000 people and over
2	Other Urban Areas	Settlements of 10,000 to 124,999 people
3	Accessible Small Towns	Settlements of 3,000 to 9,999 people and within a 30 min drive of a settlement of 10,000 or more
4	Remote Small Towns	Settlements of 3,000 to 9,999 people and with a drive time of over 30 mins but less than 60 mins to a settlement of 10,000 or more
5	Very Remote Small Towns	Settlements of 3,000 to 9,999 people and with a drive time of over 60 mins to a settlement of 10,000 or more
6	Accessible Rural Areas	Areas with a population of less than 3,000 people and within a drive time of 30 mins to a settlement of 10,000 or more
7	Remote Rural Areas	Areas with a population of less than 3,000 people and with a drive time of over 30 mins but less than 60 mins to a settlement of 10,000 or more
8	Very Remote Rural Areas	Areas with a population of less than 3,000 people and within a drive time of over 60 mins to a settlement of 10,000 or more

In this classification, the dense urban is represented by the first two categories, while the others are more closely related to rural locations.

The distribution of each of the categories is shown on the map in Figure 7. From this it is obvious that the remote rural areas make up the majority of the land area, particularly for the north of Scotland, whilst the large urban areas are Glasgow, Edinburgh, Dundee and Aberdeen. The classification document defines the land area and population for each of these areas. Aggregated over the whole of Scotland the percentage share for each of the eight categories in 2013-2014 is shown in Table 2.

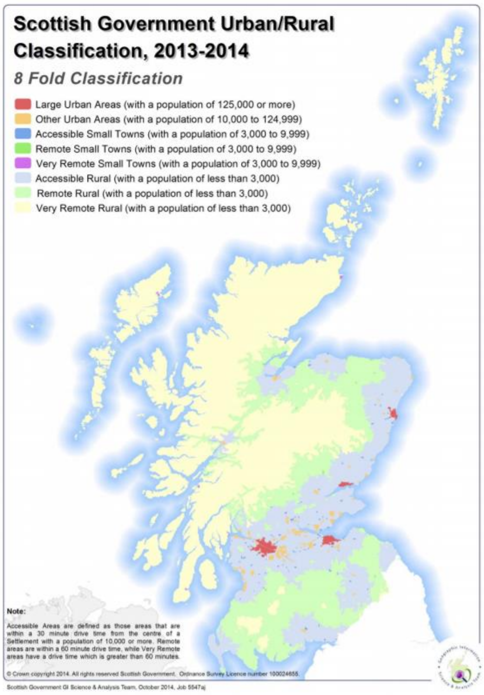

Figure 7 - Urban/rural map of Scotland

Table 2 - Urban/rural data for Scotland

Class Name	**Percentage of Total Population (%)**	**Percentage of Total Land Area (%)**
Large Urban Areas	34.5	0.68
Other Urban Areas	35.1	0.97
Accessible Small Towns	9.3	0.28
Remote Small Towns	2.2	0.07
Very Remote Small Towns	1.3	0.07
Accessible Rural Areas	11.7	27.49
Remote Rural Areas	3.2	28.41
Very Remote Rural Areas	2.9	42.04

This data shows that 69.6% of Scotland's population lives in urban areas which take up just 1.65% of the land area. An urban community should therefore be selected for this project due to the following factors:

- Urban communities represent the majority of Scotland's population, meaning that the findings from this project could potentially be replicated in a number of other communities
- The lack of land area available will mean that local renewable generation is less suitable
- There will likely be less variation in energy demand compared to rural communities, particularly with residential heating and transport
- Most of Scotland's energy demand will be in urban locations

For these reasons, an urban community should be selected for this project. Of the four key cities, Glasgow was selected as a focus due to the fact that it is the city in which the researcher is studying, but also since it the largest city in Scotland, with the population of Glasgow City estimated at 596,000 in 2017.

3.2.2 Key resources available

Since Glasgow is the largest city in Scotland, there has been significant work to date to gather data which describes the communities and challenges within the city. For this project, the following resources were particularly useful:

Glasgow City Council

- *Scottish Neighbourhood Statistics*
- Various city development plans

The *Scottish Neighbourhood Statistics* data has been generated by the Scottish Government and provides census data discretised into a number of geographic areas, including Scotland as a whole and 6976 individual data zones (neighbourhoods).

The local authority has produced a number of development plans including, the *Housing Strategy 2017 – 2022* and the *City Development Plan*. These strategies are beneficial for this project in several ways. One aspect is that they display the overall vision for the city, and how demand reduction will play a role in the city's energy strategy. Also, the strategies accurately describe the current situation of some of the communities and what challenges are common throughout Glasgow.

Understanding Glasgow

This is a project which has been developed by the Glasgow Centre for Population Health (GCPH) in partnership with a number of other institutions. The aim is to develop a database of statistics and information related to socio-economic indicators for Glasgow City. There is a wide range of domains explored such as community safety, transport, social capital, poverty and population. This data has been used several times throughout the energy demand audit process in this project and is particularly useful since a number of the indicators are discretised for each neighbourhood within the city.

STEP UP Glasgow

STEP UP (Strategies Towards Energy Performance and Urban Planning) was an EU initiative set up for 4 cities: Ghent, Gothenburg, Riga and Glasgow. The result was a *Sustainable Energy Action Plan* (SEAP) and for Glasgow this materialised as the *Energy and Carbon Masterplan*. The information shown in the masterplan indicates a strong understanding of the energy performance of the city, but also the overall direction to improve the sustainability of the city. Since this was developed in partnership with Glasgow City Council, it is reasonable to assume that the strategy will align with the *Scottish Energy Strategy*.

One issue with these sources is that this data may not be available for other communities outwith Glasgow. Should this process be replicated for other communities, other sources may need to be found to gain the same data. However, it is true that there will be many similar communities that lie within the same boundary of Glasgow City, so the process is still easily replicable for a large number of urban communities within this geography.

3.2.3 Describing Glasgow

This project went on to explore the main facts about Glasgow which influence energy demand in the city.

Understanding Glasgow provides data sourced from the UK Department of Energy & Climate Change detailing the energy consumption for Glasgow as a whole. The energy consumption by sector between 2006 and 2014 is shown in Figure 8 and the energy consumption by fuel type in 2014 is shown in Figure 9.

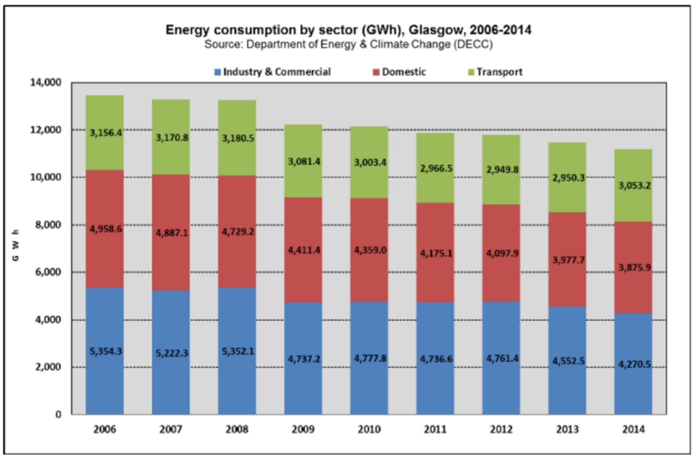

Figure 9 - Measured energy consumption for Glasgow

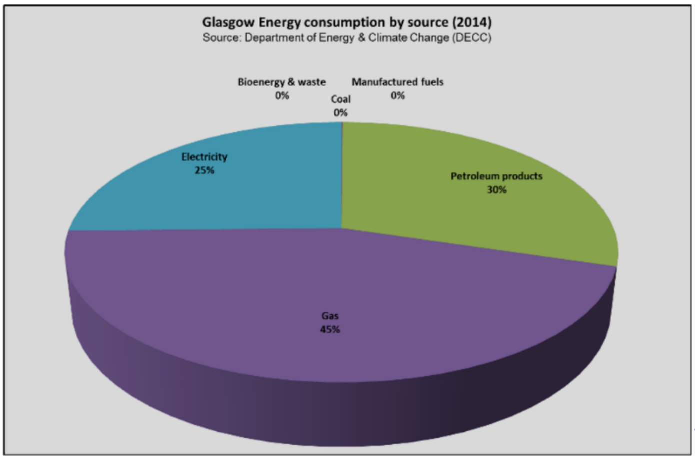

Figure 8 - Share of Glasgow energy consumption by fuel type

A clear reduction in energy consumption can be seen when looking at the energy use over the eight-year time period. This is most likely due to slight improvements in energy efficiency over this time period, i.e. improvements in insulation levels or industrial processes. This data does not however give details of where the energy demand is coming from (e.g. transport mode used) and it does not give the data for each community.

In terms of housing type, like most urban areas, Glasgow is dominated by flats, with 73% of the housing stock being flats as shown in Figure 10. This data can be found from *Statistics.Gov.Scot.*

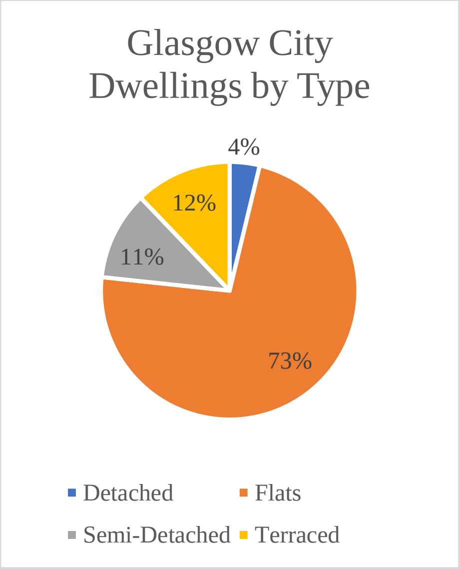

Figure 10 - Dwelling types in Glasgow

The jobs market is dominated by service jobs such as public sector education and health, hotels and finance. Only 7.9% of those in employment are in manufacturing, whilst a further 8% are employed in energy and water or construction. In general, these figures are consistent with the other Scottish cities and indeed the rest of Scotland. The energy implication is that the majority of energy demand for employment will be in commuting to and from work as well as powering and heating offices and hotels, with less energy demand for powering manufacturing equipment. It is worth noting that while there will be a small energy consumption for manufacturing in Scotland, a significant energy demand still exists to make the products which consumers buy, which are manufactured abroad. This can be a significant proportion of overall worldwide energy demand and should be considered when looking at the overall picture and national strategies for energy demand. For this project, the energy use in manufactured goods for the community was not calculated, primarily since it is such a complex and multidimensional issue and beyond the scope of this study. However, this should not deter an environmentally conscious individual or group making the decision to buy more sustainable products, or even choose not to buy products they don’t need.

Glasgow is very well connected in terms of transport. Major motorways run through the city, giving easy access to the rest of the UK. Bus and train networks are also widely used and the close proximity of services means that walking is a common method of moving around. *Understanding Glasgow* displays the census data for commuting mode for Scotland’s cities, as shown in Figure 11. Driving by car or van is still the most common mode of transport, however 54.7% of journeys are made by public or active transport compared to 41.3% for the whole of Scotland. Greater use of these facilities will most likely mean that the transport demand for the community will be low, particularly compared to rural towns. This will be captured in the energy demand audit process.

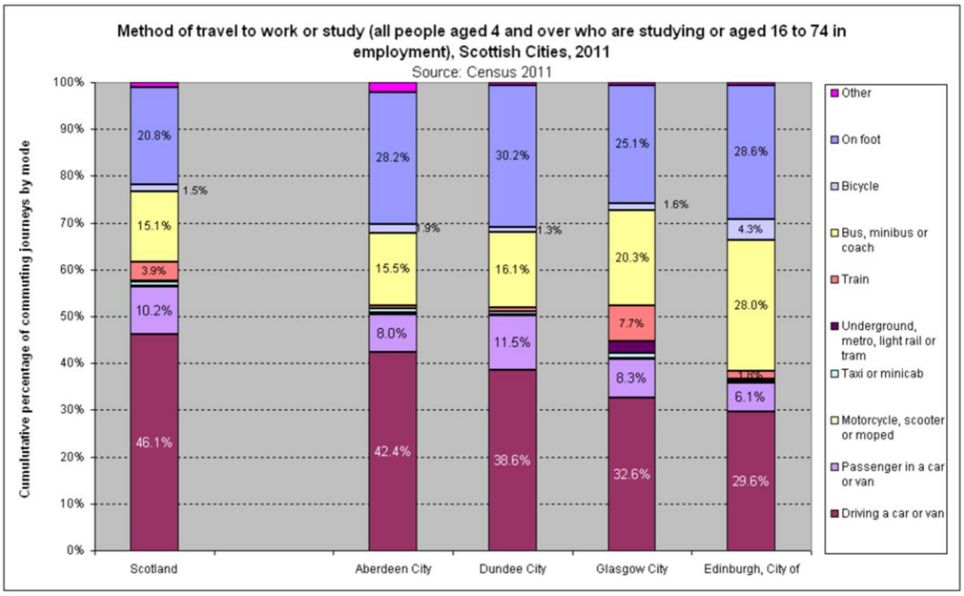

Figure 11 - Mode of travel to work or study for Scottish cities

Detailed analysis of the energy demand of the selected community will be performed in stage 3 of this project. In terms of the options of the communities to select, Glasgow City Council have defined the following neighbourhoods for Glasgow City, is shown in figure 12. One of these neighbourhoods should be selected as a focus for this project.

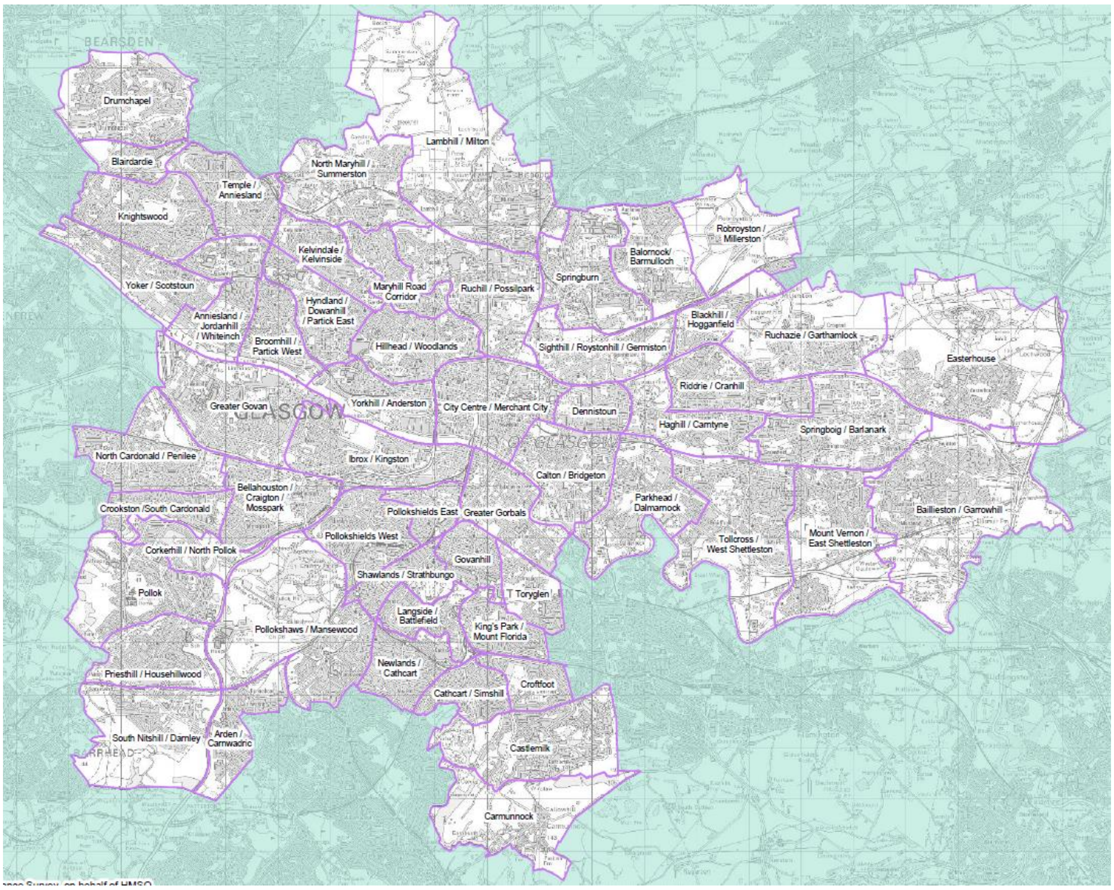

Figure 12 - Community areas in Glasgow City

3.2.4 Challenges for Glasgow

Whilst climate change is arguably the most pressing issue for Glasgow's energy future, there are a number of other key challenges which are widespread in the city. A strategy which can tackle these issues while moving towards a more sustainable energy system will positively impact the residents affected and the agencies working in the city. This means that a strategy which appears more expensive when only considering the energy payback, may actually be more cost effective when considering the wider benefits it produces. The main challenges facing Glasgow City are generally understood to be:

Fuel Poverty

Fuel poverty is defined in the *Scottish Fuel Poverty Statement* as a household which, in order to maintain a satisfactory heating regime, would be required to spend more than 10% of its income on all household fuel use. Extreme fuel poverty occurs when more than 20% of a household's income is required. The 2015 *Scottish House*

Condition Survey shows that fuel poverty at this time was at 30.7% in Scotland, with 8.3% of this in extreme fuel poverty. This figure had decreased from the year before, however the majority of this was due to reduced fuel prices, the rest due to improvements in energy efficiency performance and improved income. Fuel poverty is more common in rural locations (35%) due to increased dwelling sizes and heat loss areas, but this is still a major challenge for Glasgow with 25% of the households being fuel poor. While actions such as smart metering and district heating are said to be part of the solution to this issue, energy demand reduction should be particularly valuable here, since the cost savings are passed onto the residents and local businesses.

Health

Health issues associated with obesity are known to be a great challenge with just under a quarter of the adults in Glasgow City being classified as obese according to the *Glasgow City Development Plan*. Another issue present in cities is poor air quality. This applies to both the indoor climate with a lack of fresh air supply and to the street level. Mainly due to pollutants from road transport, in May 2016, it was reported that Glasgow, along with 40 other towns and cities in the UK and Ireland, breached World Health Organisation air pollution safety levels. One approach the UK government is taking to tackle this issue is the introduction of a ban on petrol and diesel cars and vans by 2040. Questions have been raised about the feasibility of this approach.

Transport

As stated above, Glasgow is well connected in terms of transport. It is true however that in terms of active transport, Glasgow is lagging far behind other European cities, such as Amsterdam, where the cycling culture is widespread as displayed in Figure 13. The *Energy and Carbon Masterplan*

Figure 13 - Cycling in the Netherlands

highlights the fact that Glasgow is lagging in this respect and needs to provide a “world-class sustainable transport system which is safe, reliable, integrated and accessible to all citizens and visitors”.

Regeneration

Regeneration is the process of investing in infrastructure improvements to update the facilities and properties and thereby improve the quality of life of the residents and tackle some of the wider issues of the area. This is most commonly used to address issues with housing, such as incorrect housing types for the area or poor energy efficiency. The *Glasgow Housing Strategy* identifies one of the key challenges for Glasgow being an aging housing stock. This means that a lot of the housing stock is in need of repair and improvements to reduce fuel poverty in these buildings. There are also widespread issues with affordability and overcrowding (at 17.4%, overcrowding is double the national average and the number of overcrowded households is expected to rise by 28% in the next 25 years). Regeneration is being used as a key strategy to tackle these issues. The *Energy and Carbon Masterplan* states that the rate of regeneration however has moved at a slow pace since the financial crash. Regeneration has a significant role to play in tackling the issues in many neighbourhoods of Glasgow and should be a key part of any city-wide strategy. While this project focuses on one community within the city, larger regeneration schemes should be considered as part of the demand reduction approach.

Economic prosperity

Glasgow is a large city which supports a large number and range of jobs. The *Glasgow City Development Plan* highlights that over 400,000 people work in the city, showing the scale of the Glasgow economy. There are still challenges in this area however. 60% of working-age Glaswegians were employed in 2012/13 which was 11% lower than the national average. Deprivation is also a key issue, with almost 50% of Glasgow’s residents in the 20% most deprived areas of Scotland. Any energy strategy should be able to provide economic improvements for the residents.

3.2.5 Socio-economic analysis in the project

One of the key areas of interest at the start of this project was investigating the wider socio-economic benefits of demand reduction measures, which could then be compared to other sustainable energy strategies for the community. Glasgow City Council will have substantial budgets to tackle the socio-economic issues outlined above. If a community demand reduction strategy could deliver on some of the targets, it would be easier to justify and finance such solutions. This process would be effectively evaluating the Social Return on Investment (SROI). As the project evolved, it became clear that this task was beyond the reach of the timescale available. In this project, the cost of energy has been calculated which could be used to assess the wider benefits. As a follow-on project, it would be of interest to evaluate the SROI of the measures and the potential financial opportunities which may be available for the community.

3.2.6 Current energy strategy for Glasgow

The energy strategy for Scotland has been discussed and has a limited vision for energy demand reduction beyond simple energy efficiency measures. It is important at this point to define the overall energy strategy for Glasgow to see if there are any differences in strategies.

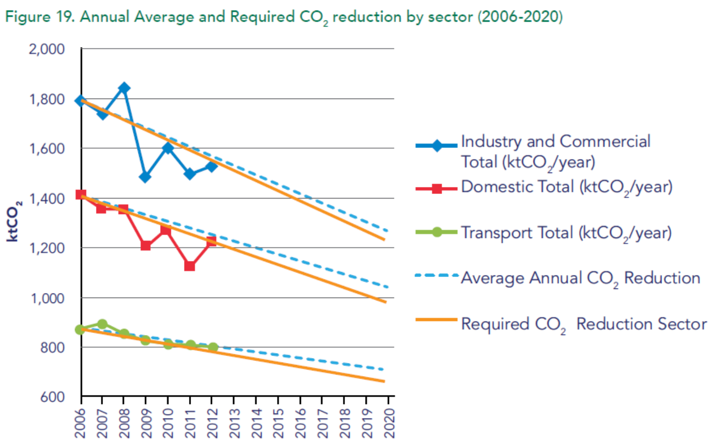

Figure 14 - Carbon targets for Glasgow

In the *Glasgow Energy and Carbon Masterplan* (part of the STEP UP EU initiative) the overall focus is on reducing carbon emissions in the city. The overall target is to achieve a 30% CO2 reduction by 2020, compared to 2006 levels. The data shown in Figure 14 describes the emissions for the three key sectors. There have been continual decreases to date for a variety of reasons and from this graph, it appears that only slightly more is required to meet the target of 30% reduction.

District heating is a particular priority. It is viewed as a means of tackling fuel poverty while allowing a transition towards low carbon heat. Extensive district heating networks are planned for key areas of the city. Energy efficiency is also specified as a policy priority here. For housing, the most effective measures which are being recommended include increasing insulation, draft proofing, double glazing and more efficient appliances and light bulbs. Improved efficiency in non-domestic buildings mainly involves a focus on ventilation and air conditioning as well as lighting, heating and appliances. It is also cited that cars will continue to have improvements in efficiency, as has been seen in the past decade.

The approach taken in the masterplan is leaning more towards advancements in the supply side of energy, particularly with heating. Technologies such as heat pumps and combined heat and power (CHP) are recommended. These will reduce the energy consumption of buildings (through improved efficiency) however heating demand will not be reduced. The targets set for reducing heating demand in buildings is only to achieve a 6% reduction, in line with Scotland's overall strategy. Also, demand side management and smart metering are to be used more widely. These can produce a small decrease in energy use, however the main purpose is to allow greater energy security.

In terms of transport, Glasgow has greater ambitions for moving towards less energy intensive modes of travel. There are continuing efforts to increase the use of public transport, while cycling is receiving a large amount of investment to increase the uptake. The drives made so far include a city-wide cycle hire scheme as shown in Figure 15 and infrastructure improvements. There does not seem to be a specific target for the increase in cycle journeys, however it is very positive that it is recognised as a priority for the city.

Figure 15 - Bicycle hire scheme in Glasgow

Renewable energy generation is also a part of the *Energy and Carbon Masterplan*. There is a wealth of renewable energy in the surrounding areas of Glasgow, with the 215 turbines of Whitelee Windfarm just 20 minutes south of the city producing 1.2 TWh per year. In terms of generation in the city itself, there are only four sites, with three of these being landfill gas. The masterplan describes several potential opportunities to increase generation, however does not commit to the deployment of these, particularly since space may be limited. Community energy projects will also be supported where possible, but again there is no target set for this. Since the electricity demand of Glasgow is so large and will continue to grow due to electrification of heat and transport, it is clear that Glasgow will need to import electricity generated elsewhere for the foreseeable future.

3.2.7 Areas of deprivation

Following this account of the energy strategy for Glasgow, it was decided that the community focussed on should be an area of high deprivation. As defined above, 50% of Glaswegians live in the 20% most deprived areas in Scotland. The Scottish Government describe deprivation as: “It does not just mean “poor” or “low income”, it can also mean people have fewer resources and opportunities”. A highly-deprived community will have common challenges with regards to energy. Fuel poverty will be common, which is often combined with lower quality housing, both in terms of disrepair and energy performance. To add to this, the residents are less likely to have disposable income to make high cost investments such as PV systems or electric cars. A demand reduction approach to energy in this type of community may tackle some of these issues. It is more likely that the area will be in need of regeneration, so may suit some of the more radical ideas explored in this project.

To describe deprivation, the Scottish Index of Multiple Deprivation (SIMD) has been developed. This ranks deprivation in terms of seven categories: income; employment; health; education; skills and training; housing; geographic access to services and crime. Each of these is ranked from 1 to 10, then combined into an overall ranking for each area. A SIMD map has been developed using this data. The map shown in Figure 16 below highlights in red the 10% most deprived areas of Scotland which are located in Glasgow City.

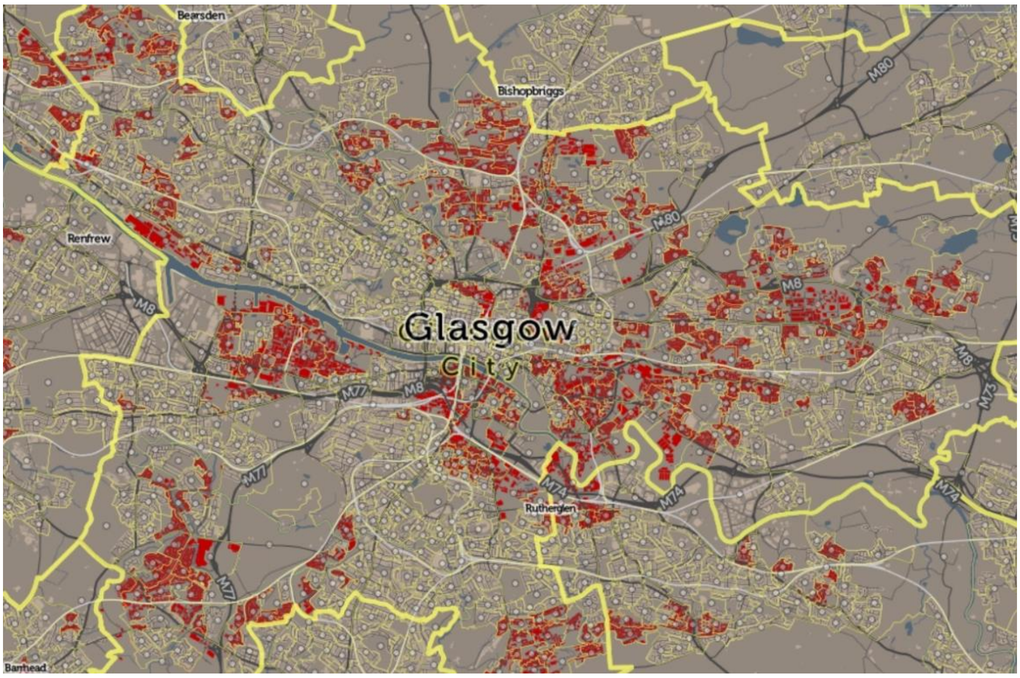

Figure 16 - SIMD map showing 10% most deprived areas in Glasgow

It is very common to have clusters of deprivation and this can clearly be seen in the map. The areas with the greatest density of deprivation are:

- North of the city centre – Maryhill and Possil Park
- North East – Sighthill and Springburn
- East – Bridgeton and Parkhead
- South – Gorbals and Govanhill
- South West – Pollock

- West – Ibrox and Govan
- On western outskirts of city – Scotstoun and Drumchapel

The community selected should be a part of one of these areas of the city.

3.2.8 Options of communities

Glasgow City Council has recognised that key communities within the city have needed redevelopment for some time, to make the facilities viable for today's lifestyles. The *Transforming Communities: Glasgow* initiative has created a number of plans for eight communities: Gallowgate, Maryhill, Laurieston, Sighthill, North Toryglen, Pollockshaws, Barmulloch and Govan/Ibrox. Several of these communities are in the same areas which have particularly high deprivation as shown in the map in Figure 17.

Figure 17 Transforming Communities: Glasgow communities of development

Transforming Communities: Glasgow aims to provide new housing, community facilities, green space and some commercial units for these communities. Six of these are active, with plans in place and redevelopment due to commence over the next few years. Sighthill is furthest through the development process with work started on site and due to be completed by mid-2020. A 3D render of the development is shown in Figure 18.

Figure 18 - Sighthill regeneration

The key components of the redevelopment include new social housing provided by Glasgow Housing Association, improved landscaping with greater biophilic design (close interaction with nature) and high quality transport connections, particularly for bicycles. While this strategy does make a clear transition towards more sustainable communities, most often it involves complete demolition of all the existing buildings and facilities. This presents two issues:

1. It is not sustainable as a city strategy to knock down and completely rebuild all housing.
2. These communities have housing and infrastructure which are significantly better than what is typical for the city.

While these communities provide useful information on the approach to regeneration, none of them can be selected for this project. This is because the buildings and infrastructure after regeneration will not reflect typical communities in Glasgow. Other options must be explored.

Another example of a development which often receives praise for its regeneration is Dalmarnock, location for the 2014 Commonwealth Games athletes' village. Again, this underwent radical changes to the area including many of the same measures as planned for Sighthill as shown in Figures 19 and 20. The site also has a gas-fed district heating scheme and extensive use of PV, with a greater emphasis on energy sustainability. While this would be an interesting community to focus on, again it is radically different from most of Glasgow City.

Figure 19 - Dalmarnock dwellings before regeneration

Figure 20 - Dalmarnock dwellings after regeneration

After these communities were deemed to be unsuitable for the purpose of this project, the *Glasgow Strategic Housing Investment Plan 2017/18 to 2021/22* was studied. This document sets out the key developments and strategy which will be taken to tackle the many challenges for housing in Glasgow. This strategy is generally aligned with the other city-wide strategies. Part of the document highlights "area-based priorities" which are communities in need of development.

The communities as part of the *Transforming Communities: Glasgow* initiative are specified here, with another community of interest being Govanhill, which has experienced social and community issues for a number of years. As part of the challenges of deprivation in Govanhill, the housing is of particularly poor quality, with predominantly pre-1919 tenements, many of which are in poor condition. Glasgow City Council has expended significant resources on this community in both reactive and active ways. Upon further inspection of the details of the community which are discussed below, Govanhill was selected as a focus for this study.

3.2.9 About Govanhill

Govanhill is situated just over 2 miles south of the city centre, a 15 minute drive by car. In total, it has over 9000 residents. This area is split into 2 “intermediate zones” as part of the 2011 census data: Govanhill West and Govanhill East & Aikenhead. This project studied Govanhill West. This area is defined in the datasets provided by *Statistics.Gov.Scot* as shown in Figure 21. The area is more clearly shown on a satellite image in Figure 22.

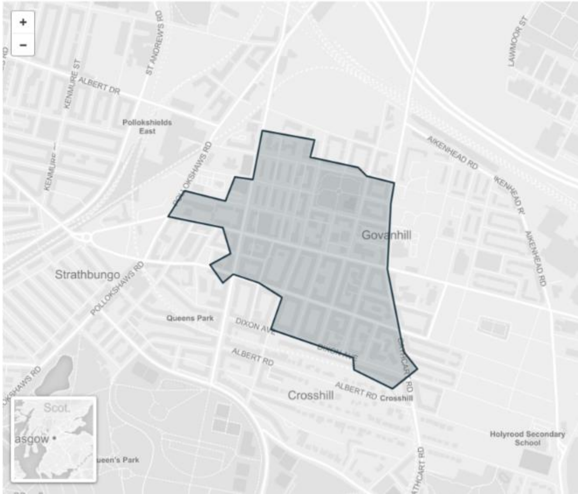

Figure 21 - Govanhill West boundary

The boundary does seem to cross through some of the terraced and tenement buildings. The exact border used for the census data is different to other data sets, which more closely follow roads. The census boundary is to be used with the discrepancies to the other datasets defined when they are studied.

The roads which roughly define the area are:

- Cathcart Road to the east
- Dixon Avenue to the south
- Langside Road and Allison Street to the north
- Victoria Road and Coplaw Street to the west

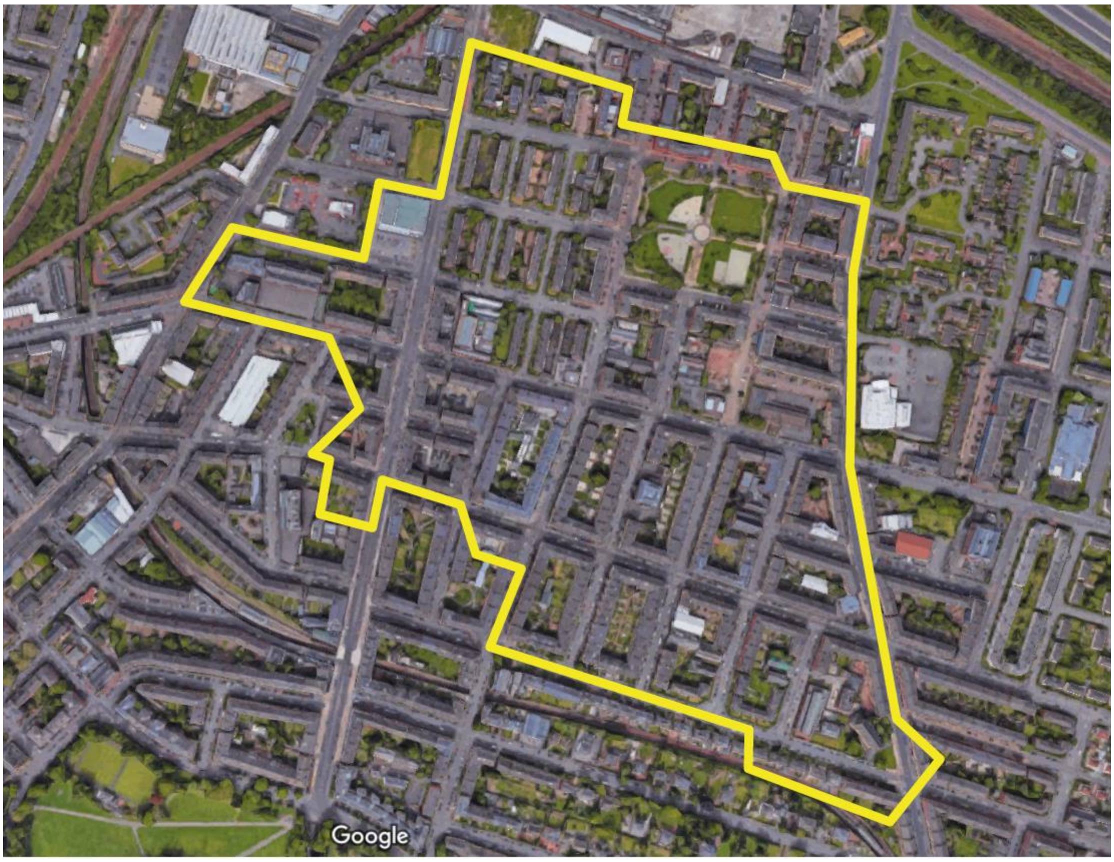

Figure 22 - Selected community boundary on satellite map

The statistics provided for this intermediate zone are:

Table 3 - Statistics for Govanhill West

Population in 2015	5430
No of dwellings in 2016	2866
% of dwellings which are flats	99.3%
Council tax band A to C (low value house price)	94.1%
Mean house price	£65,094
Dwellings per hectare	92.66

The *Govanhill Neighbourhood Profile*, produced for areas of Glasgow as part of the *Housing Strategy* also provides some insight, particularly in comparison with the rest of Glasgow. For the whole of the Govanhill area, which represents 7411 households, the majority are small households with 52.76% being occupied by one person, compared to 43.13% for the city. Despite this, overcrowding is common in terms of density per room, particularly for the private rented buildings in the area. The *Neighbourhood Profile* suggests that additional larger accommodation is required.

Also, the number of households with access to one or more cars is 38.5% (1103 households have access to a car), lower than the city average of 49.2%. This suggests that the transport energy demand will be relatively small, mainly due to the close proximity of facilities.

SIMD Data

As described above in figure 16, Govanhill is in the 10% most deprived areas in Scotland. The SIMD map splits Govanhill West into 7 areas and provides ratings for each category in each of these areas. Figure 23 shows the areas and defines the data zone codes. The data is described in Table 4. Each category is rated out of 10, with 1 being the most deprived.

Figure 23 - SIMD data zones

Table 4 - SIMD performance for Govanhill West

Deprivation Category	Comments
Overall deprivation	4 areas are rated at 1, 2 areas are rated at 2 and 1 is rated at 3
Income	Average rating of 1.7
Employment	Average rating of 2.1
Health	Average rating of 2.4
Education/skill	Average rating of 1.6
Housing	All rated at 1. This is a particularly weak area, with the overall rankings of 8th, 20th, 40th and 41st for 4 of the zones out of the whole of Scotland (around 7000 areas).
Geographical access	All rated at 10. Logical since it is only a couple of miles away from the largest city in Scotland
Crime	All rated at 1

These figures show that deprivation is an issue for Govanhill in every category except geographical access, but particularly in terms of housing and crime. The study of the wider socio-economic impacts of the strategies outlined in this project would be very relevant the community, however this is outwith the scope of this project so could form the basis of follow-on research.

South Seeds

Govanhill is within the work area of a local community organisation called South Seeds. The group has been funded through the Scottish Government's Climate Challenge Fund, which provides grants and support to enable local communities to run projects which tackle climate change. The activities of South Seeds include an energy savings handyman service, to advise and install measures in homes within the area, supporting bicycle storage in flats and local community food growing and composting.

Figure 24 - South Seeds logo

Figure 25 - South Seeds underfloor insulation

Figure 26 - South Seeds community gardens

In addition, several energy-related reports have been commissioned by South Seeds, which give a wide perspective of the characteristics of this community. A report by Ricardo Energy and Environment identified the potential of low carbon CHP district heating in the Southside area. Three areas were analysed, with one area covering about half of Govanhill West. This highlighted that there is potential for district heating in the area, mainly due to the newly constructed recycling plant nearby which produces waste heat from Biogas CHP. Exploring options to decrease the heat demand of the buildings may mean that more households could be fed with the district heating system. Also, the *Renewable Snapshot Report* for South Seeds by RE&E was created to detail opportunities in the area. This gave background on the options, but also highlighted that solar and air source heat pumps (ASHPs) may be most suitable, while ground source heat pumps (GSHPs) and biomass are less suitable. The

Renewable Energy Snapshot Report is particularly relevant to this project and is detailed in the section below.

Housing in Govanhill West

In the SIMD dataset, Govanhill West has some of the poorest quality housing in Scotland. This is mainly due to the fact that the majority of the housing was constructed towards the end of the 1800s and the fact that the housing is low value, thus making high cost investment less likely. Another factor is the ownership of housing, with Govanhill having the highest concentration of private landlords in Scotland.

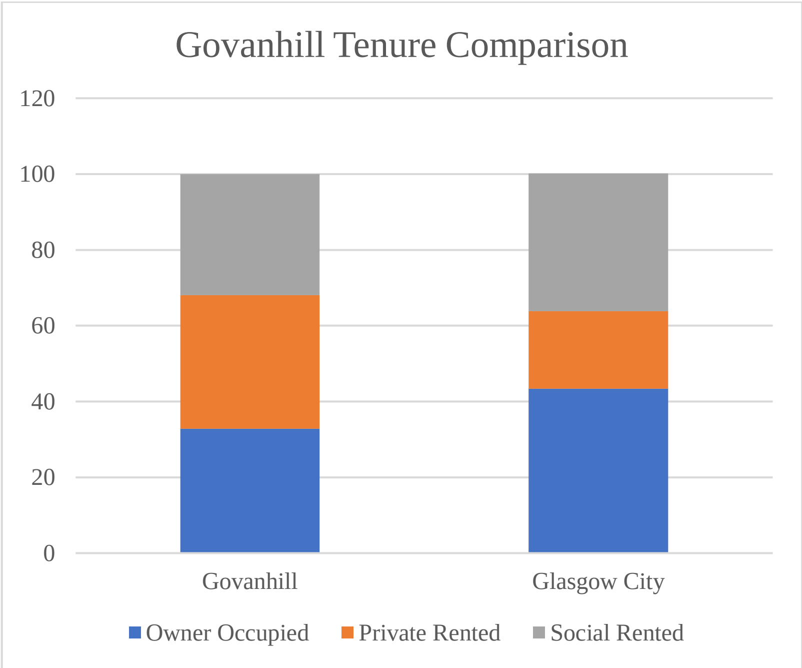

Figure 27 - Govanhill tenure comparison

A higher share of private rented accommodation tends to mean that housing is in poorer condition because landlords have less of a motive to invest in their properties, both in terms of repair and energy saving measures. The main social landlords in the area, Govanhill Housing Association and Southside Housing Association are required by law to meet the Scottish Housing Quality Standards.

The *Energy Snapshot Report* for South Seeds is a paper which defines the type of housing in the Southside area to give an indication of where future efforts should be focussed. The housing in the area is defined in terms of type of building as well as by ownership. The location and ownership of the different housing has been gathered together in the map below in Figure 28.

Figure 28 - House types in selected community

Govanhill is one of the few remaining places in Glasgow which is still populated by Victorian tenement buildings and as such a lot of the housing shares similar characteristics. Solid walls, with little to no insulation are common, as well as poor air tightness through features such as fireplaces and suspended timber flooring. The types of housing in the Govanhill West area and the typical features as described in the report are:

Block Type 1 – Short Tenements

- Cavity wall
- Chimney and suspended floor
- Relatively small windows, with low ceiling height

Figure 29 - Short tenement example

Block Type 2 – Retail Tenements

- Retail unit on ground floor
- Solid walled and chimney

Figure 30 - Retail tenement example

Block Type 3 – Dense Tenements

- Solid wall and suspended flooring
- Flat size typically small
- High glazing to wall ratio

Figure 31 - Dense tenement example

Block Type 4 – Standard Tenements

- Solid walls, suspended floor and chimney
- Simple form
- Large glazing areas

Figure 32 - Standard tenement example

Other property types in the area include:

- Terraced Housing - similar features such as solid walls and suspended timber flooring
- Other Flat Blocks – for Govanhill West, 2 storey solid walled buildings.

Since the housing in this area is generally poor with solid walls and poor quality glazing, the majority of the recommendations in the South Seeds report are for relatively moderate measures. Secondary glazing or window replacement would be likely to have the greatest impact, with draft proofing and underfloor insulation also being recommended. Measures such as changing windows or fitting internal wall insulation would be intrusive and expensive if done in a way which is sympathetic to housing character. This will be one of the main challenges when considering deeper retrofit measures in this project.

Non-domestic buildings are well distributed throughout the area with commercial properties mostly concentrated with the retail tenements on the main roads. Data for gas consumption from the UK Government records showed that there is a total of 293 commercial buildings in the area. There are a number of other buildings which are shown in Figure 33.

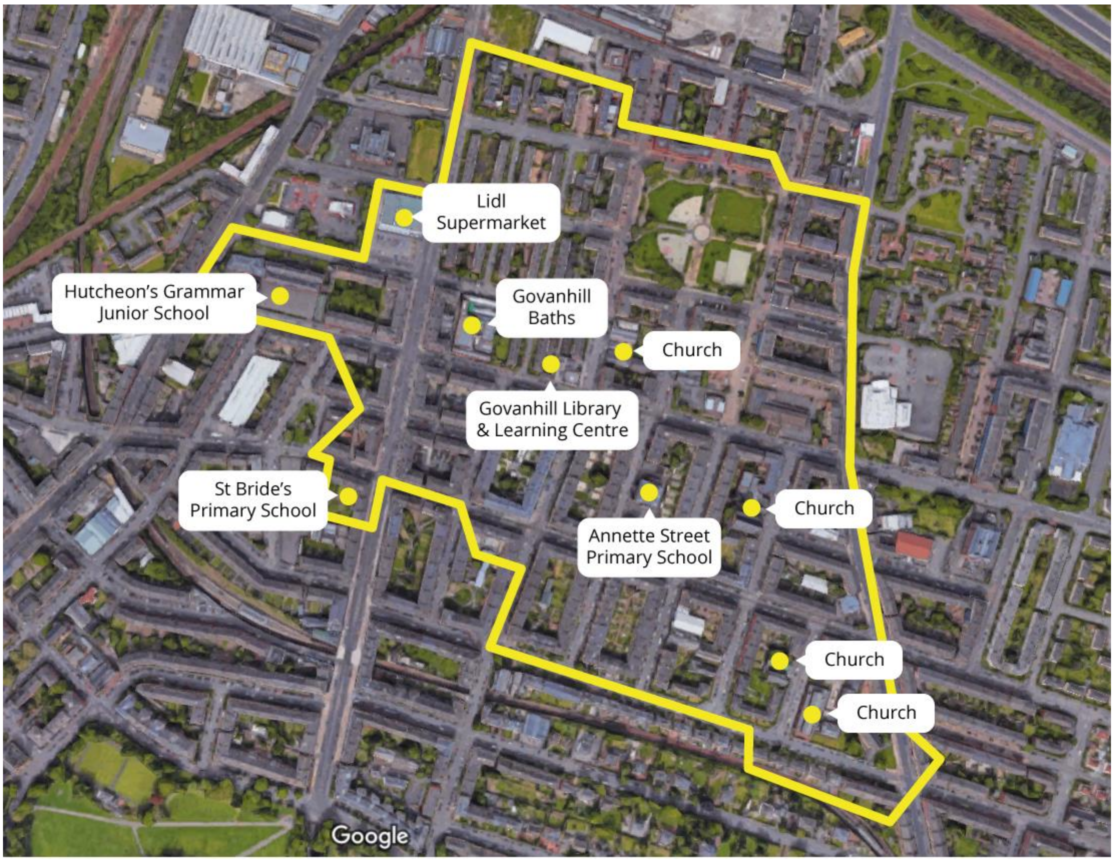

Figure 33 - Non-domestic and public buildings in community

The three schools in the area are assumed to be classified as public buildings while the other buildings marked are private non-domestic properties. The heating and electricity demand for these types of building will be accounted for in the energy demand audit process.

Expected Energy Results for Govanhill West

The information which has been described above gives a suitably detailed picture of the type of community which is being studied in this project. From this, a prediction of the relative magnitude of energy demand for the community can be made.

In terms of domestic heating demand, the Victorian, low quality housing suggests that demand is likely to be very large. Also, there is a very high dwelling density, which will also increase heat demand. It is true however that the houses are likely to be small in floor area and the majority are flats, which have a smaller heat loss area. This may mean that the heating demand per person, which is the approach taken in SEWTHA, will be small. The same can also be said with domestic electricity demand with a high overall demand but potentially low demand per person.

It is difficult to gauge what the likely non-domestic heating and electricity demand will be for the community, since it is dependent on many factors for which data is not available.

Transport demand is expected to be extremely low, when considering the figures per person. A low percentage of households have access to cars and facilities are in close proximity. This will mean that distances travelled are smaller, but also that there will be greater use of lower energy demand transport types such as public and active transport.

3.3. Stage 3 – Energy Demand Audit

To quantify the energy demand reduction potential for Govanhill West, it is essential to go through a process to quantify the current energy demands of the community. This process should aim to fulfil certain requirements:

- It should analyse the energy demand for the community in separate energy demand types and should include as many of the categories defined in SEWTHA as possible

- It should be based on real life measured data or validated energy modelling tools

- Where possible it should take into account all of the factors which are specific to this community, making the results as accurate as possible

- The process should be replicable for other communities

The literature review found that there is not yet a prescribed process to analyse community energy demand to the same detail required for this project. A number of the calculations and the general approach of SEWTHA could be applied, however it will need to be adapted for the community of focus. The process will need to be developed to fulfil all the requirements set out above.

The types of demand studied are:

- Domestic heat demand
- Public heat demand
- Non-domestic heat demand
- Domestic electricity demand
- Non-domestic electricity demand
- Transport demand

Studying these demands will allow for a good understanding of the community, allowing for quantification of the potential energy demand reduction, fulfilling the aim of the project. While other energy demands are present in the community (these will be discussed towards the end of this stage) the demands which are analysed are ones which the local community groups could develop further to achieve demand reduction in the community. Also, the majority of these demands have high costs for the locals in terms of the cost of energy. Electricity and mains gas is paid per kWh used, so reducing the demand should mean that a saving is passed on to the local residents. This may be less likely to occur with only renewable energy measures.

It is important to define the use of units here. The same units should be used for all demands and it should also be expressed in terms which are relatable for the occupants of the community and the research community. Energy demand will be expressed in the following ways:

- Total annual energy demand (GWh/year)
- Annual energy demand per dwelling (kWh/year*dwelling)
- Energy demand per person (kWh/year*person)
- Daily energy demand per person (kWh/day*person)

Describing the results with these units will quantify the demand for the whole community, but also express units which give the perspective of the individual residents in the same way as SEWTHA.

3.3.1 Domestic heat demand

Heat demand in households encompasses space heating and water heating energy demand. The demand is not the same as the kWh of gas used in boilers, which will be larger because of the inefficiency in the boiler, which will always exist. Heat demand more accurately describes the actual energy demand of the property and is an indicator of the thermal performance of the building.

In stage 2, the housing characteristics were described. A high heat demand is expected, however it is likely to be small when considering the demand per dwelling and per person. The *Scottish House Condition Survey* found that heating energy demand represents on average 87% of total household energy demand as shown in Figure 34, so this energy demand should be given a greater priority than other electricity demands.

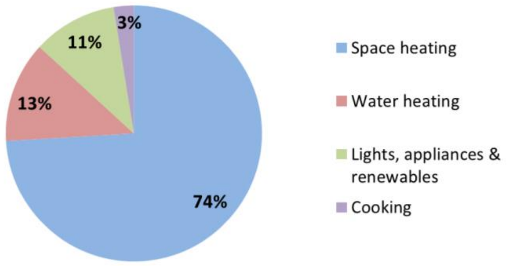

Figure 34 - Average energy consumption in Scottish dwellings

There are several ways in which the heat demand could be quantified. Surveys of properties, asking residents how much energy they use in a year would be an accurate method. This would be intrusive and is outwith the scope of this project. If suitable energy-related details of the properties are known, an energy model could be created for a small selection of properties and then aggregated over the whole building stock. There are a range of modelling tools available with simple tools such as Home Energy Model (HEM) developed at Strathclyde University, more complex tools such as the PassivHaus Planning Package and then highly discretised tools such as ESP-r, again developed at Strathclyde University. Modelling was attempted in HEM, however there was not sufficient detail found for the housing for Govanhill West to generate accurate models.

The method selected was to use data provided by the *Scotland Heat Map*. This has been developed by the Scottish Government and is based on simple energy models. Heat demand data is given per unit area, down to a resolution of 50m^2 as shown in Figure 35.

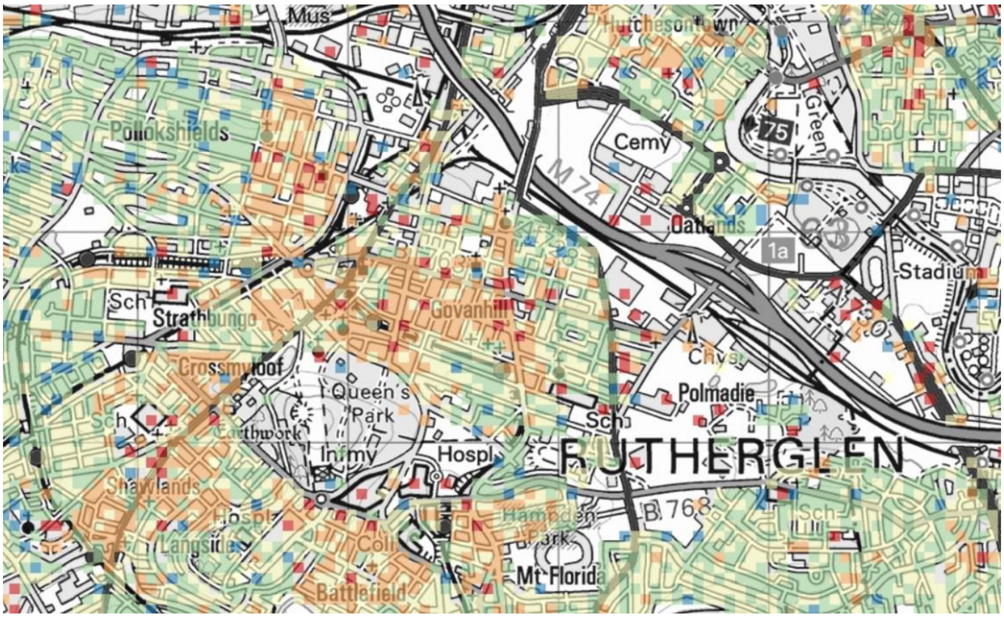

Figure 35 - Heat map of Govanhill West

The Glasgow SEAP project as part of the STEP UP initiative involved the development of an energy demand map for Glasgow in partnership with Scottish Power Energy Networks. These maps show data for heat and electricity demand for both domestic and non-domestic buildings in the city. Many attempts were made to get in touch with the project contact however there was no response. This would have been very useful information and would have provided much of the energy data needed.

Heat demand reports can be generated for required areas in two ways. Either by drawing the required area or by preselecting defined areas. Both were tried, with a comparison of the areas in Figure 36 and Figure 37.

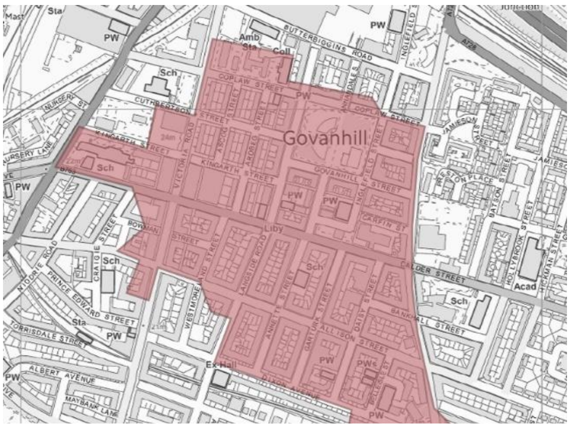

Figure 37 - Heat map drawn boundary

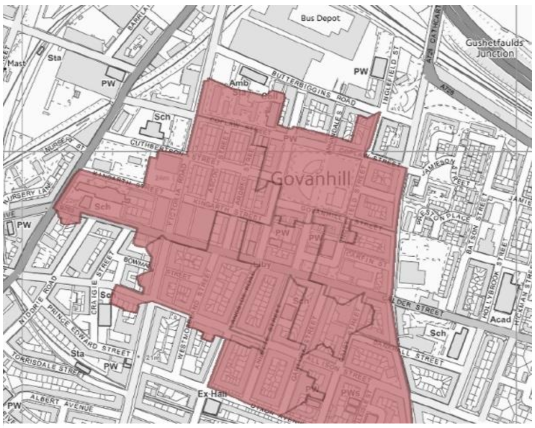

Figure 36 - Heat map predefined boundary

The boundary on the left is the defined area for this project and the data zones are shown on the right. The boundaries are roughly similar, with small differences. It is believed that these are meant to be defined as the same areas (since they are both from Scottish Government datasets), however an approximation may have been made with one of the maps.

An issue occurs when heat demand results are compared for the two areas as shown in Table 5.

Table 5 - Heat map results

How Area Has Been Selected	Area	Data Zones Covered	Total Heat Demand	Public Heat Demand
Drawing area	0.311 km^2	16	142 GWh/year	4 GWh/year
Preselected data zones	0.309 km^2	7	36 GWh/year	1 GWh/year

When the required area is drawn, the heat demand is 4 times that of the other result, despite the fact that there is minimal difference between the two areas. The help service for the heat map was contacted and they believe that the main difference is due to the fact that more data zones are included, meaning that some data is included which shouldn't be. To test this, the same process was followed for other areas in Glasgow but the same issue did not occur. It is believed this is simply an anomaly with the results of the Govanhill area.

To determine which result represents the heat demand for the community, this project therefore used the *Renewable Heat Study* by Ricardo Energy and Environment for South Seeds. As described before, this is focused on district heating potential in the Southside area. Three areas were analysed in the paper. Focussing on the Govanhill Main Opportunity Area shows that the calculated total heat demand for this community is 63,000 MWh/year for 3400 properties in the area. This is an average of around 18,500 kWh per property. There is a

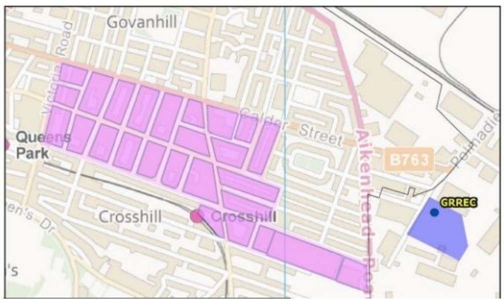

Figure 38 - Govanhill district heating potential area

total of 2,886 households in Govanhill West so the heat demand using these results should be around 53,500 MWh/year.

This figure is still significantly different from the heat map results. The heat demand in the *District Heating Study* is approximated based on 4 case study flats. All of them are assumed to have single glazed windows with little to no insulation. The *Energy Snapshot Report* by South Seeds highlighted that many of the flats in the area have double glazing, although in poor condition and South Seeds have also installed energy efficiency measures to some flats which will have reduced the heat demand. From this it can therefore be assumed that the smaller figure of 36 GWh/year total heat demand is more accurate for the area.

Public heat demand for the area is 1 GWh/year, while the other heat demand is split between domestic and non-domestic properties. It was found that the total non-domestic heat demand is equal to 4.05 GWh/year. This calculation will be described in the relevant section below. This means that the total domestic annual heat demand is 30.95 GWh/year. The results are displayed in Table 6 below.

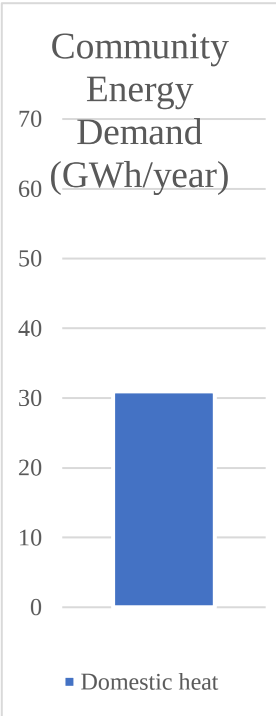

Figure 39 - Total demand after domestic heat

Table 6 - Current domestic heat demand results

Annual Energy Demand	**Energy Demand Per Dwelling**	**Energy Demand Per Person**	**Daily energy demand per person**
30.95 GWh/year	10800 kWh/year * dwelling	5700 kWh/year * person	15.6 kWh/day * person

3.3.2 Public heat demand

It is assumed that the public buildings in the area are the three schools. While there may be more buildings which are classified as public, it will not make a huge difference to the demand results here. The report from the *Scotland Heat Map* states that the total public heat demand is equal to 1 GWh/year. This figure will be used in this study.

Table 7 - Current public heat demand results

Annual Energy Demand	Energy Demand Per Building	Energy Demand Per Person	Daily energy demand per person
1.0 GWh/year	333,333 kWh/year * dwelling	184.2 kWh/year * person	0.5 kWh/day * person

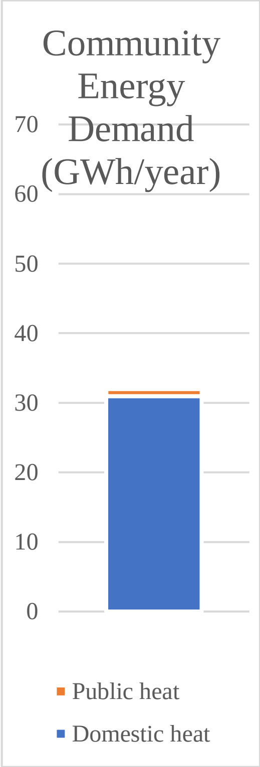

Figure 40 - Total demand after public heat

3.3.3 Non-domestic heat demand

The non-domestic buildings in the area will involve a mix of properties such as shops, restaurants and offices. These are mainly centred around the retail tenement blocks in Allison Street, Victoria Road and Cathcart Road. In general, the majority of the heating demand will be for space heating, with a small requirement for water heating. Through analysis of Google Maps, it was found that there are no industrial manufacturing companies in the area which require substantially more heat in the manufacturing processes. There is the Glasgow Recycling and Renewable Energy Centre nearby, which will require substantial amounts of heat, however this is outwith the boundary of Govanhill West.

The Sub-national energy consumption data from DECC gives highly discretised data about the metered consumption throughout the UK. The data provided for each data zone is the metered consumption, number of meters and then the mean and median consumption is calculated. Businesses as well as domestic properties are under no obligation to share their energy use. In some cases, it may be commercially beneficial that other companies do not know the energy use of businesses. The data is estimated based on meter point data provided by the electricity and gas companies. So, this will provide accurate metered data, while not specifying which properties have used how much energy.

The metered gas results show that the annual non-domestic gas consumption is 5,399,659 kWh. This represents the gas consumption, not the energy demand. This will differ since a boiler will never be 100% efficient. Also, the efficiency of boilers will be slightly less than the quoted efficiency. This is because in real life the boiler is rarely running in ideal conditions. As part of the *Scotland Heat Map* validation process, metered data is taken and compared to the modelled demand. In this process the assumed efficiency of the boiler is 75%. Using this information, the heat demand can then be calculated:

$$Heat\ demand\ =\ boiler\ efficiency\ *\ gas\ consumption\ =\ 0.75\ *\ 5.4$$

$$=\ 4.05\ GWh/year$$

This gives the results shown in Table 8:

Table 8 - Current non-domestic heat demand results

Annual Energy Demand	**Energy Demand Per Building**	**Energy Demand Per Person**	**Daily energy demand per person**
4.05 GWh/year	13,730 kWh/year * dwelling	745.8 kWh/year * person	2.0 kWh/day * person

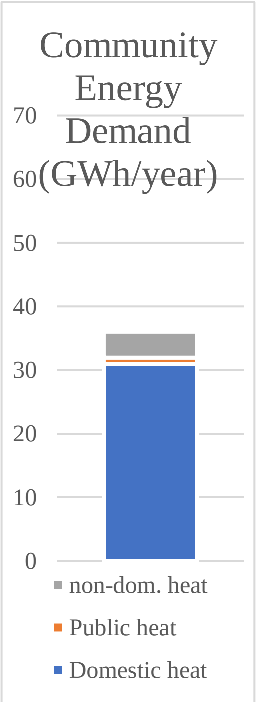

Figure 41 - Total demand after non-domestic heat

It is worth noting that some of the gas consumption for non-domestic properties will be attributed to cooking gas, particularly for catering businesses. This demand is included in the non-domestic heat demand for this study. In reality it is not considered a heat demand, however it would be difficult to determine how much gas would be used for heat and how much would be used for cooking. Also, it could be arguable that when gas is burned during cooking, the heat which is given off is then used for space heating.

3.3.4 Domestic electricity demand

Figure 35 showed that in the *Scottish House Condition Survey,* heat accounted for 87% of energy demand while electricity to supply lights and appliances accounts for only 11% of energy demand. It should therefore be expected that the electricity demand for domestic properties is significantly smaller in these results. In reality, it may be the case that electricity demand in this area is slightly higher than average. Since it is a deprived area, it is less likely that efficient appliances, which can cost a lot more, are used, although there is the argument that households suffering from fuel poverty may be less likely to use appliances to save money. A complete understanding of electricity use would only be gained through energy surveys using metered electricity use and individual appliance monitors. This is outwith the scope of this project, however could be a valuable future study.

The STEP UP project developed an electricity demand map for Glasgow, along with the heat maps. As described previously, attempts were made to get in touch with the project contact with no success. If this energy demand map were available, it could be a useful data source to study and could be compared with the results gained in this study. The Future City Glasgow project (an Innovate UK funded project, which is aiming to use smart technology to improve the city) developed the Glasgow Energy App. This showed promise to find results for a number of the demands in this project. It aims to describe the energy supply and demands throughout the city, however it was found to be difficult to understand the data and determine what values should be used. This dataset was not usable for this project.

Since the databases for Glasgow are not suitable, the *Household Electricity Survey* produced by Intertek was consulted. The 600-page document gives a detailed breakdown of the electricity use in the 251 households surveyed, broken down by appliance demand. The report is one of the biggest electrical measurement campaigns ever undertaken in Europe. It is a useful reference and should provide data which can be used to determine the electricity demand and demand reduction potential of the community studied. The report was conducted in 2012. Since, appliances have advanced and become more energy efficient however, it can be assumed that this is representative of the appliances used in the households of Govanhill, since it is unlikely the latest, most efficient appliances are common in the area. The households surveyed in the paper all reside in England and as much as possible they were selected to reflect the average household types for England. While this may be a source of error when calculating the demand for the community, a suitable source which accounts for this difference could not be found.

A breakdown of the energy demands throughout an average day are shown in Figure 42. This shows the contribution of each of the appliances as well as how much electricity demand varies throughout the day.

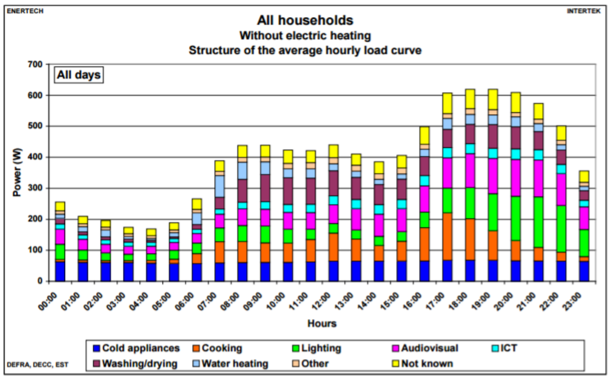

Figure 42 - Average hourly electrical load for dwellings

The key results in terms of total electricity demand are shown in Figure 43. These results describe the demand for different types of households which undertook the study. Since almost all the properties are flats, it was not useful to use the data for the house type. It was decided that the households of the community should be correlated with the household types in the survey to then gain an average demand which should be accurate for this specific community.

Household type	Annual consumption (kWh) per household	per m²	per person	Average maximum power demand (W)
Terraced house – mid-terrace	3,083	71		7,188
Terraced house – end-terrace	4,258	81		7,685
Terraced house – small (up to 70 m²)	3,421	75		7,156
Terraced house – medium/large (above 70 m²)	4,399	52		10,568
Semi-detached house	4,009	76		7,888
Detached house	4,256	66		7,312
Bungalow	3,789	59		8,683
Flat	3,510	77		7,625
Single pensioner household (65+ years old)	3,427	64	3,427	6,984
Single non-pensioner household	3,853	69	3,853	7,211
Multiple pensioner household	3,812	70	1,906	7,788
Household with children	3,672	68	966	7,277
Multiple person household with no dependent children	4,232	77	1,912	8,569
All households	3,567	71	2,142	7,665

Figure 43 - Average annual electricity consumption

There are 5 different household types which have been defined in Figure 43. The first step was to gather information on how households are categorised from the data available for Glasgow. *Understanding Glasgow* describes Glasgow's household types as shown in Figure 44.

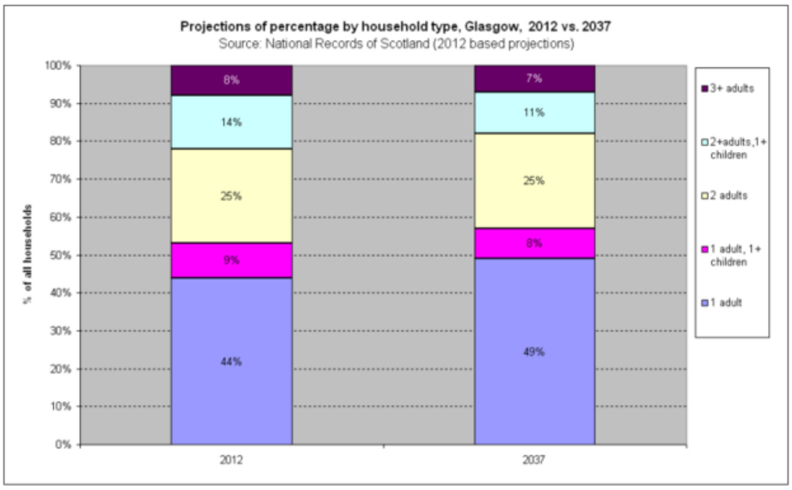

Figure 44 - Glasgow household types

The Household categories here are described in terms of the number of adults and the number of children in the household, while the *Household Electricity Survey* expressed the households in terms of whether the occupants are pensioners and whether there are children. This means that some adaptation of the household types will need to be made.

The data in Figure 44 is for the whole of Glasgow. This can be compared to data in the *Govanhill Neighbourhood Profile*. First studying the 1 person households, the *Neighbourhood Profile* expresses these in terms of under 65s and over 65s. The figures for the city as a whole are 30.4% and 12.8% respectively, while the figures for Govanhill are 42.1% and 10.63%. This means that the total number of households with 1 occupant is 52.75% for Govanhill. The lone parent with dependent children classification is also different for the area with 61.21% of the 9.8% of households with lone parents having children, resulting in 6% of the households being 1 adult, 1+ children. In total, there are 19.2% of households in the area with dependent children. This means that 13.2% of households are classified as 2+adults, 1+ children, since 6% are one adult with children. This leaves 28% of the households which are either 2 adults or 3+ adults. Assuming the same ratio between the two of these categories which is present for the whole of Glasgow, the percentage of each household type is shown in Figure 45.

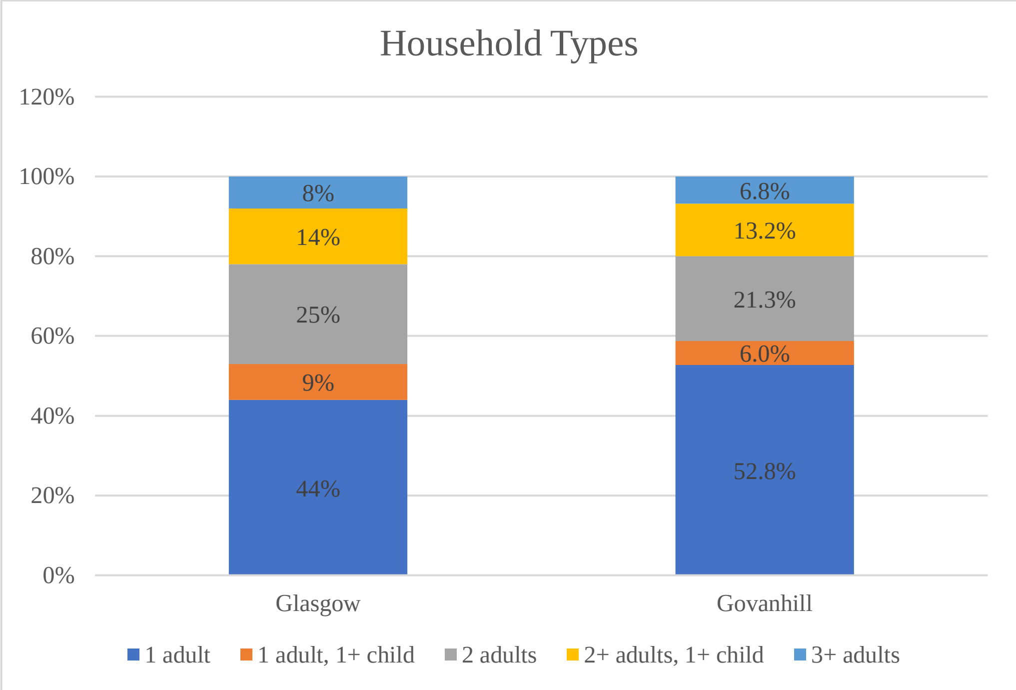

Figure 45 - Comparison of household types for Glasgow and Govanhill

These results should then be translated into the categories which are in the electricity survey. For the category for a single occupant, the percentage above 65 years of age must be calculated. These have been defined in the section above for the whole community. As a percentage of the single person households, 79.85% are non-pensioners with the remaining 20.15% being pensioners. From the electricity consumption in the study, these household types require on average 3,853 kWh and 3,427 kWh respectively. The average demand for these households can be calculated using:

Average demand for 1 adult households = percentage of non-pensioner households*demand for non-pensioner households + percentage of pensioner households*demand for pensioner households

$$= 79.85\% * 3853 + 20.15 * 3427 = 3767\ kWh/year$$

The same calculation method is applied for the households with 2 adults, with multiple pensioner households requiring on average 3,812 kWh/year, while multiple non-pensioner households requires 4,232 kWh/year. This gives the following calculation:

$$Average\ demand\ for\ 2\ adult\ households\ =\ 79.85\%\ *\ 3812\ +\ 20.15\ *\ 4232$$

$$=\ 4147\ kWh/year$$

In the study, households with children use on average 3672 kWh/year. This figure is used for both households with one adult and children as well as 2+ adults and children. Then households with 3+ adults will be the same classification as multiple person households with no dependent children.

These results are collected in Table 9 below:

Table 9 - Assumed household types and average electricity demand for Govanhill

Category	**Average Annual Electricity Demand**	**Share of households**
1 adult	3767 kWh/year	52.8%
1 adult, 1+ children	3672 kWh/year	6.0%
2 adults	4147 kWh/year	21.3%
2+ adult, 1+ children	3672 kWh/year	13.2%
3+ adults	4232 kWh/year	6.8%

Multiplying the average electricity demand with the share of the households results in an average annual electricity demand for Govanhill West of 3861 kWh.

This figure was initially used as the current value of domestic electricity demand for the community. Upon further inspection, however, it was altered. Further into the survey report, the average percentage demand for each appliance was quoted. These values and the calculated energy demand are shown in Table 10 below:

Table 10 - Initial consumption per appliance

Appliance Type	**Quoted Percentage of Total Annual Demand**	**Calculated Appliance Demand (kWh)**
cold appliances	16%	626
cooking	14%	533
lighting	15%	595
audio-visual	14%	556

ICT	6%	236
washing/drying	14%	525
water heating	7%	274
other	4%	143
not known	10%	375

Studying the data which is presented for each of these appliances, all seem suitable and representative of the households in Govanhill West apart from the results for cold appliances. Figure 46 shows the combination of cold appliances in the households measured in the survey. For some households 4 cold appliances are used. This may be possible for large households with a lot of space, such as rural detached properties. Thinking realistically about the space available in the dense flats of an urban community, it is very unlikely that more than 2 cold appliances will be present in these households. The annual energy consumption for the different types of appliance are as follows:

Table 16 Combination of cold appliances per households

Combination of cold appliances per households	Number of households	Number of items
1 fridge-freezer	88	1
1 refrigerator, 1 upright freezer	41	2
1 fridge-freezer, 1 chest freezer	18	2
1 fridge-freezer, 1 upright freezer	16	2
1 refrigerator, 1 chest freezer	9	2
1 refrigerator, 1 fridge-freezer	9	2
1 refrigerator, 1 fridge-freezer, 1 upright freezer	8	3
1 refrigerator	7	1
2 refrigerators, 1 upright freezer	7	3
1 refrigerator, 1 upright freezer, 1 chest freezer	6	3
2 fridge-freezers	5	2
1 refrigerator, 1 fridge-freezer, 1 upright freezer, 1 chest freezer	3	4
1 refrigerator, 2 upright freezers	2	3
2 refrigerators, 1 upright freezer, 1 chest freezer	2	4
2 refrigerators, 2 upright freezers	2	4
1 fridge-freezer, 1 upright freezer, 1 chest freezer	1	3
1 refrigerator, 1 fridge-freezer, 1 chest freezer	1	3
1 refrigerator, 1 fridge-freezer, 2 upright freezers	1	4
2 refrigerators, 1 chest freezer	1	3
2 refrigerators, 1 fridge-freezer, 1 upright freezer	1	4

Figure 46 - Electricity survey average no. of cold appliances

- Refrigerator: 162 kWh
- Fridge-freezer: 427 kWh
- Upright freezer: 327 kWh
- Chest freezer: 362 kWh

Then calculating the demand for the households with up to 2 appliances results in the following energy use shows in Table 11 below:

Table 11- Cold appliance combinations

Appliances Installed	No. of Households in Survey	Cold Appliance Electricity Consumption (kWh/year)
1 Fridge-freezer	88	427
1 refrigerator, 1 upright freezer	41	489
1 fridge-freezer, 1 chest freezer	18	789
1 fridge-freezer, 1 upright freezer	16	754
1 refrigerator, 1 chest freezer	9	524
1 refrigerator, 1 fridge-freezer	9	589
1 refrigerator	7	162
2 fridge freezers	5	854

The average electricity consumption over all the households is 515 kWh/year. Compare this to the previous estimate in Table 10 of 626 kWh/year, it is likely that there will be a smaller demand within the community for these appliances.

All other appliances will have the same electricity demand as stated previously. The final electricity demand by appliance type is:

Table 12 - Calculated electricity demand per appliance for community

Appliance Type	Percentage of Total Annual Demand	Appliance Demand (kWh)
cold appliances	14%	515
cooking	14%	533
lighting	16%	595
audio-visual	15%	556
ICT	6%	236
washing/drying	14%	525
water heating	7%	274
other	4%	143
not known	10%	375
	Total Annual Electricity Demand	**3750 kWh**

This figure can be used for the total domestic electricity demand of the community. If surveys are conducted within the community, it would be interesting to compare the measured results for the appliances to determine how accurate these results are and to see where improvements in appliance efficiency could be made.

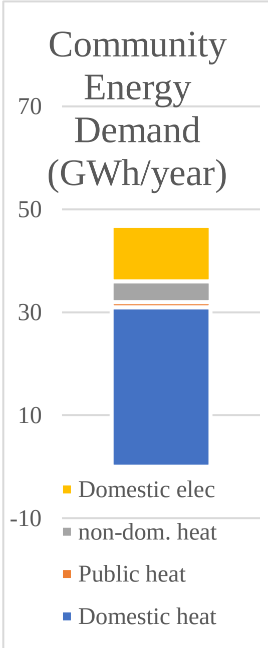

Figure 47 - Total demand after domestic electricity

The final domestic electricity results for the community are as follows:

Table 13 - Current domestic electricity demand results

Annual Energy Demand	Energy Demand Per Dwelling	Energy Demand Per Person	Daily energy demand per person
10.75 GWh/year	3750 kWh/year * dwelling	1980 kWh/year * person	5.4 kWh/day * person

3.3.5 Non-domestic electricity demand

This data was collected from the same source as non-domestic heat, sub-national energy consumption data from DECC. No efficiency needs to be applied here, so the results can be generated directly from the dataset. The non-domestic electricity demand is defined in Table 14 below:

Table 14 - Current non-domestic electricity demand results

Annual Energy Demand	Energy Demand Per Dwelling	Energy Demand Per Person	Daily energy demand per person
4.7 GWh/year	15940 kWh/year * dwelling	866 kWh/year * person	2.4 kWh/day * person

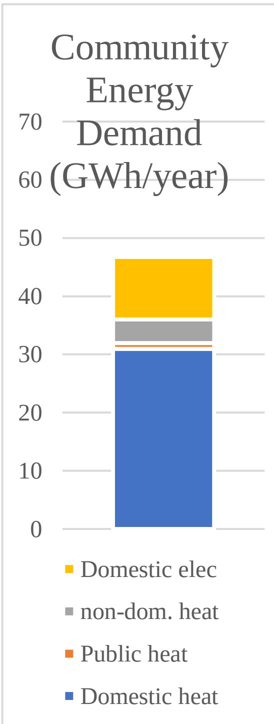

Figure 48 - Total demand after non-domestic electricity

It is assumed here that the electricity demand for public buildings is included in this figure, since there was no data available specifically for these buildings.

It is also worth noting the comparison of non-domestic heat and electricity. The total annual heat demand for public and non-domestic buildings is 5.05 GWh with the electricity demand of 4.7 GWh. These results are comparable, while the domestic heat demand is almost 3 times that of the domestic electricity demand. Electricity demand is expected to be higher for non-domestic buildings since more appliances will be used to ensure positive working environments and to suit customers. Typical appliances will be lights, computers and ventilation. The heating demand will however be smaller since less time is spent in commercial buildings than in homes, plus offices and shops need to be heated during the daytime when temperatures are significantly higher. Add to this the casual gains from the appliances and the heat demand for these buildings will be significantly lower.

3.3.6 Transport demand

Govanhill is close to the largest city in Scotland, with excellent transport connections easily accessible, both in terms of local motorways and public transport. In total, the *Neighbourhood Profile* suggests that 38.5% of households in the area have access to one or more cars or vans. This is compared to a figure of 49.2% for the whole city and 69.5% for all of Scotland. *Understanding Glasgow* has data which thoroughly describes transport in Glasgow. The city has the highest traffic volume of the 4 Scottish cities, mainly due to its large size. Figure 48 shows the transport mode selected for commuting for Scotland and for the 4 cities. Glasgow has a relatively small share of the journeys made by driving a car or van although it still dominates other transport modes. The other most common modes are bus, minibus or coach and travel on foot. It is likely that the largest influence of mode choice will be the distance travelled and facilities available. It would be useful to understand how different modes compare in this respect. Travel by foot will be the mode type with the lowest energy demand. Cycling makes up only 1.6% of journeys.

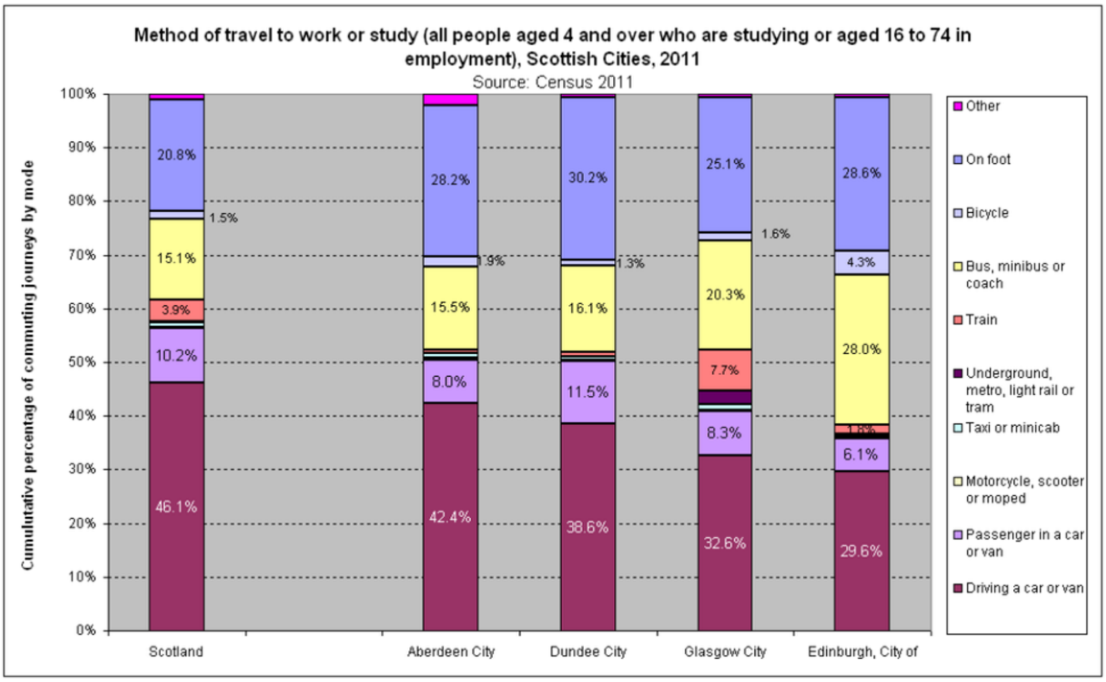

Figure 49 - Mode of travel to work or study in Scottish cities

The approach used to calculate the energy demand for transport in the SEWTHA paper is likely to be applicable here. The calculation is shown in Figure 50:

$$\begin{array}{c}\text{energy used}\\ \text{per day}\end{array} = \frac{\text{distance travelled per day}}{\text{distance per unit of fuel}} \times \text{energy per unit of fuel.}$$

Figure 50 - SEWTHA car transport calculation

This takes into account the drive type and fuel efficiency of the car, which is separate from the distance travelled. The distance travelled will be the main variable for the community, so an appropriate method should be followed to determine this data.

Multiple sources were studied to determine a suitable dataset for the area. Many of these were inadequate mainly because travel was expressed in terms of number of journeys by mode, without data presented for the distance travelled by mode. It is vital to take into account the distance when considering transport. For example, a walk to work would be one journey, while a transatlantic plane holiday flight would also be one journey.

A suitable data source was found in the form of the *Scotland Commute Map* by DataShine. This sources data from Scotland's Census and the National Records of Scotland. It is an interactive map which identifies where people travel to and from for each data zone location as well as describing how many travel by what type of mode. A snapshot of the interface is shown in Figure 51. The data for travel mode, how many commuters and destination can allow the calculation of energy demand for any community in Scotland. There is also a similar map which gives this data for all of the regions in the UK.

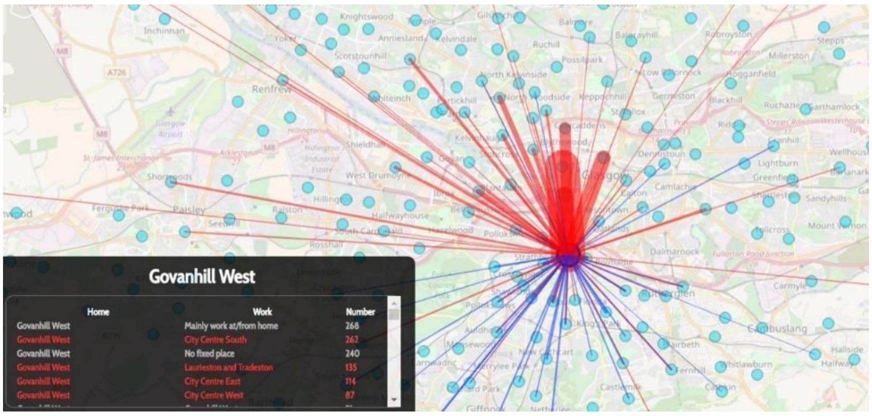

Figure 51 - Scotland Commute Map screenshot of Govanhill West

The issue with this data is that it only covers commuting, which is only a part of the total reasons for travel. It will still be significant however so should be used as a basis for this calculation. Information of this quality for other travel purposes will be difficult to develop, since other transport reasons are more irregular. It was decided that commuting energy demand and other transport energy demand would be analysed separately for this project.

The approach taken here was first to collect all of the data for people commuting from Govanhill West to other data zones. This data also described the number that travelled by each mode type. It was assumed that the people who were commuting from other areas into Govanhill West would be included in the energy demands of the other areas. These were therefore not analysed. Google Maps was then used for each of the destinations to determine the distance travelled by each mode. The exact locations selected were as close as possible to the centre points described in the map. In reality people will travel to other locations in the data zone, however this is a suitable approximation. Different mode types were taken into account when identifying the distance travelled using Google Maps. Walking will take the most direct route, while car journeys may take a slightly longer one. The journey made by bus is often much longer and the distance to walk to and from bus stops was also taken into account to ensure that only the distance travelled by bus was measured. These results were then processed in Microsoft Excel to determine the total distance travelled by each mode. There are some undefined destinations described as “no fixed place”. The distance used for these was simply the average distance for that mode type.

The locations which tend to be the most common destinations include the city centre area. Also there are a substantial number of journeys made to other areas south of the river which are relatively close to Govanhill as well as some to the east and west of the city centre, which are known as highly active areas.

In total 1530 journeys are made to work in the area with a total distance of 4,170 miles travelled. The calculated results for each of the mode types is as shown in the table below:

Table 15 - Govanhill West commute data

Commute Mode	**Number of people (Percentage)**	**Average distance per journey (miles)**	**Total Distance Travelled (miles) (Percentage)**
Mainly work at/from home	268 (18%)	-	0 (0%)
Train/metro	108 (7%)	2.51	271 (7%)
Bus/coach	472 (31%)	2.92	1379 (33%)
Car (driving)	368 (24%)	5.37	1977 (47%)
Car (passenger)	20 (1%)	10.8	216 (5%)
Bicycle	9 (1%)	2.7	24 (1%)
On foot	276 (18%)	1.1	303 (7%)
Other	9 (1%)	-	-

There are a number of interesting findings in these results. 18% of the people work from home, which is higher than may be expected for a city. As expected, bus, car travel and walking are dominant, but it is bus travel which has the largest proportion of journeys. The average distance travelled is also surprising. The distance walked is on average 1.1 miles while train, bus and bicycle journeys are all around 3 miles in distance. While logic says that car journeys should be significantly longer than all other transport modes, it is actually only 5.4 miles, double the average distance cycled. These factors suggest that with sufficient support, a large shift towards more sustainable and active transport modes could be feasible.

The next step was to quantify the energy demand from commuting travel. This was based on the same calculation method as SEWTHA shown in Figure 50. The distances calculated from the commute map is for a one-way journey, so the distances were multiplied by two, to gain the daily distance travelled, and then by 224 working days in the year (252 working days – 26 days holiday entitlement). To keep consistent with the units used in SEWTHA, this was then converted to km. For car commuting, the fuel efficiency figure is used which is 33 mpg = 12 km/litre. This figure may seem low, particularly since some new cars are quoting around 70 mpg, however the cars in the area are likely to be older than average, and the majority of the journey will be in the urban environment, both resulting in a low value. A survey of residents' car use would provide more accuracy here. The energy density of the fuel is taken to be 10 kWh/litre. The energy consumption for cars is calculated as follows:

$$
\begin{aligned}
Energy\ Demand\ &=\ total\ distance\ *energy\ density\ /\ fuel\ consumption \\
&=\ 1{,}424{,}743\ km\ *\ 10\ kWh/litre\ /\ 12\ km/litre \\
&=\ 1{,}187{,}300\ kWh
\end{aligned}
$$

The energy consumption for public transport uses specific energy figures from SEWTHA. An electric high-speed train (train journeys are assumed to be electric for inner city trains) can achieve 3 kWh per 100 seat-km when full. A conservative estimate would be that the trains are 50% full, so this should be increased to 6 kWh per 100 seat-km. For buses, the energy usage of all London buses was 32 kWh per 100 seat-km. This figure should be used.

The calculation for trains is as follows:

$$Energy\ Demand = Distance\ travelled\ (km) * Specific\ energy\ (kWh/km)$$
$$= 195{,}629 * 0.06 = 11{,}700\ kWh$$

And for buses:

$$Energy\ Demand = Distance\ travelled\ (km) * Specific\ energy\ (kWh/km)$$
$$= 994{,}064 * 0.32 = 318{,}100\ kWh$$

The energy consumption for walking and cycling is ignored here. While it is true that the calories required to move people with active transport will need to be supplied through an increased consumption of food, this increase is negligible compared to other demands and food energy demand is not studied in this project. The energy demand for commuting is as follows:

Table 16 - Community commute energy demand by mode type

Commute Mode	**Energy Demand (MWh) (Percentage)**
Work from home	-
Train/metro	11.7 (1%)
Bus/coach	318.1 (21%)
Car (driving)	1187.3 (78%)
Car (passenger)	0 (0%)
Bicycle	0 (0%)
On Foot	0 (0%)
Other	0 (0%)

As expected, car transport dominates here, particularly since it will only be one person in the car and cars are a very energy intensive form of transport.

The energy demand for school transport was then calculated. There are 491 school children in the community, and with a total of 4 schools in and around the area, it is assumed that they are enrolled at these schools, giving an average distance travelled of around 0.5 miles. On average 58% of school children walk to school with only 24% of the journeys being by car. Applying the same calculation method used for commuting, it was found that the annual demand is only 39 MWh. This is a tiny fraction of the total community energy demand and since most of these journeys will be combined with the commute, the demand for school transport can be neglected.

An in-depth study was made to find a source which relates the distance travelled by commuting to other journey purposes. No data was found which provides a similar amount of detail as the *Scotland Commute* source and some assumptions had to be made. The *Annual Mileage of 4 wheeled Cars by Ownership and Trip Purpose: England, 2002 to 2016* defines the annual mileage of cars in terms of commuting and total mileage. This data is can be assumed to be accurate for Scotland and the community in focus. Commuting on average accounts for 2,800 miles out of a total of 7,800 miles. Maintaining this ratio means that the energy demand for other car transport is 2.79 times that of commuting energy demand:

$$\begin{aligned} &Energy\ demand\ for\ other\ car\ travel \\ &\qquad = ratio * energy\ demand\ for\ commuting = 2.79 * 1187.3 \\ &\qquad = 3{,}307\ MWh. \end{aligned}$$

To determine the demand for other public transport, the *Road Use Statistics Great Britain 2016* was used. On average, a person in the UK uses a train 27 times in a year (12 of these for commuting) and a local bus 61 times a year (11 for commuting). These figures may seem low, however this is averaged over the whole UK population. The ratios for these are 2.25 and 5.55 respectively. This means that the total demand for other transport by rail is 26.4 MWh, while it is 1,764 MWh for buses. A summary of the energy demand for other travel is shown in Table 17.

Table 17 - Energy demand for other travel by mode type

Transport Mode	**Energy Demand for Other travel (MWh)**
Car	3307.4
Train/metro	26.4
Bus/coach	1764.0
Total	5097.9

This concludes the analysis of the transport energy demand. The final energy demand for transport is shown below in Table 18.

Table 18 - Current transport energy demand results

Travel Type	Annual Energy Demand	Energy Demand Per Dwelling with cars	Energy Demand Per Person	Daily Energy Demand per Person
Commuting	1.7 GWh/year	1580 kWh/year * dwelling	320 kWh/year * person	0.9 kWh/day * person
All Other travel	5.1 GWh/year	4620 kWh/year * dwelling	939 kWh/year * person	2.6 kWh/day * person

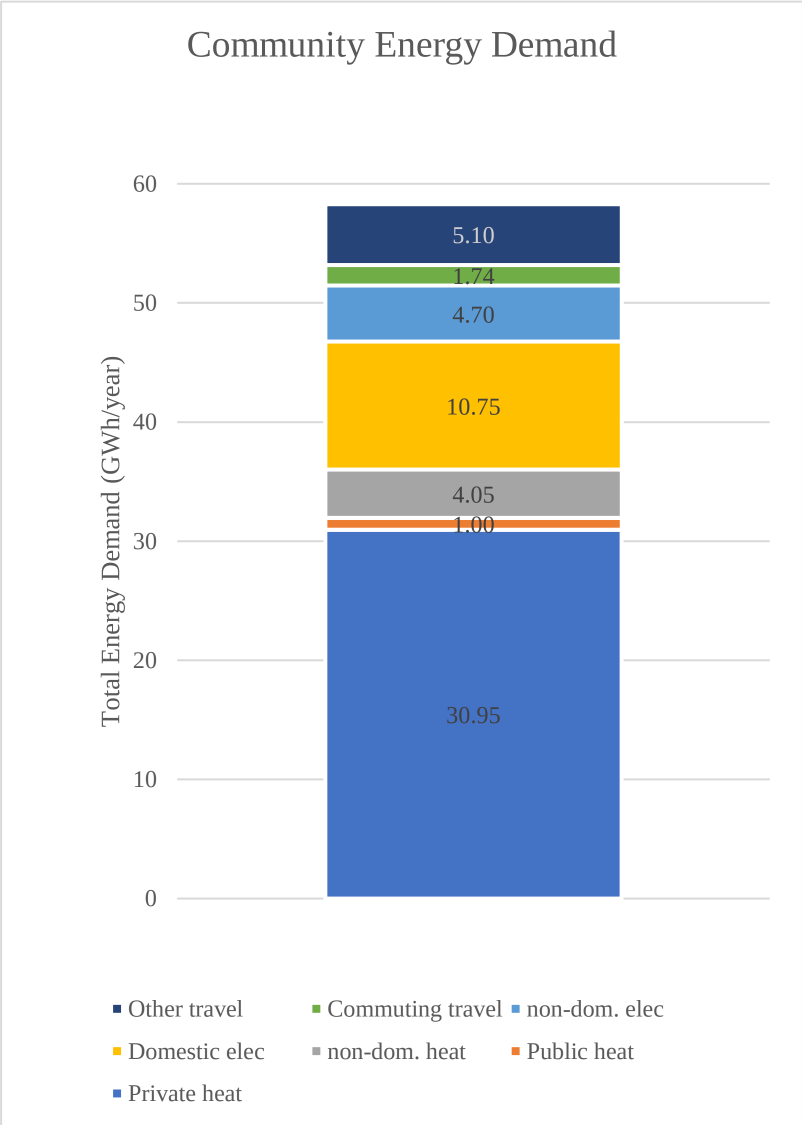

Figure 52 - Total demand after transport

3.3.7 Total energy demand for the community

All the energy demands studied in this project have now been quantified. A summary of the results for each demand type is in Table 19.

Table 19 - Summary of current energy demands by demand type

Energy Demand Type	**Annual Energy Demand (GWh/year)**	**Energy Demand Per Building Type**	**Energy Demand Per Person**	**Daily energy demand per person**
Domestic heat	30.95	10800 kWh/year*dwelling	5700 kWh/year*person	15.6 kWh/day*person
Public heat	1.0	333,333 kWh/year*building	184.2 kWh/year*person	0.5 kWh/day*person
Non-domestic heat	4.05 GWh/year	13730 kWh/year*building	745.8 kWh/year*person	2.0 kWh/day*person
Domestic electricity	10.75 GWh/year	3750 kWh/year*building	1980 kWh/year*person	5.4 kWh/day*person
Non-domestic electricity	4.7 GWh/year	15940 kWh/year*building	866 kWh/year*person	2.4 kWh/day*person
Commuting travel	1.7 GWh/year	1580 kWh/year*building	320 kWh/year*person	0.9 kWh/day*person
All other travel	5.1 GWh/year	4620 kWh/year*building	939 kWh/year*person	2.6 kWh/day*person

3.3.8 Calculating energy costs

Quantifying the energy demand for different types allows the calculation of costs to the consumer. Fuel poverty will most likely be common in the area, so this will be an important factor for the residents.

First studying domestic heating, it is assumed that all households are heated using mains gas boilers. This is the most common heating type and is expected for inner city homes. While there may be a handful of electrically heated properties in the area, for the purpose of this study, these are neglected. A quick search on the property site Zoopla was conducted and only one property out of around 40 had electric heating. In reality, these households will be paying significantly more for their heating energy, since electricity is more expensive. Energy prices are well recorded and UK average figures were sourced from the UK Government datafile, *Average Variable Unit Costs and Fixed Costs for Gas for GB regions.* The average unit costs for gas in 2016 for South Scotland is 0.037 £/kWh with an average fixed cost of 87.35 £/year. Also, the efficiency of the boiler needs to be accounted for, so an efficiency of 75% is assumed here. Calculating the costs for an average household in Govanhill West:

$$Annual\ cost\ of\ domestic\ heat = cost\ per\ unit * (average\ heat\ demand/boiler\ efficiency) + Fixed\ costs$$

$$= 0.037\,£/kWh * (10{,}800\,kWh/75\%) + £87.35 = £620$$

The same process can be applied to domestic electricity as follows:

$$Annual\ cost\ of\ domestic\ electricity = cost\ per\ unit * average\ heat\ demand + Fixed\ costs$$

$$= 0.13\,£/kWh * 3750\,kWh + £79.24 = £567$$

The price of energy for non-domestic properties varies depending on the size of the company. The shops in the area will be small, however they may be part of a large chain which benefits from lower energy prices. Data on prices is available from the UK Government. The average price for electricity in the first quarter of 2017 was 0.1081 £/kWh. The gas price is more variable, with the price dropping recently presumably due to the drop in oil price. The average price for the last 4 quarters is 0.02282 £/kWh. No fixed cost is given for these properties. Again, a boiler efficiency of 75% is used. In total, there are 295 non-domestic properties. This feeds into the following calculations:

$$Annual\ cost\ of\ non-domestic\ heat = cost\ per\ unit * (average\ heat\ demand/boiler\ efficiency)$$

$$= 0.02282\,£/kWh * (24405\,kWh/75\%) = £418$$

$$Annual\ cost\ of\ non-domestic\ electricity$$
$$= cost\ per\ unit\ *\ average\ electricity\ demand$$

$$= 0.1081\ £/kWh\ *\ 15942\ kWh\ =\ £1723$$

The cost of public heat is not calculated here since it is unclear if there are in fact only 3 public buildings.

The *Quarterly Energy Prices* Report from the UK Government gives the retail prices for motor fuels (diesel and petrol). While the price has varied significantly over the last 2 years, the latest prices seem to be stable at £1.17 for diesel and £1.15 for petrol. There is approximately an equal share of each type, so a fuel price of £1.16 is used. A total of 1103 households have cars, so the total cost of car fuel for these households is:

$$Annual\ cost\ of\ car\ fuel$$
$$= energy\ demand\ per\ dwelling\ with\ cars$$
$$*\ (cost\ of\ fuel\ /\ specific\ energy)$$

$$= 3075\ kWh\ *\ (£1.16/10\ kWh/litre)\ =\ £473$$

Of this, £125 is for commuting, £348 is for other car transport.

The cost of fuel for public transport is not considered here since the majority of the costs for bus and train fares will be other operational costs.

Table 20 summarises the energy costs.

Table 20 - Energy costs results

Energy Demand Type	Fuel Demand (kWh) (Fuel Type)	Annual Fuel Costs (£)	Average Monthly Fuel Costs (£)
Domestic heat	14,400 (gas)	620	51.68
Domestic electricity	3750 (electricity)	567	47.23
Non-domestic heat	24,410 (gas)	418	34.81
Non-domestic electricity	15,940 (electricity)	1,723	143.61
Car transport	2,390 (diesel/petrol	473	39.39

3.3.9 Calculating CO2 emissions

Following the energy costs, carbon emissions were calculated. As described in the introduction of this paper, carbon emissions reduction is one of the key challenges for the energy sector and ambitious targets have been set out for Scotland. The database, *UK Government GHG Conversion Factors for Company Reporting* defined the carbon emissions per kWh of unit energy for different fuel types. Other GHG emissions result from the combustion of fuels. For example, nitrogen oxide is particularly high with diesel vehicles. Only CO2 emissions are considered here, since this is the primary GHG.

The database specifies that the value which should be used for natural gas is 0.184 kgCO2e/kWh. The electricity mix is forever evolving and the progressions towards low carbon renewable generation such as wind power has been part of the success story for Scotland so far. The current conversion factor quoted is 0.412 kgCO2e/kWh. This will decrease over the next few decades, until electricity is near zero carbon. This is one of the main reasons why electrification of heat and transport is part of Scotland energy strategy. The emissions from diesel is on average 0.246 kgCO2e/kWh, while petrol is 0.233 kgCO2e/kWh. From Transport Scotland statistics, there are 1,321,000 registered diesel cars and 1,522,000 petrol cars in Scotland. Assuming this ratio, the average for transport emissions is 0.239 kgCO2e/kWh. In reality, diesel cars produce less emissions per mile, due to increased efficiency, however this is simplified in this analysis. The contribution of buses and electric trains were also taken into account in these calculations.

Using this data gives the following emissions for all the energy demands:

Table 21 – Energy CO2 emissions results

Energy Demand Type	**Fuel Demand (MWh) (Fuel Type)**	**CO2 Conversion Factor (kgCO2e/kWh)**	**Total Emissions (Tonnes CO2)**
Domestic heat	41,267 (gas)	0.184	5,695
Public heat	1,333 (gas)	0.184	184
Non-domestic heat	5,400 (gas)	0.184	865
Domestic electricity	11,748 (electricity)	0.412	1,669
Non-domestic electricity	4,703 (electricity)	0.412	4,429
Commuting travel	2,386 (diesel and petrol)	0.240	573
All other travel	5,098 (diesel and petrol)	0.240	1,224
		Total Annual CO2 Emissions	**14,638**

Figure 53 shows a comparison between the share of energy demand and carbon emissions for the different demand types. This reflects the different CO2 conversion factors of fuels. Domestic heat still has the largest proportion of the CO2 emissions, however it is almost equalled by the non-domestic electricity emissions. Obviously with further decarbonisation of electricity this will evolve, but other actions can be made to reduce the carbon emissions of electricity.

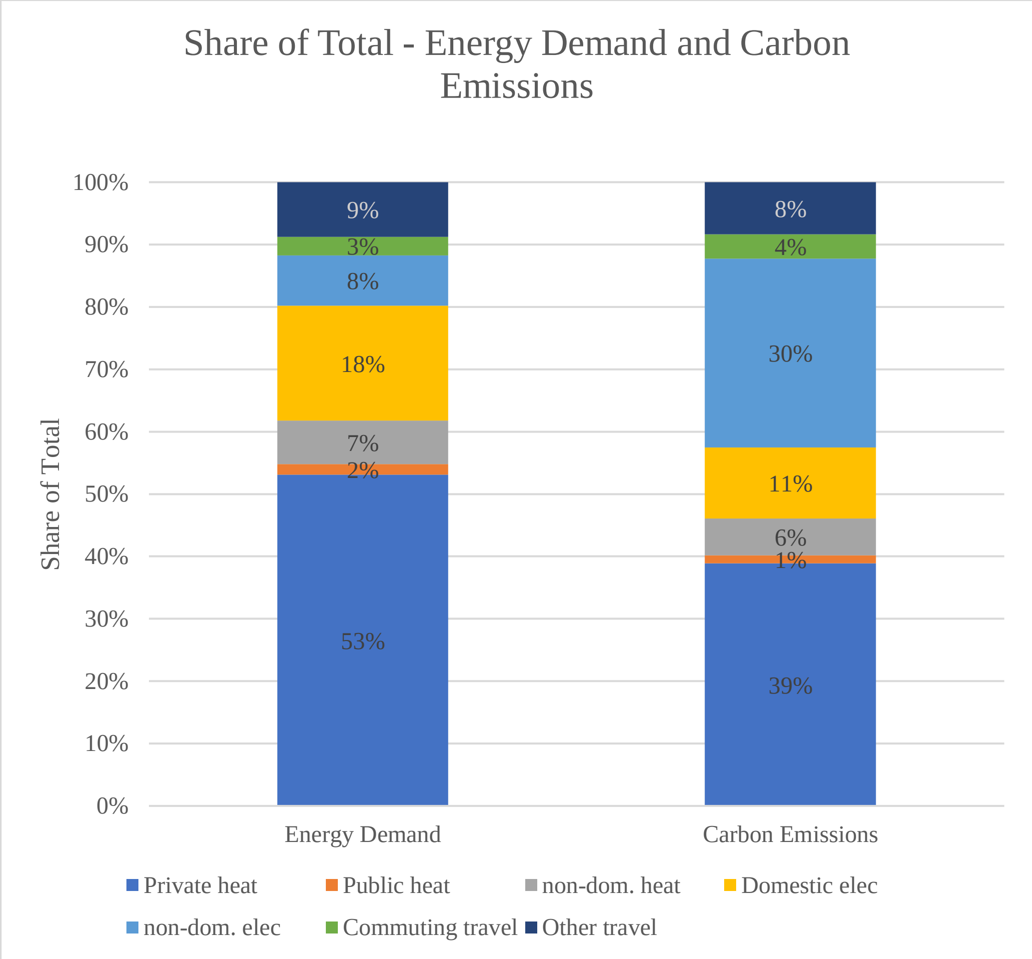

Figure 53 - Comparison of share of energy demand and CO2 emissions by demand type

3.3.10 Reflection on energy demand results

The first question when reflecting on these results will be: "Do they make sense?" First looking at the proportion of each of the demands, the energy supply and demand data for Glasgow can be compared. This is sourced from the *Glasgow Energy and Carbon Masterplan.*

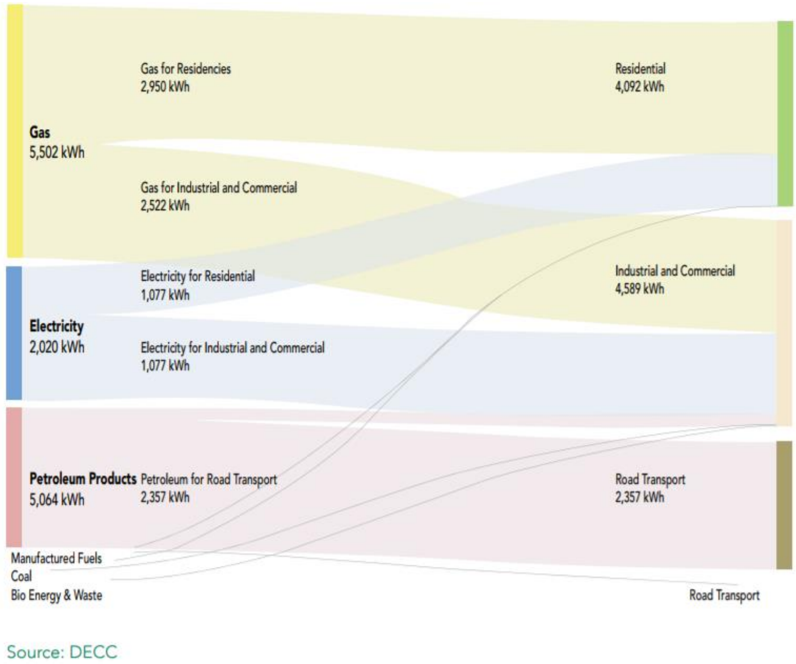

Figure 54 - Energy consumption for Glasgow (2012)

From the results in this study, domestic (residential) energy demand accounts for more than 70% of the demand for the community, whereas for the whole of Glasgow this is 37% of energy consumption. The cause for this will likely be down to the fact that Govanhill is predominantly households, whereas areas such as the city centre will have a much higher concentration of commercial buildings. Another difference is the transport consumption, which has a significantly smaller share for the community. This is perhaps due to the community travelling less, however may be an issue with the calculation method followed in this methodology.

Another comparison is the demand for heat compared to electricity. The trend is consistent with the city-wide results for both domestic and non-domestic demands. Heat makes up approximately 75% of the consumption for Glasgow, which is approximately the same proportion gained in this study. The demand for gas for all commercial properties is just over half of the total non-domestic demand. This is similar with the results in this study, when considering the actual gas consumption.

Greatest Causes of Errors

As far as possible, credible and accurate data sources were used for the datasets. As such, a large amount of time during this project was spent finding the appropriate data. However it is expected that there will always be errors in the calculations and results. The areas of the study where the largest errors are likely to occur are:

- Domestic electricity
  - This is based on a study conducted for a range of housing throughout England. The majority of housing in Govanhill is flats and fuel poverty is common and these will be the biggest factors which change these results. These factors were taken into account as far as possible.
- Private and public heat demand
  - This data is from the *Scotland Heat Map*. This is based on in-depth modelling and is continually being improved to increase the accuracy. There are many factors which contribute to the heat demand of building however, so it is likely that there are households with a wide range of heat demands. Also, the improvements made by the community group South Seeds will result in a lower heat demand for the community.
- Other travel
  - Compared to other datasets, transport should represent a larger proportion of the total demand. It was found to be difficult to find suitable data for this and some approximations had to be made.

Actions to Improve the Accuracy of Results

By far the most effective means of achieving this is to conduct a community energy demand survey. Questionnaires for residents about their energy use and costs would be a strong indicator of the accuracy and can be used to compare measured results with theoretical values. To gain further understanding of where the energy demand comes from (e.g. the consumption for specific electrical appliances) a more intrusive measurement study could be applied to all of the energy demands. A survey is highly recommended if the findings of this study are taken further.

Other Energy Demands Which Could be Considered

Every action an individual takes has an energy demand, from the clothes we wear to putting the bins out. Calories will even be burned during sleep. SEWTHA calculates these demands with the results shown in Figure 55. The largest demands will exist with "stuff", that is all of the physical things we buy apart from food and fuel. Making and transporting these items can be seen to have the largest share on energy demand. Work has been done to help residents reduce this demand in the area. South Seeds has generated a map which shows residents where to repair, recycle and reuse products as shown in Figure 48. If this energy demand data was available for the community, the impact of more sustainable actions could be analysed. Part of the issue here is that the problem is so multidimensional that it may be difficult to fully understand the energy demand impact of buying products.

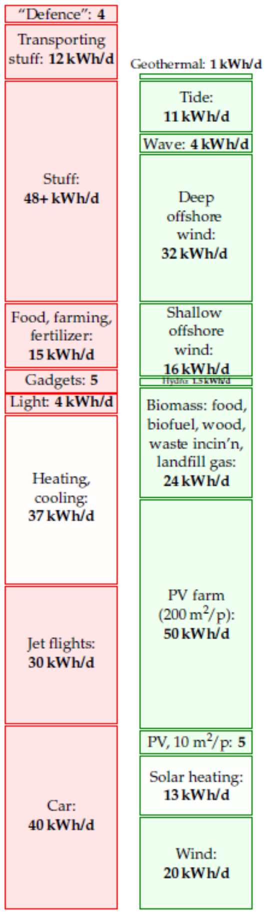

Figure 55 - Other energy demands in SEWTHA

The same can be said for food. *Indicators of Sustainable a Food System* by the Department of Environment Food and Rural Affairs was used to determine that the energy demand of food in the community was 21.8 GWh/year, double the demand of domestic electricity. This was based on very rough assumptions and was not deemed to be accurate enough to be included in this study. Again, the issue is multi-dimensional and complex to understand. It would be interesting to determine the impact of the local food growing facilities and determine the most sustainable food practices for this community in the future.

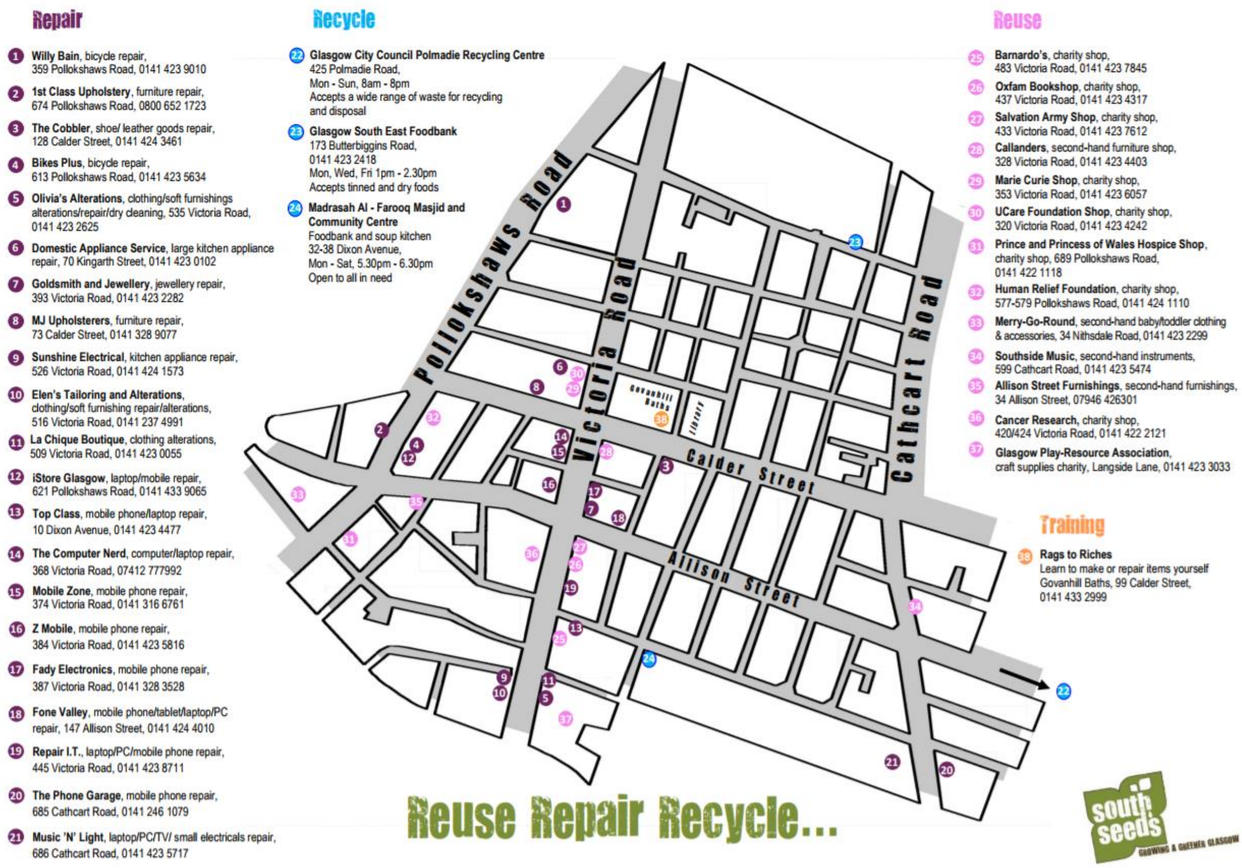

Figure 56 - Map of reuse, repair and recycling businesses in Govanhill

3.4. Stage 4 – Quantify Demand Reduction Potential

The next stage of this project is to study the energy demand reduction potential by identifying the measures which can be used and quantifying the reduction for this community. Each demand will be analysed separately to quantify the demand reduction potential and then the measures can be compared to determine which are most effective. The results shown here could be used to generate scenarios which could be taken forward as a community development programme. These scenarios could be compared to other options such as a strategy where buildings are demolished to make way for new ones, or a scenario with local renewable energy.

A range of measures were studied, to try to give a complete view of the options available for the demands which have been calculated. Some measures are simple, such as installing low energy lightbulbs or cycling to work, which can be undertaken by the residents with advice and support from local action groups. Others would require significant action from outside parties such as electric buses or ultra-low energy building retrofit. Simpler measures will be easy to act on in the next couple of years, while more involved measures are part of a multi-year strategy.

The Energy Demand Audit process has in general used an analytical approach based on fundamental principles. Quantifying the demand reduction potential can be based on the same calculations, which should simplify the process. In general, the demand reduction can be expressed as a % reduction of a certain demand. i.e. if all commuters were to switch to cycling, this would save x% on the commuting transport demand. Then the % saving on total transport demand and total community demand can be calculated. This method will be used throughout this process.

3.4.1 Domestic heat demand reduction

There are a number of different factors which will determine the energy use in the households of the community, so it was decided that energy models must be created for the domestic buildings. There are a wide range of software options available. A previous student project which studied building retrofit options in Scotland listed the following software options:

- **ESP-r** – highly discretised dynamic simulation
- **PHPP** – simplified building energy simulation with monthly results of energy demand
- **SAP** – simplified software used in construction industry to determine CO2 emissions of buildings
- **HEM** – Based on ESP-r results, giving results of building retrofit measures

The software HEM was used here, since it is simple to set up, specific for building retrofit and is based on the ESP-r modelling tool, which has had several studies confirming the accuracy of the modelling.

There are a number of options for reducing demand in buildings, some requiring considerably more work than others. The measures which were studied are defined in Table 22.

Table 22 - Domestic building retrofit levels

No.	Model Name	Measures installed
1	Poor_pre	Single glazing, poor air tightness, 100mm loft insulation, high efficiency combi boiler
2	Improved_pre	As above, with poor double glazing (DG)
3	Best_pre	As above, with new DG, 200mm loft insulation
4	Best+ach_pre	As above, with standard air tightness
5	Cond	As above, + condensing boiler
6	Sol_therm	As above, + solar thermal
7	ASHP	As model 5, with air source heat pump (ASHP)
8	Br_gas	As model 5 + 300mm loft insulation, internal insulation on front façade, standard efficiency mechanical ventilation and heat recovery unit (MVHR)
9	Br_ASHP	As above with ASHP
10	Sil_gas	As model 8 + external insulation, tight air tightness
11	Sil_ASHP	As above with ASHP
12	Gold_gas	As model 10 with triple glazed windows, super-efficient MVHR
13	Gold_ASHP	As above with ASHP

The first 4 models with "pre" in the model name are all standards which might be present in the community. Some flats may be particularly poor quality to the standard of model 1 and some households may have installed measures to the standard of models 2, 3 and 4. This will affect the options and effectiveness of the retrofits. The calculations are based on averages so this is taken into account over the whole community. Note that the worst performing model still has 100mm of loft insulation. The *Scottish House Condition Survey* specifies that only 1% of households have no insulation, so can assume that the minimum is 100mm of insulation.

Models 5,6 and 7 are based on improvements to the services of the building, with models 6 and 7 using renewable heat in the form of solar thermal and an ASHP respectively. There are other options for renewable heat, however the options selected were deemed most suitable in the *Renewable Snapshot Report* commissioned by South Seeds.

Models 8 through to 13 are all based on the PassivTEN concept created by John Gilbert Architects. The measures required are described in the paper *PassivTEN: Upgrading Glasgow's Tenements to PassivHaus Standard,* which was written to explore means of significantly reducing heat demand in tenement buildings, which make up the majority of housing in Govanhill West. Three different standards were developed:

1. Bronze (models 8 and 9)
    - Aiming for 30% reduction in energy
2. Silver (Models 10 and 11)
    - Aiming for 50% reduction in energy
3. Gold (Models 12 and 13)
    - Passivhaus (EnerPHit) standard refurbishment

These three options explore more involved measures to reduce the heat demand of the community. The PassivHaus standard (Gold) is generally considered the lowest energy standard for buildings. All three options would face significant challenges for these to be feasible which would need to be addressed through further design development. Modelling the energy demand reduction in this study may allow for a greater understanding of the potential benefits of such extreme measures.

Certain other parameters needed to be defined for the modelling. Four different building sizes were studied. It was assumed 1,2 and 3 bedroom flats represent the majority of housing. This is supported by the R*enewable Heat Study* conducted for the area, which showed four examples of flats, with a maximum of 3 bedrooms. Also models were created for terraced properties to represent the rest of the households. All of the flats were modelled as top floor flats. 8 additional models were created to study the effect of flat position by creating middle and ground floor flats. This was created for models 1, 4, 8 and 12. The floor areas for each of the household types was taken from the PassivTEN paper to be:

- 1 bedroom flat: 47 m^2
- 2 bedroom flat: 63 m^2
- 3 bedroom flat: 83 m^2
- Terraced house: 83 m^2

The next step was to define the specification of the models in a database. An image showing a part of this database is included in appendix 1. In total, there were 60 models (4 * 13 + 8). The HEM modelling was then carried out.

The postprocessing was an involved process which required work to find out which of the models most accurately reflect the current building stock. The first step was to take the raw data available from HEM in a Microsoft Excel file. The main results of interest were the heat demand (for both space heating and water heating) as well as the energy consumption (i.e. the gas consumption). The results for modelled heat demand can be seen in Figures 57 and 58 The models for the 1 bedroom flats is on the left, with the 2-bedroom next, then the 3-bedroom, terraced and the models changing flat position on the right.

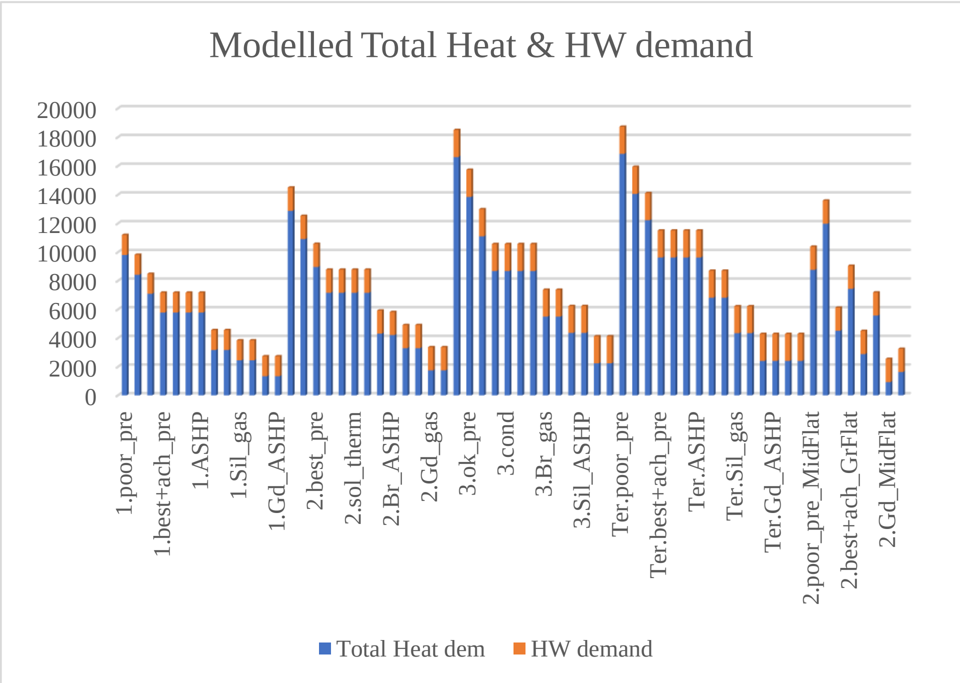

Figure 57 - Heat demand resulted from HEM modelling

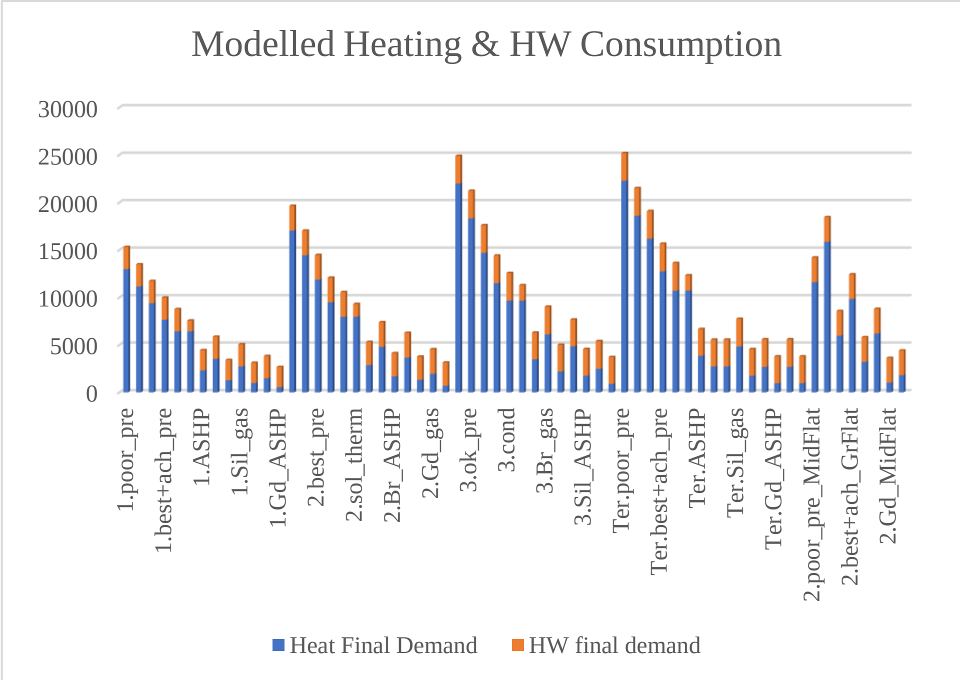

Figure 58 - Heating energy consumption from HEM modelling

The most noticeable result is the significant demand reduction which can be achieved over the worst performing models. There is also a significant increase in demand as the size of the property is increased, with a 3 bedroom flat having a heat demand around 60% larger than a 1 bedroom flat. Also, the heat demand is the same for a number of models. This is because the building fabric is the same, while the services are improved (i.e. an ASHP instead of a gas boiler). This improvement is included in the energy consumption in Figure 58.

The next step was to define the proportion of the housing for each of the house sizes. This was based on the number of people occupying each household and occupancy rating. An in-depth search was made to gain other figures for the number of flats for each bedroom size in the area, which would have been more accurate, however no such source was found. The *Neighbourhood Profile* for Govanhill gives the data on the household size shown in Figure 59.

3 HOUSEHOLD SIZE (Specific Source: Census Table QS40

	Frequency	N/hood	City
Occupied by One person	3,910	52.76%	43.13%
Occupied by Two people	1,860	25.10%	30.35%
Occupied by Three people	701	9.45%	13.71%
Occupied by Four people	492	6.64%	8.41%
Occupied by Five people	275	3.71%	3.16%
Occupied by Six people	94	1.27%	0.73%
Occupied by Seven people	45	0.60%	0.26%
Occupied by Eight or more people	34	0.45%	0.16%
ALL OCCUPIED HOUSEHOLD SPACES	**7,411**		

Figure 59 - Household sizes for Govanhill

The occupancy data which is provided as part of the *Neighbourhood Profile* is calculated based on the number of occupants and the number of rooms in total (i.e. lounge, kitchens, bedrooms and bathrooms) The general rules for the occupancy rating roughly follows:

1. One room per couple or lone parent
2. One room for every pair of same sex children under 16
3. One room each is children are different sexes.
4. Add 2 rooms to this total

It is assumed that the 2 rooms added at the end are for rooms other than bedrooms, so subtracting 2 away from the total should give the number of bedrooms for the property. As an example, a 1 adult household should have 1 bedroom, while a household with a couple and one child of each sex should have 3 bedrooms. Table 23 describes the number of bedrooms for each of the assumed household types and the % of the households:

Table 23 - calculated share of each household type in community

Household Size	**Possible Occupants**	**No. of Rooms**	**No of Bedrooms**	**% of households for each**
1	1 adult	3	1	**52.76%**
2	couple	3	1	**23.6%**
2	adult + child	4	2	**1.5%**
3	3 adults	4	2	**4.4%**
3	Couple + child	4	2	**2.0%**
3	adult + 2 ch (same sex)	4	2	**1.5%**
3	adult +2ch (m+f)	5	3	**1.5%**
4	couple + 2ch (same sex)	4	2	**2.6%**
4	couple + 2 ch (m+f)	5	3	**2.6%**
4	adult + 3 ch	5	3	**1.5%**
5	couple + 3ch	5	3	**3.7%**
6	couple + 4ch	5	3	**1.27%**
7	couple + 5ch	6	4	**0.60%**
8	couple + 6ch	6	4	**0.45%**

The % of each household is based on the household size data. It also used data for the percentage of households with dependent children (19.2%) and lone parents with dependent children (6%). Households of a similar type (e.g. lone parents) were assumed to have equal share between them.

Now that the number of households have been calculated, the overoccupancy data can be applied to find out the actual number of bedrooms. The occupancy rating averages for the area are shown in Figure 60. The occupancy rating is the number of rooms present compared to the ideal figure, so -1 means that there are more rooms than required, 1 means there is 1 too few rooms and 2 means there are 2 few rooms.

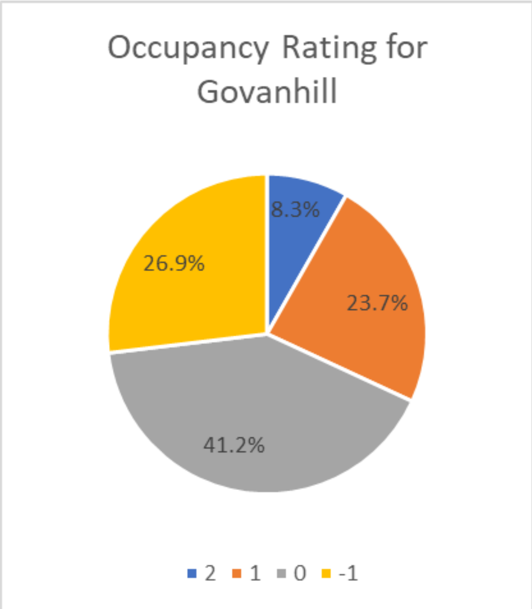

Figure 60 - Occupancy rating in community

This average occupancy rating was then multiplied by each of the household types. For example, a household with one adult and one child (should have 2 bedroom) makes up 1.5% of the total households. For this example, the calculations are:

- 1 bedroom = 26.9% * 1.5% = 0.4% of total population
- 2 bedroom = 41.2% * 1.5% = 0.62%
- 3 bedroom = 23.7% * 1.5% = 0.35%
- 4 bedroom = 26.9% * 1.5% = 0.12%

This calculation was processed for all the household types and then the percentage of households summed together to achieve the following results for the whole community:

- Number of 1 bedroom flats = 46.3%
- Number of 2 bedroom flats = 32.5%
- Number of 3 bedroom flats = 16.5%
- Number of 4 bedroom flats = 3.9%
- Remaining (larger than 4 bedroom) = 0.8%

The 4 bedroom and remaining flats were taken to be represented by the terraced HEM models. In reality, this may have a significant degree of uncertainty. The likelihood that almost half of all households being only 1 bedroom flats is low, however this is the best method which was available.

Following on from this the effect of flat position was calculated. The models for the retrofit measures were all modelled as top floor flats. Eight separate models were made for a 2 bedroom flat to study flat position. Mid floor flats will have a significantly smaller heat demand since there is negligible heat loss from the ceiling. Ground floor flats have little heat loss from the ceilings, but significant heat loss from floors. It is much less common for households to have floor insulation in these buildings than loft insulation. Some of the work conducted by South Seeds is to install underfloor insulation in ground floor flats which have no insulation at all. In most cases, it is difficult to install this so the ground floor models for poor_pre best+ach_pre and Br_gas are assumed to have no underfloor insulation resulting in a U-value of 0.7. This is the same as the Bronze PassivTEN concept. The Gd_gas ground floor model has 300mm of insulation resulting in a U-value of 0.13. These four models were selected since they are all similar to other models which can represent all 13 building performance levels. The following results were obtained for the change in heat demand by flat position:

Table 24 - Modelled effect of flat position

Model	Other models which are similar	Change in Heat Demand with Mid Floor Flat (%)	Change in Heat Demand with Ground Floor Flat (%)
Poor_pre	Ok_pre	-31.9	-7
Best + ach_pre	Best_pre, Cond, Sol_therm, ASHP	-37	3.8
Br_gas	BR_ASHP, Sil_gas, Sil_ASHP	-33	29.2

Gd_gas	Gd_ASHP	-46.9	-6.5

The percentage of the housing stock by flat position was then calculated. Through study of the block type map as part of the South Seeds *Energy Snapshot Report*, the approximate percent of stock of each type was calculated. This data is presented in Table 25.

Table 25 - Share of housing stock by building type

Block Type	**No of Top Floor Flats**	**No of Mid Floor Flats**	**No of Ground Floor Flats**	**Approximate Share of Stock (%)**
Short Tenement	1	1	1	12.4
Retail Tenement	1	2	0	29.9
Dense Tenement	1	2	1	29.9
Standard Tenement	1	2	1	23.7
Others	1	0	1	4.1

The number of each flat is based on the number of storeys for the buildings. Retail tenements have shops underneath so have no ground floor flats. This means that position of flat for the housing stock is:

- Top floor flat: 29.6%
- Mid floor flat: 50.9%
- Ground floor flat: 19.6%

The proportion of housing stock by flat size and position has now been developed which allows for the calculation of the potential energy demand reduction through building retrofit. The calculated average energy demand for the energy standards is as follows:

Table 26 - Modelling energy results for each building level

No.	Model Name	Heat Demand (kWh)	Heat Energy Consumption (kWh/year)	System Overall Efficiency (%)
1	Poor_pre	11,552	15,749	73
2	Improved_pre	10,033	13,738	73
3	Best_pre	8,530	11,748	73
4	Best+ach_pre	7,140	9,911	73
5	Cond	7,140	8,729	82
6	Sol_therm	7,140	7,505	95
7	ASHP	7,140	4,595	155
8	Br_gas	5,151	6,348	81
9	Br_ASHP	5,151	3,789	135
10	Sil_gas	4,309	5,569	77
11	Sil_ASHP	4,309	3,464	124
12	Gold_gas	2,793	3,899	72
13	Gold_ASHP	2,793	2,890	97

The average heat demand of domestic buildings in the community was quantified to be 10,799 kWh. This is between the heat demand for model 1 – Poor_pre – and model 2 – Improved_pre. This suggests that the HEM modelling for these models is suitably accurate. In reality every household will have different heat demands. Some may be worse than these models while others will be significantly better.

These are the results for individual houses. If these retrofit standards were applied to all housing in the area, the total demand reduction potential of each of the measures are quantified in Table 27:

Table 27 – Domestic heat demand reduction potential

Retrofit Standard	Demand if applied to all housing (GWh)	Demand Reduction (GWh)	Percentage (%)	Consumption if applied to all	Consumption reduction (GWh)	Percentage (%)

Current Housing Stock	30.95	-	-	41.3	-	-
Improved_pre	28.8	2.20	7	39.4	1.89	5
Best_pre	24.4	6.50	21	33.7	7.60	18
Best+ach_pre	20.5	10.49	34	28.4	12.86	31
Cond	20.5	10.49	34	25.0	16.25	39
Sol_therm	20.5	10.49	34	21.5	19.76	48
ASHP	20.5	10.49	34	13.2 (electric)	28.10	68
Br_gas	14.8	16.19	52	18.2	23.07	56
Br_ASHP	14.7	16.27	52	10.9 (electric)	30.41	74
Sil_gas	12.3	18.60	60	16.0	25.31	61
Sil_ASHP	12.3	18.60	60	9.9 (electric)	31.34	76
Gold_gas	8.0	22.94	74	11.2	30.09	73
Gold_ASHP	8.0	22.94	74	8.3 (electric)	32.99	80

A building retrofit scheme which encapsulates all the buildings in the area is a feat which would present huge challenges to be achieved. The table above instead shows the impact that such a scheme could have. The measures which are relatively simple, such as installing good quality double glazing (Best_pre) achieves a significant demand reduction. These measures will be significantly less expensive than the more intrusive measures, which would make them more attractive to residents and housing associations. Renewables can also play an important role. The model Sol_therm shows that in this case, if solar thermal could supply all of the buildings, the energy consumption reduction from this would be 3.5 GWh. Heat pumps have a huge impact on the energy consumption for all the models, typically resulting in a 25% to 40% reduction in energy consumption. Calculations would need to be made to determine what this would mean in terms of costs for residents, since electricity is more expensive. If further design is undertaken and heat pumps deemed suitable, then there is the additional benefit that this could be supplied by renewable electricity, in which case true zero carbon heat will be achieved. While simple measures are effective, the benefit of deep retrofit measures cannot be ignored. The energy consumption reduction of 33GWh is unlikely to be achieved by any other action for this community. The measures would be intrusive, however if they are part of a large-scale regeneration scheme, then a significant improvement on the sustainability of the community could be achieved.

3.4.2 Public heat demand reduction

In this study, public buildings have been assumed to be the 3 schools in the community. The buildings will likely be vastly different in terms of energy performance due to various factors such as size, heating system used, age of building etc. This makes it difficult to predict the heating energy demand reduction potential, which will be known by the operators and various groups involved (i.e. Glasgow City Council). If improvements can be made to reduce energy demand, then these will already be part of the strategy for the buildings. Also, the annual heat demand is only 1 GWh, which is small compared to the other energy demands. Due to these factors, it was decided that energy demand reduction of public heat would not be appropriate and is not evaluated in this project.

3.4.3 Non-domestic heat demand reduction

The current non-domestic heat demand for the community is 4.05 GWh/year split between the 295 properties, resulting in an average heat demand of 13,727 KWh. As with the domestic heat demand, there will be significant variety in the types of building and energy demand. The building fabric of the properties will be different from domestic properties. For example, the shops on the ground floor of the retail tenement building type have almost all the street facing side as glazing and in some cases, this will be single glazing. Figure 61 shows examples of the typical non-domestic properties in the area.

Figure 61 - Typical non-domestic properties in community

The variety in property types would make it challenging to accurately predict the savings of community wide approach. There is potential that if energy saving measures are applied to domestic properties that a similar scheme could be applied to non-domestic properties. For example, if air source heat pumps are used to supply heat to the flats above the commercial properties, they could also be part of the same development scheme. The same can be said for the more involved retrofit standards (bronze, silver and gold). If external and internal insulation, air tightness layers and MVHR systems are applied to all buildings in a block, the commercial building could be retrofitted in the same process.

One factor which needs to be considered is the gas consumption for cooking, in restaurants. This is included in the heating demand (which can be argued since the heat emitted for cooking food would be casual gains to heat the building). The retrofit measures would however not result in a reduction of the gas demand for cooking. The paper Food Preparation and Catering by the Carbon Trust defines that cooking represents 42% of the heat demand in catering businesses. It is assumed that all of the cooking is fed using gas. Using Google Maps, the number of restaurants to other businesses on Cathcart road was calculated. 7 out of 30 businesses were catering businesses, so the percentage of gas consumption which is for cooking is:

$$\% \; of \; gas \; demand \; for \; cooking = \frac{no \; of \; catering \; businesses}{no \; of \; businesses} * \% \; of \; heat \; demand \; for \; cooking$$

$$= \frac{7}{30} * 42\% = 9.8\% \; \cong 10\%$$

This demand will remain unchanged, so it can be assumed that applying the same measures which are being applied to domestic buildings would achieve 90% of the percentage demand reduction. This means that the following energy demand reduction can be achieved in the community:

Table 28 - Non-domestic heat demand reduction potential

Retrofit Standard	**Demand if Applied to all Units (GWh)**	**Demand Reduction (GWh)**	**Percentage (%)**	**Consumption if Applied to all**	**Consumption Reduction (GWh)**	**Percentage (%)**
Current Housing Stock	4.05	0.26	6	5.40	0.22	4
Improved_pre	3.8	0.77	19	5.2	0.89	17
Best_pre	3.3	1.24	30	4.5	1.51	28
Best+ach_pre	2.8	1.24	30	3.9	1.91	35
Cond	2.8	1.24	30	3.5	2.33	43
Sol_therm	2.8	1.24	30	3.1	3.31	61
ASHP	2.8	1.24	30	2.1	2.72	50
Br_gas	2.1	1.91	47	2.7	3.58	66
Br_ASHP	2.1	1.91	47	1.8	2.98	55
Sil_gas	1.9	2.19	54	2.4	3.69	68
Sil_ASHP	1.9	2.19	54	1.7	3.54	66
Gold_gas	1.3	2.7	67	1.9	3.88	72
Gold_ASHP	1.3	2.7	67	1.5		

The same findings can be drawn here which have been made for the domestic heat demand reduction. There is the added benefit for the businesses that an energy demand reduction will reduce running costs. This will increase their competitiveness which could have a benefit to the local economy.

3.4.4 Domestic electricity demand reduction

The total community demand was calculated to be 10.75 GWh, as average of 3750.3 kWh per dwelling. The energy demand for each of the appliances was found to be:

Table 29 - Current domestic electricity demand per appliance

Appliance Type	**Percentage of Total Annual Demand**	**Appliance Demand (kWh)**
cold appliances	14%	515
cooking	14%	533
lighting	16%	595
audio-visual	15%	556
ICT	6%	236
washing/drying	14%	525
water heating	7%	274
other	4%	143
not known	10%	375
	Total Annual Electricity Demand	**3750 kWh**

The measures which have been considered are replacement of appliances with more efficient options as well as the residents' choice of what appliances they have.

To study energy efficient appliances, the website of the Currys.co.uk was used. The annual consumption is given for the majority of appliances based on the EU energy label. A sample of the most efficient options was taken and then the annual energy demand was averaged to give the energy consumption which could be achieved for each appliance. Also, the price of the appliances selected had to be towards the lower end of the range, with properties which are typical for that appliance (e.g. volume of refrigerator). The sample of cold appliances is shown in Table 30.

Table 30 - Options for efficient cold appliances

Appliance	Model	Annual Energy Demand (kWh)	Rating	Cost	**Average Annual Energy Demand (kWh)**
Refrigerator	LEC L5511W	117	A+	£ 129.00	**122**
	Indesit TLAA10UK	122	A+	£ 123.00	
	Essentials CTL55W15	128	A+	£ 180.00	
Fridge-freezer	Essentials C50BW16	204	A+	£ 189.00	**229**
	LOGIK LFC50B14	226	A+	£ 220.00	
	HOTPOINT RFAA52P	258	A+	£ 219.00	
Upright freezer	BEKO FFP1671W	307	A+	£ 329.00	**284**
	INDESIT U16F1T	286	A	£ 400.00	
	HOTPOINT UI8F!	258	A+	£ 489.00	
Chest freezer	HOOVER CFH106AWK	168	A+	£ 139.00	**178**
	LEC CF100L	175	A+	£ 170.00	
	HOOVER CFH157AWK	190	A+	£ 199.00	

Using the same combination of appliances which have been described in the energy demand audit, the average energy consumption of energy efficient cold appliances which are used is 318 kWh.

The energy consumption for cooking is generally dependant on how the appliances are used, with no quoted energy demand for the cooking appliances. There is the option to install an electric induction hob. The quoted energy saving varies significantly depending on the source from 15% to 50%. As a conservative estimate, it was assumed that a 25% energy saving is possible resulting in the following energy demand:

$$Energy\ Demand\ for\ hob = Original\ Demand\ for\ Hob * (1 - Energy\ Saving\ \%)$$

$$= 226 * (1 - 0.25) = 169.5\ kWh/year$$

This is an energy saving of 56.3 KWh. This is a relatively small saving and if the hob is currently fuelled by gas, it may increase the running cost, negating the benefit to the resident. The measure was still considered since the data suggests electric cooking is common.

The electricity demand survey found a mix of TV types including CRT, LCD and Plasma. The average annual energy consumption of a TV was found to be 199 kWh/year. Using the same approach as cold appliances, 15 more efficient options currently on the market were analysed. The average A rated TV uses 135 kWh/year, while the average A+ rated TV uses 93 kWh/year. The calculation of these considered the average time which the TV is turned on, off and on standby. If the TVs are replaced with A+ rated units, then the electricity consumption is decreased by 106 kWh/year.

Washing and drying was considered next. The average annual energy consumption by appliance type as found in the electricity survey was:

- Washing machine = 161 kWh/year
- Washer/dryer = 243 kWh/year
- Clothes dryer = 394 kWh/year
- Dishwasher = 294 kWh/year

Based on the quoted energy consumption of appliances available at Currys.co.uk, replacing the appliances with new ones would increase the energy consumption, even for A+++ rated appliances. This suggests that the energy labels do not reflect the actual use of appliances and no further calculation could be made to determine the actual energy use of the appliances. This aspect was therefore neglected.

The final aspect of energy efficient appliances evaluated was lighting. Figure 62 shows the survey data for number of lights of each bulb type. According to a lighting guide from Homebase, the power consumption different bulbs which provide 180 lumens of light are:

- Incandescent: 25W
- Halogen: 18W

- Florescent and CFL: 5W
- LED: 4W

If this lamp size was used throughout the households (using the average number of lamps), then the average power consumption of bulbs would be 16.8 W. LED bulbs consume much less power and are in general a simple and cost effective option. If the LED bulbs are installed throughout the household, then a 76% saving on lighting energy demand would be achieved resulting in an annual electricity demand reduction of 456 kWh/year.

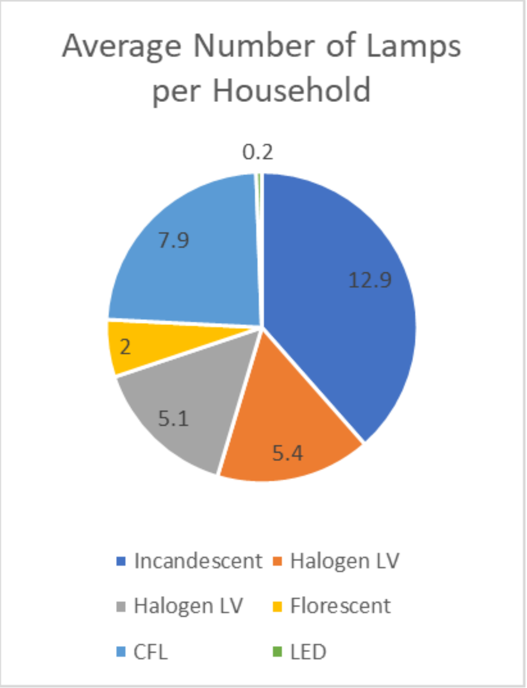

Figure 62 - Assumed average no. of lamps in households

Following on from energy efficient appliances was the impact of the choice of appliances. The survey made the recommendation that the use of a laptop instead of a desktop computer could save 51% of the ICT energy consumption. With the current consumption of 236 kWh/year, this can result in a saving of 115 kWh. This figure is assumed for this project.

In terms of cold appliances, the average demand with efficient appliances is 318 kWh/year. If only a fridge freezer can be used for each household, then this would consume 229 KWh/year, resulting in a 28% energy saving. This percentage saving is assumed eve where fewer efficient cold appliances are used.

For audio-visual, the energy consumption for appliances other than the TV (audio-visual site) is 357 kWh/year, which is significantly more than the 93 kWh/year of an A+ rated TV. This demand will be made up of a variety of appliances (e.g. sound systems, DVD players, games consoles etc.) In reality, it is possible for almost all of this demand to be negated, however it is unlikely that the residents would elect to do this. As an approximation, it is assumed that a 40% reduction is possible with careful choice of audio-visual appliances, reducing energy demand by 143 kWh/year.

The final item studied was selection of clothes washing appliances. If households were to air dry clothes, instead of using drying machines, this would reduce the electricity consumption. In this case, all households would have a washing machine (requiring 161 kWh/year) and assume that 50% of households have dishwashers (requiring an average of 147 kWh/year), this gives a total consumption of 308 kWh/year. This is a decrease in energy consumption of washing/drying of 143 kWh/year. The issue with air drying the clothes indoors is that it increases the heating energy demand, since the moisture has the effect of cooling the air. To add to this, the increase of moisture in the air may increase the risk of health issues for the residents. This approach would only be suitable with some form of ventilation system, such as the PassivTEN retrofits. It was decided that this option would not be a suitable measure for reducing energy demand for the properties of Govanhill, so was neglected for this study.

Now that the potential domestic electricity demand has been calculated for each household, the total community energy demand reduction of applying these measures can be collated:

Table 31 - Domestic electricity demand reduction potential

Type of Measure	**Measure Applied**	**Saving per Dwelling (kWh/year)**	**Demand if Applied to All Housing (GWh)**	**Demand Reduction (GWh)**	**Percentage (%)**
Efficient appliances	Efficient cold appliances	197	10.2	0.56	5%
	Induction hob	57	10.6	0.16	2%
	A+ rated TV	106	10.4	0.30	3%
	LED lighting	456	9.4	1.31	12%
Choice of appliances	Laptop instead of desktop	115	10.4	0.33	3%
	Combined fridge-freezer	28% of cold appliance demand (143kWh)	10.3	0.41	4%

	Reducing audiovisual site	143	10.3	0.41	4%
All	All Measures combined	1163	7.4	3.33	31%

3.4.5 Non-domestic electricity demand reduction

Electricity makes up the majority of energy demand in commercial properties. In total for Govanhill West, the demand is 4.7 GWh/year, which is higher than non-domestic heat, which was calculated to be 4.05 GWh/year. Since electricity is a more expensive fuel, this will make up the majority of energy costs for local businesses, so it is in their interests to reduce their electricity demand as far as feasible.

A local business directory website was used to determine if any businesses operate in the area which require significantly higher heat demands, such as heavy manufacturing. There are no such businesses within this community, so the heat demand which is to be reduced is associated with space and water heating.

The Carbon Trust has created several sector specific publications to advise on cutting carbon and saving money on the workplace. Of the sectors available, the retail sector is most similar to the businesses in Govanhill. Most of the businesses will be centred around the retail tenements of the main streets. The Carbon Trust document for retail defined the share of energy demand as shown in Figure 63.

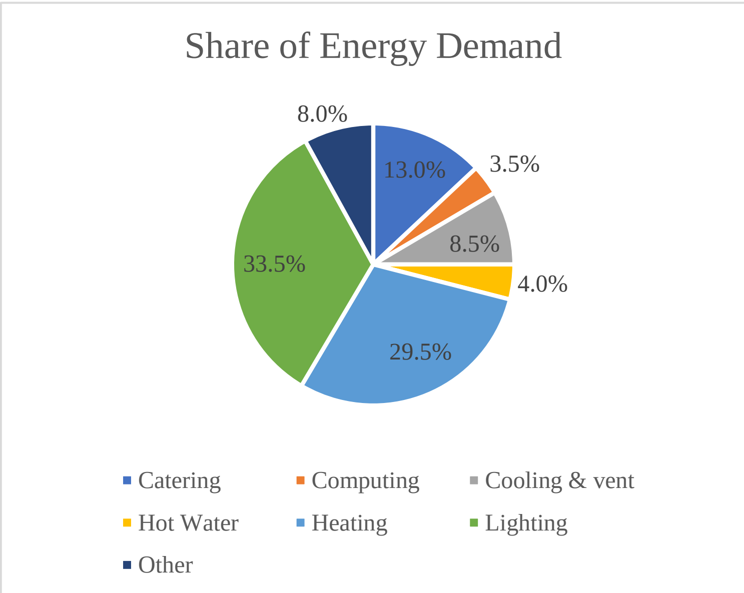

Figure 63 - Assumed snare of energy consumption on retail properties

It can be assumed that the demand for catering, hot water and heating is provided by gas. This leaves 53.5% of the demand for electricity. This is almost exactly the same share for the Govanhill community (53.7%) which confirms this assumption. The average electricity consumption per business was calculated to be 15,942 kWh/year, so the electricity demands by type are as follows:

Table 32 - Share of electricity consumption in non-domestic properties

Demand Type	**Share of Electricity Demand**	**Demand (kWh/year)**
Computing	6.5%	1043
Cooling & vent	15.9%	2533
Lighting	62.6%	9982
Other	15.0%	2384

The energy saving measures which are recommended in the Carbon Trust document and the expected savings are:

- Occupancy sensors for lighting: 20% of lighting demand
- Low energy light bulbs: 75% of lighting demand
- Switch off non-essential lighting out of business hours: 10% of lighting demand
- Turn off unnecessary equipment: 5% of total electricity demand

Since lighting energy demand accounts for 63% of electricity demand it is logical to focus the efforts here, with three options for energy demand reduction which when combined together result in an 88% reduction in lighting energy demand. The results of applying the demand reduction measures in the community area as follows:

Table 33 - Non-domestic electricity demand reduction potential

Measure Applied	**Saving per Business Unit (kWh/year)**	**Demand if applied to all housing (GWh)**	**Demand Reduction (GWh)**	**Percentage (%)**
Occupancy sensors for lighting	1996	4.1	0.59	13
Low energy light bulbs	7487	2.5	2.21	47
Lighting off out of business hours	998	4.4	0.29	6
Turn off unnecessary equipment	797	4.5	0.24	5
All measures combined	8484	2.2	2.5	53

These results show that simple measures can have a huge impact. Installing low energy light bulbs is easily done and has the biggest effect here. The Carbon Trust document states that "a 20% cut in energy costs represents the same bottom line benefit as a 5% increase in sales." If a significant proportion of the businesses in the area can achieve the levels of demand reduction here, this would be of great benefit to the businesses but could also attract other businesses to the area.

3.4.6 Transport demand reduction

The following measures were evaluated in this section:

- Commuting:
    - Car pooling
    - Public transport – for both bus and train
    - Cycling
- All travel
    - Energy efficient driving – through car driver training
    - Electric vehicles

The calculations for this were based of the collected commute data. Different scenarios for the measures were generated. The Microsoft Excel “Roundup” function was used to ensure that the number of journeys by each more remained as positive integers. For example, if 11 commuting journeys are made to a destination by car and a maximum of 3 people could car pool, then 5 car journeys would be made (3*3 + 2).

For carpooling, 2 scenarios were made, one where 2 people share one car and another where 3 people share. These scenarios resulted in a reduction in the distance travelled to work of 48% and 64% respectively. These figures are different from ½ and 2/3 since due to the Roundup calculation.

8 scenarios were created for public transport (4 each for bus and train). The scenarios are as follows:

- Scenario 1 – All car journeys by public transport
- Scenario 2 – 20% of journeys
- Scenario 3 – All journeys less than 5 miles
- Scenario 4 – All journeys less than 10 miles

The 3 scenarios created for cycling are:

- Scenario 1 – All car journeys less than 3 miles by bicycle
- Scenario 2 – All journeys less than 5 miles
- Scenario 3 – All journeys less than 10 miles

For these scenarios, the rest of car journeys remained the same, with one person driving to their destination.

The Energy Savings Trust has undertaken several investigations and initiatives to improve the fuel consumption of drivers, mainly with drivers as part of a company. The FuelGood driver training initiatives involved one day training on fuel efficient driving techniques and has been delivered to 35,000 business drivers. The efficiency improvement which is achieved on the day is on average 15%, with a long-term improvement of 6.2%. This long-term saving has been used for the creation of another scenario. In this case, the increased efficiency also applies to the car journeys for purposes other than commuting.

Both electric cars and buses were studied. An Autocar online article gave data for the tested economy of 4 electric cars. The results are:

Table 34 - Sample of electric car options

Car model	**Tested Economy (miles/kWh)**	**Economy (kWh/100km)**
BMW i3	5.3	11.7
VW e-golf	4.2	14.8
Hyundai Ioniq	4.7	13.2
Nissan Leaf	3.8	16.4
Average	4.5	**14**

The average of 14 kWh/100km will be used to calculate the energy consumption of electric cars. SEWTHA, when calculating the potential of electric cars, uses the value of 15 kWh/100km, which shows that this assumption is suitable. The same mileage which is currently driven by households is assumed to be the same with this scenario.

A Report from the National Renewable Energy Laboratory states that the Proterra electric bus was measured to achieve 2.17 kWh/mile, which equates to 17.35 miles per diesel gallon equivalent (mpdge). A BBC report states that London diesel buses achieve 5.3 mpg. This means that the electric bus is 3.27 times as efficient as the diesel option which are operating in Glasgow. The final scenario was a combination of electric cars and buses.

Performing the calculation for the scenarios which have been described, the following demand reduction figures may be possible.

Table 35 - Transport energy demand reduction potential

Measure Type	no.	Scenario Description	Saving On	Demand if Applied to all Households (GWh)	Demand Reduction (GWh)	%
Carpooling	1	2 people	48% on car commuting	6.3	0.57	8
	2	3 people	64% on car commuting	6.1	0.76	11
Buses	3	all commutes	54% on car commuting	6.0	0.82	12
	4	20% of commutes	9% on car commuting	6.7	0.14	2
	5	All commutes <5 miles	15% on car commuting	6.6	0.22	3
	6	All commutes <10 miles	34% on car commuting	6.3	0.52	8
Train	7	all commutes	81% on car commuting	5.6	1.23	18
	8	20% of commutes	14% on car commuting	6.6	0.21	3
	9	All commutes <5 miles	22% on car commuting	6.5	0.34	5
	10	All commutes <10 miles	51% on car commuting	6.1	0.78	11
Cycling	11	All commutes <3 miles	11% on car commuting	6.7	0.16	2
	12	All commutes <5 miles	24% on car commuting	6.5	0.36	5
	13	All commutes <10 miles	55% on car commuting	6.0	0.84	12
Driver training	14	Efficient driving	6% on all car driving	6.6	0.36	4
Electric transport	15	Electric cars	71% on all car driving	2.8	4.07	59
	16	Electric cars and buses	78% on car and bus transport	2.5	4.29	63

The energy demand reduction in some of these scenarios is much smaller than what can be achieved through other energy demand reduction schemes, particularly measures to reduce domestic heat demand. With several of these scenarios, it would be much easier to implement than the more impactful measures. For example, it would be much easier to implement an efficient driving training scheme than it would be to retrofit all buildings to an improved standard. This must be considered when choosing a future community development strategy.

Also, any combination of the measures could be implemented that, when combined could have a significant energy demand reduction. Care must be taken here when calculating the demand reduction. For example, if 50% of commutes currently driven by car are made by bus, this would result in an energy demand reduction of 0.41 GWh/year. If then the remaining commutes under 3 miles were travelled by bicycle, this would result in a further 0.8 GWh/year reduction (half of the figure in Table 35). This would be a total reduction of 0.49 GWh, rather than the summation of the figure in the table which would be 0.57 GWh/year. The 4th column in the table has been used to assist with this.

Electric vehicles (EVs) have a significant impact on the energy demand, with electric cars reducing the energy demand of car transport by 71%**.** This is one of the main benefits of EVs and if used throughout the transport sector, it will have a significant reduction on overall transport energy demands. Plus, the vehicles can be charged up by low carbon renewables. There are always questions raised as to whether the electricity network could cope with the added demand, and it would be worth thinking back to the first phrase of this paper: “the greenest unit of energy is the one you don’t use.” A more logical and sustainable option would most likely be to move towards other modes of transport such as bus and bicycle.

3.4.7 Accounting for CO2 emissions and costs

Now that all of the energy demand reduction measures have been quantified, the impact on fuel costs and community CO2 emissions was quantified. The same factors used in the energy demand audit were used here as follows:

Table 36 - Factors used for cost and CO2 emissions

Fuel	**Costs (£/kWh)**	**CO2 Conversion Factor (kgCO2/kWh)**
Gas	Domestic: 0.037	0.184
	Non-domestic: 0.1081	
Electricity	Domestic: 0.13	0.412
	Non-domestic: 0.02282	
Diesel	0.116	0.240

The cost savings were calculated per building type, while the CO2 emission reduction was calculated over the whole community. The numbers per building type for Govanhill West are:

- Number of domestic dwellings = 2,866
- Number of non-domestic units = 295
- Number of dwellings with access to cars = 1103

Also, the effect of changing heating and transport fuels from gas and diesel to electricity was taken into account with the calculations. Some of the results are shown in Table 37. A full table of results can be found in the appendix.

Table 37 - Sample of effect of demand reduction on fuel costs and CO2 emissions

Energy Demand Type	**Measure**	**Energy Consumption Reduction (GWh)**	**Average Cost Savings (£) per Building**	**Total CO2 Emissions Reduction (Tonnes)**
Domestic heat	Cond	16.25	210	2990
	ASHP	28.10	-65	2166
	Br_gas	23.07	298	4245
	Gd_gas	30.09	388	5537
	Gd_ASHP	32.99	157	4181
Non-domestic heat	Best+ach_pre	1.51	117	279
	Br_gas	2.72	341	500
	Gd_gas	3.54	444	652
	Gd_ASHP	3.88	-138	369
Domestic electricity	efficient cold appliances	0.56	26	232
	LED lighting	1.31	59	538
	Total with all measures	3.33	151	1373
Non-domestic electricity	Low energy light bulbs	2.21	809	910
	Total with all measures	2.50	917	1031
Transport	Carpooling 3 people	0.97	102	233
	All commutes <5 miles by bus	0.22	-	54
	All commutes <5 miles by train	0.34	-	81
	All commutes <5 miles by bicycle	0.36	38	87
	Efficient driver training	0.28	29	67
	Electric cars	4.07	376	1457
	Electric cars and buses	4.29	-	2079

Focussing on costs, the higher cost per unit of electricity compared to gas means reducing electricity demand has a much larger effect, particularly with non-domestic properties. These have a very high electricity demand and gas for businesses cost 4.7 times as much as electricity. This also means that care must be taken when heat pumps are used to supply the heat demand. For non-domestic properties, even with the Gold standard retrofit, the use of a heat pump will increase the cost of heating. For heating demand, the simple measures with gas heating can still have a significant reduction in heating costs, so will most likely be the most cost effective options.

In general, the measures with the largest carbon reduction have the largest consumption reduction, since gas and diesel carbon emissions are comparable. Electricity has a greater CO_2 conversion factor, so electricity reduction has a greater effect here, similar to costs.

3.4.8 Reflection on Results of Energy Demand Reduction

The potential of the energy demand reduction measures within Govanhill West have now been analysed, where a wide range of options have been studied. Basing the calculations on the process of the energy demand audit simplified the process and as far as possible the measures have been made accurate and relevant to the characteristics of the community. Each of the energy demand sections concluded with a table of results which could be used to support future decisions to improve the sustainability of the community. The energy demand reduction which has been calculated and provided in these tables is the maximum potential reduction for each measure. If only half of the community has the measure applied, then it could be assumed that half the demand reduction would be achieved. Also, the impact of other measures being applied should be accounted for if these results are used in the future, as described in the transport section.

Most effort should be on reducing domestic heat demand, since this accounts for over 50% of the energy demand of the calculated community. Simple measures such as slight improvement to windows and air tightness can have a significant impact on energy demand, fuel costs and CO_2 emissions for the community. For example, upgrading all dwellings to have good quality double glazing, standard air tightness and a condensing boiler could save 16.25 GWh of gas consumption and 2,990 tonnes of CO_2 for the community and £210 in fuel costs per dwelling. The more extensive building retrofit approaches show that up to a 74% (33GWh) energy demand reduction can be achieved for domestic heat if the Gold standard could be achieved. With an approach like this, care must be taken to ensure that the benefits are passed on to residents and that the measures could be affordable.

Measures to reduce domestic electricity demand would also be valuable to the residents, since the cost of electricity is higher. Again, simple measures can often be very effective. Installing low energy lighting is often a measure recommended by South Seeds. Other measures such as choice of appliances can have a similar impact and could be implemented through advice to residents and landlords.

The majority of energy demand and costs for businesses is in electricity. By far the measure with the biggest impact is installing LED lighting throughout, which can reduce electricity demand by 47%, The combination of all the electricity demand reduction measures evaluated could result in a 53% saving. This would significantly reduce the running costs for the business, which could benefit the economic development in the community.

The measures studied for transport have a relatively small effect. This is since the energy demand from transport is small compared to the heat and electricity demand, based on this calculation method. The greatest impact is through the move towards EVs, however based on current cost of vehicles, this move may be an unlikely step for the community in the near future.

The simplest of measures should not be ignored. When these are combined, the energy demand could be reduced more than some of the more intrusive measures. Also, often these measures are in the control of the residents, so further development on making sure the residents are aware of the potential benefits would be a worthwhile development.

How Could This be Achieved

Several of the measures investigated are currently being installed by the local group South Seeds such as secondary glazing. These measures have been shown to massively reduce the energy consumption of the dwellings in which they have been installed while also improving the living standards of the residents.

More involved approaches to reduce the energy demand of the community, such as PassivTEN retrofit will face numerous challenges before it could be implemented throughout a significant proportion of the community. This is particularly true for the costs of measures. For example, the average price of the 4 electric cars considered is

£27,000. For the PassivTEN building retrofit standards to be implemented in any of the buildings, this would need to be part of a community wide regeneration strategy. This would likely be similar to the Transformational Regeneration Areas such as Sighthill, however it would involve building retrofit, rather than newbuild. The result of such a strategy would be vast improvements in terms of sustainability as well as living conditions for the residents. It should be stated there are many challenges faced with the current building stock which may mean such standards are not attainable, such as the high cost of installing internal wall insulation and MVHR systems, the high concentration of private landlords and how the scheme could be financed.

The measures involved in deep building retrofit would involve significant design work, requiring the input of an outside body. An example of a deep retrofit development is EnergieSprong. This is a Dutch imitative which aims to develop a market for affordable, attainable net-zero energy retrofits. The cost of the retrofit is paid for through the savings made by the residents, similar to the Green Deal scheme which used to exist in the UK. The issue with this approach is that it is still under development and no such retrofits exist in the UK. To deliver the buildings at scale requires the development of an entire industry which is able to mass produce building components in an industrial manner. If this can be achieved, then a community wide deep retrofit strategy could be considered.

Figure 64 - Example of EnergieSprong retrofit, using industrial approach

Figure 65 - Example of EnergieSprong applied to tenement flats

As described above, the cost of electric cars at their current price point is likely to make them unattainable for the majority of the population and particularly for Govanhill. One approach to increasing the feasibility of electric cars in the area is to have a car club sharing scheme. Here, the community would own cars and then residents would book the use of a car when required. This could be applied to any car such as a more efficient internal combustion car, however the energy benefit of electric vehicles would be preferable in terms of reducing energy consumption. One example is the social enterprise Co-wheels. This company has a network of cars which can be hired throughout Glasgow City and provide resources and support for community owned based car clubs. If this could be implemented for the community, then car ownership in the community would be decreased further. In Co-wheels' *Impact Report*, it states that "75% of members are less likely to buy a car in the next few years, due to joining our car club". So long as it does not increase mileage, there may

Figure 66 - Community owned electric car

also be the added benefit of increasing the access of a vehicle to households which currently do not.

To support energy demand reduction programmes, there will need to be suitable support from the local council, particularly with making infrastructure suitable for the changes which have been studied. One exciting scheme in the pipeline is the South City Way. An Artists impression is shown in Figure 67. This development will create improved cycling links to the city centre, running on Victoria Road, which runs through Govanhill. This will create a much safer and more enjoyable experience for commuters looking to cycle from the community into the city centre. Projects like this take time to be developed, however they are essential as part of a city's strategy to reduce energy demand and improve the livelihood of the many communities.

Figure 67 - South City Way cycling infrastructure improvements

3.5. Stage 5 – Consultation

The purpose of this stage was to gain a wider perspective of the demand reduction and thoughts of the demand reduction measures from members of industry. Two companies were consulted: EnergieSprong UK (by phone) and South Seeds (face to face meeting). Also, the EUED energy demand research centre was contacted for opinions, however this was left too late in the project timeline to arrange a meeting.

3.5.1 EnergieSprong

EnergieSprong UK is a division of EnergieSprong (ES) which is assisting in the development of the ES approach in the UK. There is currently one pilot project underway with a further 200 in the pipeline. Since domestic heat has the most potential for demand reduction, it was logical to investigate this further. The call aimed to understand more about what has already been done for the development of ES and where the opportunities were to make the approach suitable. Nicholas Doyle, a member of the market development team at ES UK, offered his time to discuss the project. Technical information was also provided by Ron van Erck of Stroom Versnelling, the company most involved with ES development in the Netherlands. These were the main findings of the discussion:

1. Current size of EnergieSprong developments

Currently there are around 2,000 ES buildings in the Netherlands, with a small proportion of these being newbuild. A further 10,000 have been confirmed with around 100,000 in the pipeline.

2. Approaches most commonly used

In terms of the technologies used, the approach is energy agnostic, so long as it can achieve the targets of affordable net zero energy buildings with a minimum guarantee of 30 years. The most common approaches are:

- Thermal envelope resulting in <30 kWh/m^2*a heating demand (almost to PassivHaus EnerPHit standard)
- All electric, usually with ASHPs
- Heat recovery ventilation
- PV covering roof. Typical single family dwelling has 5.5 to 7 kWp of PV

The PassivTEN design for deep retrofit included one façade of internal wall insulation. It is most common to use external wall insulation for the ES projects, however it was stated that this could be achievable at scale.

In terms of cost, the Dutch examples are being delivered for €65,000, roughly equivalent to £60,000. At a larger scale, this could decrease to £45,000. The specific costs would vary depending on the project so would need further development to see if this was affordable.

3. Role in community development

It was discussed that the main benefit is not just about saving energy or money, it is more about further development of the area and taking the opportunity to make it suit the needs of the residents. It was said that "energy costs are only one part of the project". Through the design process, it is essential that the non-energy needs and challenges of the residents and housing association are part of the end product. This will engage residents, increase their benefit and add value to the retrofit approach. If further development of a Govanhill building retrofit scheme were to be pursued, then it should take this approach to ensure that the end result has the maximum possible benefit, both in terms of energy and non-energy needs.

4. Potential in Scotland

Mr Doyle stated that he believes that Scotland has a lot of potential for ES developments. A large proportion of the housing is suitable and financially there may be greater opportunities. Also, the political attitude in Scotland is more favourable and fuel poverty is more of an issue, which is true for the Govanhill area. This suggests that the market could be developed in Scotland, however there would still be unique challenges for Govanhill which may make it unfeasible to implement in the community.

Finding out more about the ES approach is useful for the project, since it displays how the demand reduction measure with the biggest impact could be implemented. There is still the question of the feasibility for the community, since the product has not been proven in the UK and the housing types may present a challenge, however with rapid development of the concept in the last few years, future developments may be possible. Another interesting finding is the importance of non-energy factors in the design process. This could play a part of a community regeneration strategy, which could tackle some of the wider issues in the area, adding value to the project.

3.5.2 South Seeds

As detailed in the community selection stage South Seeds is a community organisation aiming to tackle climate change in the Southside area, which includes Govanhill West. Their work is heavily related to this project and they are acting to help residents to reduce energy demand. A meeting was conducted towards the end of the project with three of their core members to discuss the measures and the feasibility of their implementation in the community. A lot of useful insight was gained about the community and the developments which have already happened in the community. The main findings from the discussion was:

- Their main area of work

Figure 68 - demonstrator of PVC secondary glazing installed by South Seeds

In terms of demand reduction their most common installation is PVC secondary glazing for windows, which is attached to the windows using adhesive magnetic strips. A demonstrator of this system is shown in Figure 68. This solution has been proven to be a cost-effective measure which will decrease air leakage and improve window U-value, sometimes even better than some double-glazing units. This is a simple solution which will be appropriate for most single glazed properties and it is been shown in the demand reduction results that improving window quality can have a significant reduction in consumption. Also, one of the members has undertaken more than 400 home energy audits over the years, which will be an effective means of recommending measures to residents.

- Social housing expansion

The local housing association Govanhill HA is buying up privately owned properties in the area. Social housing is likely to be of a much higher standard in terms of energy, so this scheme could decrease domestic heat demand in the area.

- Main difficulties in the area

Private landlords do create difficulties with what measures are installed in properties. Since the landlords do not see the benefit of energy improvements in the property, they are much less willing to allow such measures. Also, the property prices are low in the area and it is often the case that any investment in the property will not see any increase in sale price.

South Seeds expressed that they would like to see the implementation of deep building retrofit throughout the community. In reality, when taking into account all of the difficulties which would be faced in implementing this, it is unlikely to be achievable for the Govanhill.

- Likely differences in results

There were many factors discussed which would affect the results of this study. For example, there is a high concentration of taxi drivers in the area. It is unclear how this is accounted for in the commuting data, however this would make the impact of public and active transport much smaller. Also, there is a quick turnover of residents. This would affect the calculated energy demand of areas such as domestic electricity. The final aspect which would have a significant impact is the Nextbike bicycle hire service which has been installed in the area since the census data for commuting. All of these factors will have a significant impact on energy demand in the community.

It was very useful to gain the perspective of South Seeds on the Demand Reduction methods explored. Learning about the community directly showed that some of the modelling carried out in the project will have some degree of error, since it does not represent the community as it is today. For future energy demand reduction studies, it is highly recommended that data is gathered about the community directly, either through energy surveys or through finding out more about the characteristics of the community. There will always be limitations in the data available.

4. Discussion

The objective set out at the start of this project was:

Assess the demand reduction potential for an urban community in Scotland.

Following a literature review to gain understanding of available information, a selection process for the community was conducted, which resulted in Govanhill West being selected. The energy demand of the community was assessed in terms of heat, electricity and transport energy requirements. This was followed up by an in-depth study of available demand reduction techniques with the consultation being the last stage of the project. In following this process, the objective has been achieved.

The main outcome of the project is a methodology to assess the energy demand and demand reduction potential of a community, which could be applied to other urban communities. Wherever possible, accurate and up to date information was used to provide accurate and relevant data. The calculated current energy demand is shown in Figure 69.

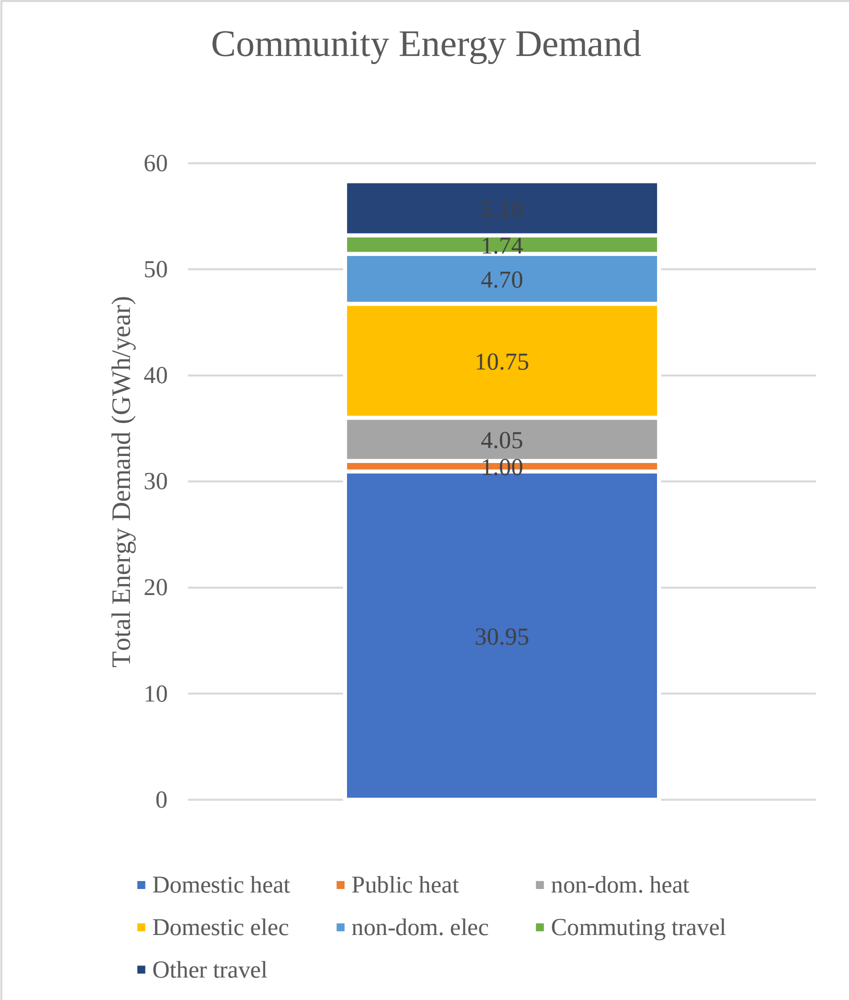

Figure 69 - Summary of current community energy demand results

The energy demand reduction results presented in Step 4 show the maximum potential demand reduction of each measure in the community. This can be used to inform future development strategies in the community, with the impact of increasing the sustainability of the community.

There are limitations in the methodology followed, which falls under 3 main categories:

1. Multiple data sources

The literature review found no defined process for demand reduction assessment which could be used in the study. Throughout the process multiple sources were used for data and often assumptions had to be made. While these were as accurate as possible, this does affect the accuracy of the results.

2. Results based on modelling

Modelling tools were use, particularly when assessing the demand reduction of domestic heat. The model is as accurate as possible and has had multiple studies conducted to confirm this, however there will always be some uncertainty, particularly when taking into account factors such as underheating of properties.

3. Community information not included in data

The meeting with South Seeds highlighted several properties of the community which are not accounted for in the data available and therefore not accounted for in this study. To improve this, a physical energy survey of the area is recommended for any further work.

4.1. Further Work

Following on from this project, future project could be:

1. Review process with more intrusive data collection

This could involve questionnaires or home energy surveys

2. Repeat process for another urban community

The methodology was developed to be replicable for other urban communities and is particularly suited for Glasgow city. Applying the same process to another community could allow for further development of the process and inform future decisions for that community.

3. Develop detailed design approaches for implementation of measures

A range of measures for the each of the demand types were quantified in terms of their maximum potential for energy demand reduction. One of these measures could be developed to determine how best to achieve the best possible energy demand reduction.

4. Investigate other areas of EUED research

The EUED research paper covered in the literature review described three themes of this type of research:

- Theme A – More for Less
    - How can demand reduction be achieved
- Theme B – Supply and demand
    - Demand and technology implications of decarbonizing energy supply
- Theme C – Equity, social justice and securities
    - How and why does energy demand vary between different sections of the population

The work of this project falls into Theme A. Further work could be undertaken to investigate the other themes for the Govanhill West community. For example, Theme C could involve a study and quantify of the socio-economic benefits of energy demand reduction as shown in Figure 69 from *Capturing the "Multiple Benefits" of Energy Efficiency in Practice: The UK Example* from the Carbon Trust.

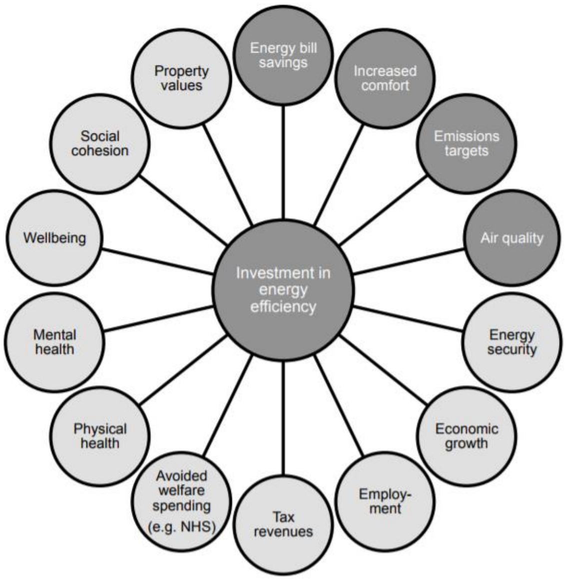

Figure 70 - The multiple benefits of energy demand reduction

This area of study was originally considered for this project and would be particularly relevant for the community studied. If the additional benefits shown above can be calculated in terms of financial benefit, then the extensive demand reduction measures could be more attainable.

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6. Appendices

6.1. Appendix 1 – HEM Modelling Input Parameters

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1						Insulation									
2	No	Model Name	Bedrooms	Floor area (m2)	Quality	Glazing	Loft	Wall	Floor	ach	H fuel	H type	HW sys	Vent	Renew
3	1	1.poor_pre	1	47	Poor	5	0.45	1.7		poor	gas	h.eff	combi	natural	
4	2	1.ok_pre	1	47	okay	3	0.45	1.7		poor	gas	h.eff	combi	natural	
5	3	1.best_pre	1	47	best	2	0.25	1.7		poor	gas	h.eff	combi	natural	
6	4	1.best+ach_pre	1	47	best + ach	2	0.25	1.7		standard	gas	h.eff	combi	natural	
7	**5**	**1.cond**	**1**	**47**	**best + ach**	**2**	**0.25**	**1.7**		**standard**	**gas**	**cond**	**combi**	**natural**	
8	6	1.sol_therm	1	47	best + ach	2	0.25	1.7		standard	gas	cond	combi	natural	sol therm
9	7	1.ASHP	1	47	best + ach	2	0.25	1.7		standard	elec	ashp	tank	natural	
10	8	1.Br_gas	1	47	Bronze	2	0.13	0.45		standard	gas	cond	combi	standard	
11	9	1.Br_ASHP	1	47	Bronze	2	0.13	0.45		standard	elec	ashp	tank	standard	
12	10	1.Sil_gas	1	47	Silver	2	0.13	0.22		tight	gas	cond	combi	standard	
13	11	1.Sil_ASHP	1	47	Silver	2	0.13	0.22		tight	elec	ashp	tank	standard	
14	12	1.Gd_gas	1	47	Gold	0.8	0.13	0.22		tight	gas	cond	combi	super	
15	13	1.Gd_ASHP	1	47	Gold	0.8	0.13	0.22		tight	elec	ashp	tank	super	
16	14	1.Esp_gas	1	47	Gold	0.8	0.13	0.22		tight	gas	cond	combi	super	PV mono
17	15	1.Esp_ASHP	1	47	Gold	0.8	0.13	0.22		tight	elec	ashp	tank	super	PV mono
18	16	2.poor_pre	2	63	Poor	5	0.45	1.7		poor	gas	h.eff	combi	natural	
19	17	2.ok_pre	2	63	okay	3	0.45	1.7		poor	gas	h.eff	combi	natural	
20	18	2.best_pre	2	63	best	2	0.25	1.7		poor	gas	h.eff	combi	natural	
21	19	2.best+ach_pre	2	63	best + ach	2	0.25	1.7		standard	gas	h.eff	combi	natural	
22	20	2.cond	2	63	best + ach	2	0.25	1.7		standard	gas	cond	combi	natural	
23	21	2.sol_therm	2	63	best + ach	2	0.25	1.7		standard	gas	cond	combi	natural	sol therm
24	22	2.ASHP	2	63	best + ach	2	0.25	1.7		standard	elec	ashp	tank	natural	
25	**23**	**2.Br_gas**	**2**	**63**	**Bronze**	**2**	**0.13**	**0.45**		**standard**	**gas**	**cond**	**combi**	**standard**	
26	24	2.Br_ASHP	2	63	Bronze	2	0.13	0.45		standard	elec	ashp	tank	standard	
27	25	2.Sil_gas	2	63	Silver	2	0.13	0.22		tight	gas	cond	combi	standard	
28	26	2.Sil_ASHP	2	63	Silver	2	0.13	0.22		tight	elec	ashp	tank	standard	
29	27	2.Gd_gas	2	63	Gold	0.8	0.13	0.22		tight	gas	cond	combi	super	
30	28	2.Gd_ASHP	2	63	Gold	0.8	0.13	0.22		tight	elec	ashp	tank	super	
31	29	2.Esp_gas	2	63	Gold	0.8	0.13	0.22		tight	gas	cond	combi	super	PV mono
32	30	2.Esp_ASHP	2	63	Gold	0.8	0.13	0.22		tight	elec	ashp	tank	super	PV mono
33	31	3.poor_pre	3	83	Poor	5	0.45	1.7		poor	gas	h.eff	combi	natural	
34	32	3.ok_pre	3	83	okay	3	0.45	1.7		poor	gas	h.eff	combi	natural	
35	33	3.best_pre	3	83	best	2	0.25	1.7		poor	gas	h.eff	combi	natural	
36	34	3.best+ach_pre	3	83	best + ach	2	0.25	1.7		standard	gas	h.eff	combi	natural	
37	35	3.cond	3	83	best + ach	2	0.25	1.7		standard	gas	cond	combi	natural	
38	36	3.sol_therm	3	83	best + ach	2	0.25	1.7		standard	gas	cond	combi	natural	sol therm
39	37	3.ASHP	3	83	best + ach	2	0.25	1.7		standard	elec	ashp	tank	natural	
40	38	3.Br_gas	3	83	Bronze	2	0.13	0.45		standard	gas	cond	combi	standard	
41	39	3.Br_ASHP	3	83	Bronze	2	0.13	0.45		standard	elec	ashp	tank	standard	
42	40	3.Sil_gas	3	83	Silver	2	0.13	0.22		tight	gas	cond	combi	standard	
43	41	3.Sil_ASHP	3	83	Silver	2	0.13	0.22		tight	elec	ashp	tank	standard	
44	42	3.Gd_gas	3	83	Gold	0.8	0.13	0.22		tight	gas	cond	combi	super	
45	43	3.Gd_ASHP	3	83	Gold	0.8	0.13	0.22		tight	elec	ashp	tank	super	
46	44	3.Esp_gas	3	83	Gold	0.8	0.13	0.22		tight	gas	cond	combi	super	PV mono
47	45	3.Esp_ASHP	3	83	Gold	0.8	0.13	0.22		tight	elec	ashp	tank	super	PV mono
48	46	Ter.poor_pre	3	83	Poor	5	0.45	1.7	0.7	poor	gas	h.eff	combi	natural	
49	47	Ter.ok_pre	3	83	okay	3	0.45	1.7	0.7	poor	gas	h.eff	combi	natural	
50	48	Ter.best_pre	3	83	best	2	0.25	1.7	0.7	poor	gas	h.eff	combi	natural	
51	49	Ter.best+ach_pre	3	83	best + ach	2	0.25	1.7	0.7	standard	gas	h.eff	combi	natural	
52	50	Ter.cond	3	83	best + ach	2	0.25	1.7	0.7	standard	gas	cond	combi	natural	
53	51	Ter.sol_therm	3	83	best + ach	2	0.25	1.7	0.7	standard	gas	cond	combi	natural	sol therm
54	52	Ter.ASHP	3	83	best + ach	2	0.25	1.7	0.7	standard	elec	ashp	tank	natural	
55	53	Ter.Br_gas	3	83	Bronze	2	0.13	0.45	0.7	standard	gas	cond	combi	standard	
56	54	Ter.Br_ASHP	3	83	Bronze	2	0.13	0.45	0.7	standard	elec	ashp	tank	standard	
57	55	Ter.Sil_gas	3	83	Silver	2	0.13	0.22	0.13	tight	gas	cond	combi	standard	
58	56	Ter.Sil_ASHP	3	83	Silver	2	0.13	0.22	0.13	tight	elec	ashp	tank	standard	
59	57	Ter.Gd_gas	3	83	Gold	0.8	0.13	0.22	0.13	tight	gas	cond	combi	super	
60	58	Ter.Gd_ASHP	3	83	Gold	0.8	0.13	0.22	0.13	tight	elec	ashp	tank	super	
61	59	Ter.Esp_gas	3	83	Gold	0.8	0.13	0.22	0.13	tight	gas	cond	combi	super	PV mono
62	60	Ter.Esp_ASHP	3	83	Gold	0.8	0.13	0.22	0.13	tight	elec	ashp	tank	super	PV mono
63															
64	61	2.poor_pre_MidF	2	63	Poor	5		1.7		poor	gas	h.eff	combi	natural	
65	62	2.poor_pre_GrFl	2	63	Poor	5		1.7	0.7	poor	gas	h.eff	combi	natural	
66	63	2.best+ach_MidF	2	63	best + ach	2		1.7		standard	gas	h.eff	combi	natural	
67	64	2.best+ach_GrFl	2	63	best + ach	2		1.7	0.7	standard	gas	h.eff	combi	natural	
68	65	2.Br_MidFlat	2	63	Bronze	2		0.45		standard	gas	cond	combi	standard	
69	66	2.Br_GrFlat	2	63	Bronze	2		0.45	0.7	standard	gas	cond	combi	standard	
70	67	2.Gd_MidFlat	2	63	Gold	0.8		0.22		tight	gas	cond	combi	**super**	
71	68	2.Gd_GrFlat	2	63	Gold	0.8		0.22	0.13	tight	gas	cond	combi	**super**	

6.2. Appendix 2 – Summary of Energy Demand Reduction Results

25	Demand Type	Measure	Energy Consumption	Cost Savings	Total CO2 Emissions
26			Reduction (GWh)	(£ per building)	Reduction (Tonnes)
27					
28	Domestic heat	Ok_pre	1.89	24	349
29		Best_pre	7.60	98	1398
30		Best+ach_pre	12.86	166	2367
31		Cond	16.25	210	2990
32		Sol_therm	19.76	255	3635
33		ASHP	28.10	-65	2166
34		Br_gas	23.07	298	4245
35		Br_ASHP	30.41	40	3119
36		Sil_gas	25.31	327	4656
37		Sil_ASHP	31.34	82	3503
38		Gd_gas	30.09	388	5537
39		Gd_ASHP	32.99	157	4181
41	Non-domestic heat	Ok_pre	0.22	17	41
42		Best_pre	0.89	69	165
43		Best+ach_pre	1.51	117	279
44		Cond	1.91	148	352
45		Sol_therm	2.33	180	428
46		ASHP	3.31	-348	132
47		Br_gas	2.72	341	500
48		Br_ASHP	3.58	-249	244
49		Sil_gas	2.98	374	548
50		Sil_ASHP	3.69	-209	289
51		Gd_gas	3.54	444	652
52		Gd_ASHP	3.88	-138	369
53					
54	Domestic electricity	efficient cold appliances	0.56	26	232
55		induction hob	0.16	7	67
56		A+ rated TVs	0.30	14	125
57		LED lighting	1.31	59	538
58		Laptop	0.33	15	136
59		combined fridge freezer	0.41	19	169
60		reducing audio-visual appliances	0.41	19	169
61		Total with all measures	3.33	151	1373
62					
63	Non-domestic electricity	Occupancy sensors for lighting	0.59	216	243
64		Low energy light bulbs	2.21	809	910
65		Reduced lighting out of business hours	0.29	108	121
66		Turn off unnecessary equipment	0.24	86	97
67		Total with all measures	2.50	917	1031
68					

Appendix 2 cont.

69	Carpooling	2 people	0.57	60	137
70		3 people	0.76	80	182
71	Buses	all commutes	0.82	86	196
72		20% of commutes	0.14	14	33
73		All commutes <5 miles	0.22	24	54
74		All commutes <10 miles	0.52	54	124
75	Train	all commutes	1.23	129	295
76		20% of commutes	0.21	22	50
77		All commutes <5 miles	0.34	35	81
78		All commutes <10 miles	0.78	82	186
79	Cycling	All commutes <3 miles	0.16	17	38
80		All commutes <5 miles	0.36	38	87
81		All commutes <10 miles	0.84	88	201
82	Driver training	Efficient driving	0.28	29	67
83	Electric transport	Electric cars	4.07	376	1457
84		Electric cars and buses	4.29	-	2079