University of Strathclyde
Engineering

'A Set of guidelines for a preliminary investigation into using District Heating and Cooling together with Sustainable Buildings in Glasgow'

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Abstract

‘Sustainable development is best explained as taking a common sense approach to the way we live our lives by balancing out the social, economical and ethical aspects of each decision that we make. We have to think carefully about the impacts of our choices to ensure that we minimise harm and maximise the benefits in these areas for the local community and beyond, now and in the future.’…*Glasgow City Council*

It is the hope that this project, in some way, will aid in the research into the development of technologies that, combined, will directly impact the local environment and the standard of living in Glasgow.

Working together with Glasgow City Council and the University of Strathclyde, a project was accepted to develop a set of guidelines into the large-scale implementation of district energy schemes in Glasgow that would have massive environmental, economic and social benefits for the local community, and set a precedent for the rest of Scotland, and the UK.

The findings will demonstrate an understanding of the contributing factors to a successful district energy scheme, understand the historical events that have influenced district energy in the UK, and develop a model of a future development, which due to its nature, could have potentially global attention.

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1. Introduction

This project is aimed at developing a new set of guidelines that will significantly contribute to the large scale implementation of district heating and/or cooling (DHC) within Glasgow City Centre and specifically, in conjunction with the development of the Commonwealth Games Village in 2014 and surrounding projects. Researching district energy including previous case studies in the United Kingdom and from around the world will illustrate the main factors that impact a new DHC system. Although the technology has existed for many years, it has a relatively unpopular image. Only fairly recently has this opinion altered towards a positive one due to a few climatic factors. This thesis will demonstrate to its reader; an insight into the past history of DHC in the UK, present technology and the components that contribute to a successful system, and the future potential of DHC. Combining that with a technical case study from a future development in Glasgow; it is intended to demonstrate the potential for the large scale implementation of district energy schemes.

1.1 Project Background

On the 27th of June a bill titled ‘Sustainable Glasgow Feasibility Study’ was passed through Glasgow City Council. The proposed feasibility study will provide the city with evidence to support investment in a range of projects that will contribute to the city’s environmental and sustainable objective. The study will also allow the Sustainable Glasgow concept to be developed in a way that will maximise the potential and ensure the most positive outcome from this investment for Glasgow and its people [20].

The proposed study aims to:

- Assist in developing and defining the vision of a Sustainable Glasgow.
- Develop the relationships necessary to making Sustainable Glasgow a reality.
- Develop the evidence base necessary (costs, benefits, risks, technical feasibility, option appraisal) for the consortium, Glasgow City Council, Scottish Enterprise, Scottish Government and other potential partners to make informed strategy and investment decisions.
- Assist the consortium, Glasgow City Council, Scottish Enterprise, Scottish Government and other potential partners to agree the desired outcomes and critical success factors for the Sustainable Glasgow investment programme.

- Evaluate the carbon emissions reductions that would be achieved through investment in district heating, sustainable transport, waste water management and other options.
- Examine options to work with the 2014 Commonwealth Games and other public and private investment programmes to demonstrate real leadership in sustainability.
- Identify and assess options for the development of district heating and cooling networks, sustainable transport networks and improved water and waste water handling.
- Identify and assess options for the development of telecommunications infrastructure alongside a district heating network.
- Identify the regulatory compliance requirements for the implementation of the Sustainable Glasgow programme.
- Agree a preferred business model, approach and decision making structure to making Sustainable Glasgow a reality.

The scope of the feasibility study will include the following:

- The geographic scope of the study will be based on the City of Glasgow (however adjacent areas may be included where particular opportunities are identified)
- The study will cover all sectors of energy demand – domestic, industrial, services, and transport
- The study will cover options for provision of low carbon energy to Glasgow;
- The study will cover options for the development of a high-speed fibre optic network linked to the roll-out of district heating.

1.2 Project Outline

Analysing the way energy is used and distributed in different types of buildings is a vital process in the move to a more sustainable future. It is vital for a sustainable future that this consideration is studied in depth from an inner city perspective. Glasgow as a city has tremendous potential for this type of analysis and being the biggest city in Scotland should give the local council the drive to reach its sustainable potential and become a market leader in advancing other projects around Scotland and the UK.

The report detailed in the *project background* illustrates this drive and provides the scope for this project, and the broad range of subjects that were available to research. The main body of research within this thesis is the history of DHC in the UK and the study of implementing a district heating and/or cooling network into a new development on the outskirts of Glasgow City Centre. The area of DHC is a relatively unpopular and untried on a large scale within Glasgow. Some small-scale projects are known of including the Hutchesontown development in Glasgow's east end where four high rise flat developments introduced a single DHC scheme successfully. Other bigger schemes are known around the UK and will be discussed as part of the literature review.

The aim of this thesis is to directly research the possibility of a new DHC scheme in Glasgow and look at the technology used in previous case study schemes, reducing future risk and providing Glasgow City Council with the required information to implement such a scheme. A new DHC scheme will always differ from other new and previous schemes, as technology changes and the customers to which each scheme will benefit will change. The following brief list details the main aspects of a new district energy scheme:

- Building Types
- Demand Profiles
- Heating and Cooling
- Supply Options
- Distribution Network
- Economic Analysis
- Carbon Savings
- User Behaviour

This project will involve researching these topics and investigate the important factors that contribute to a successful scheme; resulting in a set of guidelines developed for the preliminary investigation into the large scale implementation of DHC in Glasgow. Following on from the set of guidelines and recommendations from the investigation, a theoretical demand profile will be generated and matched against different supply options using a university developed modelling package, Merit.

1.3 Main Objectives and Methodology

The main project objectives are:

- To research the main components of a district heating and cooling system.
- To investigate other case studies in Scotland, the UK, and abroad.
- To research various supply options.
- To understand the history of DHC, and specifically, in the UK.
- To develop a demand profile based on building types and available resources.
- To analyse particular demand profiles using the university programme, Merit.
- To develop a set of guidelines and recommendations based on the research and analytical findings.
- To suggest new areas of research.

1.4 Dissertation Outline

In addition to the List of Contents, the dissertation outline will give a brief summary of each section within this thesis. Section *2 – District Heating and Cooling* presents a broad overview of the research carried out and will present the main body of research and details the many areas that contribute to a successful DHC scheme. As well as the descriptive section there will be sub-sections on case studies that can act as a guide for future projects. Section *3 - Case Study Development* will introduce the subject of sustainability in Glasgow, what initiatives the council has been involved in, and also what targets they have set in relation to UK targets. Following on from this topic will be an introduction to the case study and how it was developed. *4 - Environmental and Economic Study* will discuss the other important factors that contribute, alongside the technical assessment, to a successful DHC scheme. *5 - System Description and Modelling* outlines the main body of investigation within the project and introduces the technical programming and analysis that was developed using the university owned application, Merit. *6 - Results and recommendations* will discuss the analytical results and make recommendations that should benefit any future research in the provision of DHC in Glasgow. In Section *7 – Conclusions*, a summary of the project findings will conclude this thesis and finally, in section *8* details of *References* can be found.

2 District Heating and Cooling

This section describes the basic elements of a district heating and cooling system. District heating and cooling is commonly a network mixed with different technologies and components associated to several industries. This can lead to complications when integrating these technologies together, but can also result in a low carbon energy network that provides a more environmentally friendly alternative to fossil fuel generation. Below in Figure 1 a simple DHC model is shown. The central heat source is supplied to public, domestic and commercial sector buildings.

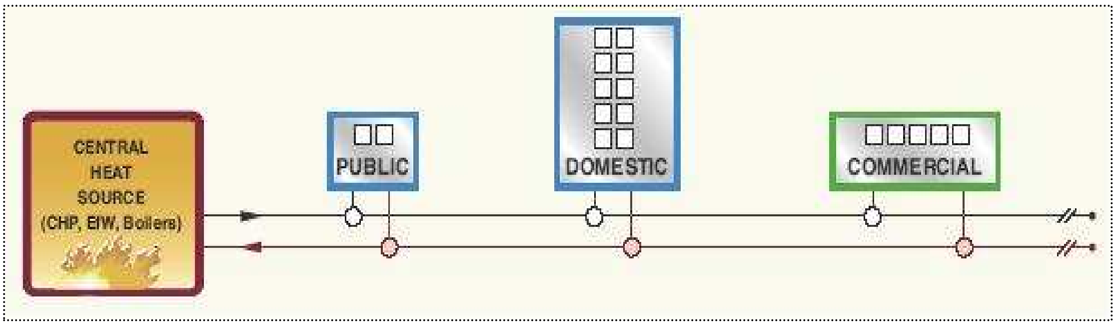

Figure 1: Simple District Heating and Cooling Model [17]

District energy systems connect many thermal users to few energy sources via a piping network using environmentally optimum fuel sources including:

- Combined Heat and Power (CHP).
- Industrial waste heat.
- Energy from waste.
- Biomass.
- Geothermal.

DHC systems are one of the most significant ways, and not normally recognised for this, to:

- Maximise the efficiency of the thermal electricity generation process by providing a means to use the waste heat.
- Share heating and cooling loads.
- Achieve fuel flexibility; opportunities for CHP and to develop renewable energy in a cost-effective way.

This section of the report will cover the following areas of DHC:

- Literature Review
- A brief history of District Heating and Cooling
- Comparing DHC in the UK with other European Countries
- DHC system Pre-requisites
- Energy production alternatives
- Emission considerations
- De-centralised energy production
- System component at the users' location
- Combined Heat and Power
- Geothermal
- Waste management and recovery
- Solar energy
- Biomass Energy
- Wind, wave and tidal energy

2.1 *Literature Review*

With the scope of the project detailed in *1.2 Project Background* being quite large, the project began with a list of areas of interest that was felt could be of benefit to any ongoing research. After researching the topic of DHC the following list was generated:

- DHC system optimisation:
    - Improving the economics for production, distribution and customers.
    - End-user (DH companies and utilities) friendly optimisation tools.
- District cooling:
    - Improving the efficiency and economics of district cooling.
    - Specific innovative cooling techniques.
- Economy of distribution technologies:
    - Reduced costs and payback of DHC systems including low density areas.
    - Improving the quality /lifetime of pipes including joints.
    - Improved techniques and technologies for distribution maintenance issues.

- Small scale DHC/CHP Systems:
    - Decreasing investment costs through improved technology and modular systems integration of renewable energy.
- Thermal storage:
    - Large and small scale thermal storage.
- Institutional issues:
    - Position of DHC in the current energy market; what institutional factors can assist implementation of DHC system.
- Environmental aspects:
    - Impact of DHC and CHP on reducing pressure on electricity transmission and distribution systems.
    - DHC/CHP in emerging green-house gases emission trading schemes.
- Trends in the built environment:
    - The impact of low-energy buildings on the future of DHC: new-build and retrofit.

The remainder of section 2's topics can be viewed as an extension of the literature review.

2.2 Brief History of District Heating and Cooling

District heating traces its roots to the hot water heated baths and greenhouses of the ancient Roman Empire. District systems gained status in Europe during the middle-ages and Renaissance, with one system in France in continuous operation since the 14th century. Across the Atlantic, the U.S. Navel Academy in Annapolis began steam district heating service in 1853.

Although these and numerous other systems have operated over the centuries, the first commercially successful district heating system was launched in Lockport, New York, in 1877 by American hydraulic engineer Birdsill Holly[3], considered the founder of modern district heating.

In his day, Holly was widely known as an inventor and entrepreneur. He held 150 patents in his lifetime, second number only to his friend Thomas Edison. Most of Holly's creations involved water, pumps and power. They included the fire hydrant and the first district system of fire fighting, the water-pressure gauge, the water tap, the expansion joint and more relevant, commercial central steam heating.

With the 1877 installation of the Lockport district heating system, the Holly Steam Combination Co. was born. Over the next five years, the company implemented nearly 50 systems including one that still serves downtown Denver today. In 1882, the business was acquired by American District Steam Co., whose investors had earlier purchased the rights for the Holly system in New York. They went on to sell hundreds more district heating systems throughout the world over the next 80 years.

The future of many of these systems were in doubt as in many early cases, power utilities completely lost interest in the district heating systems and did not provide sufficient funding for maintenance of the systems. The result was that, after some years, the systems started to lose customers; the reliability for heat supply went down and finally the whole system closed down. For example, in Minnesota in the 1950s there were about 40 district heating systems; today only a few remain. In the year 2000 the percentage of houses supplied by heat from district heating in some European countries was as follows:

Country	Percentage of DH (%)
Iceland	**95**
Estonia	**52**
Poland	**52**
Denmark	**51**
Sweden	**50**
Slovakia	**40**
Finland	**49**
Hungary	**16**
Austria	**12.5**
Germany	**12**
Netherlands	**3**
United Kingdom	**1**

Table 1: Percentage of houses supplied by DHC in selected European countries [1]

Penetration of DHC into the heat market is very different by country. Penetration is influenced by different factors, including environmental conditions, availability of heat sources and economic and legal framework.

In Iceland the prevailing positive influence on DH is the availability of easily captured geothermal heat. In most East European countries energy planning includes the development of cogeneration and district heating. Negative influence in the Netherlands and UK can be attributed partially to milder climate and also stiff competition from natural oil and gas supply, discussed further in the next section.

2.3 *Comparing DHC in UK with other European Countries*

In the UK, the development of DHC and CHP historically was much slower compared with other European countries. The First CHP plant began operation in Manchester in 1911 [2], supplying steam to nearby office blocks and public buildings. The first district scheme to heat domestic buildings is reported to have been completed also in Manchester in 1919, though it failed as a result of pipeline corrosion. Pre-war, apart from some small-scale limited schemes for public buildings and industry, DH was virtually unheard of for domestic space heating and water. After the war DH and CHP temporarily appeared attractive in the light of the feared coal shortages. A committee was set up in 1946 under the Building Research Board and it recommended that CHP stations should be considered in the planning of future generating capacity, in particular in connection with the reconstruction of cites and the formation of new housing estates.

Even with this recommendation, only one scheme was set up in the immediate post-war period, the Pimlico district heating scheme. Exhaust heat from the giant Battersea power station which had started operating in 1933 was supplied to a new housing estate across the River Thames from 1951 onwards. An early problem was found that the electricity supply industry was prepared to sell waste heat at power plant boundaries, but was not prepared to invest in the construction and management of heat supply systems.

There was no significant further development in the UK until the late 1960’s and early 1970’s. A number of smaller district schemes were set up to supply heat to large new housing estates, none of which however, involved CHP. At this stage customer experience with these limited district schemes was rather unfavourable, in contrast to consumer reaction on the continent which has been overwhelmingly positive.

In 1973 the energy crisis prompted the Central Policy Review Staff to consider DH in order to save energy. A government committee was then set up to look into the case for DH. An initial report in 1977 suggested that there was no immediate economic case for DH but that rising fuel costs might soon alter this picture. The final report, published in 1979, considered DH a worthwhile option only in the longer term but argued that the option should be opened up in view of the long lead times involved. Following this recommendation, a lengthy process was set in motion consisting of further reports and feasibility studies. In 1985 the government backed an idea of setting up ‘lead cities’ where a district scheme would be set up to demonstrate the feasibility of the technology in the UK. Although money was made available to investigate each case, for over a decade no single project had past the stage of feasibility studies.

At present, there is a marked difference in the development of DHC in Europe compared to the UK. There are many factors over the years that describe this difference. The high level of public subsidies available to DHC developers in Europe compared with the UK, where subsidies are less clear. Subsidies in Europe have contributed to the advancement of DHC development.

In Germany the main backers of DHC are public utility companies in predominantly community ownership [4]. In the UK local authorities have not in general considered energy supply as part of their responsibility, although more recently a few authorities have become more interested in certain aspects of energy conservation policy including DHC. The electricity supply companies in the UK, on the whole, have shown little interest in DH.

In Germany the main motivation to pursue DHC from the beginning was purely economical. Local energy utilities perceived district schemes not only as a sound economical investment, but also as an important strategic measure to preserve their independence. Technical progress in power station technology and transmission lines had made the centralised production of electricity a possibility, and by the 1920’s large utility companies' looked at seeking full control over the entire electricity market. This caused local utilities, with their small inefficient small power stations to be threatened. In developing CHP and DH local utilities could improve their chances of survival. In the UK, an equivalent conflict between local and centralised companies raged in the 1920's and 1930's but local authorities did not take up CHP or DHC technology. The main reason appeared to be the strong preference for open coaled fire with an animosity against central heating systems. With blocks of flats in the major cities preferring coal fires throughout the 1930's, any district system would have been very difficult to market.

While the construction boom of the 1960's and 1970's created an ideal opportunity for the introduction of DHC on a large scale, the heating market was instead successfully seized by the two major nationalised energy industries competing with each other: electricity and gas. Neither the electricity nor the gas industry in the UK saw CHP/DHC as part of their expansion strategy. Both regarded it as a potential competitor in the domestic heating market. Furthermore, the electricity's main aim of producing electricity as cheaply as possible required the construction of bigger power plants, which for environmental and technical reasons were predominantly sited relatively far away from demand centres. This effectively ruled out developing combined electricity generation and district heating schemes. In European countries that had taken up the DH technology, neither the electricity nor the gas sector had the unitary organisation that the UK had. Instead there is a very complex system of organisations comprising in some areas a two-tier structure with one group of large companies responsible for bulk supply and another group of community companies primarily responsible for distribution. While electricity and gas industries are, in the main, separate entities at national level, in many of the bigger towns one community utility is responsible for the supply of electricity, gas and heat.

It is often the framework of available fuels, the existing pattern of the existing heating market and the dominant interests of the energy utilities that influences the outcome of government policy regarding DHC in both countries:

- Firstly the domestic sector in Europe relied far more than the UK one on the use of oil as fuel. There was therefore a strong case for reducing the number of oil-fired heating systems and therefore save oil by the introduction of DHC

- Secondly, the emerging environmental concern in the 1970's could draw on DHC as a measure of reducing emissions from coal- and oil-fired single home heating. The successful earlier removal of open coal fires in the UK and the dominance of less heating measures including gas, electricity, and smokeless coal made this argument less pressing in the UK.
- Thirdly, the substantial North Sea oil and gas resources at the UK's disposal made the reduction of energy consumption, in general, and oil consumption in particular, far less urgent. Rich energy supplies from local resources also made the economical case for DHC more difficult.
- Fourthly, the existence of only a few, relatively small, DH networks made the introduction of DH in the UK economically more difficult. Across Europe DH systems could grow incrementally and most potential DH schemes could probably be implemented by extensions of already existing systems.
- Fifthly, the UK had no organisations willing to promote any potential DHC effort. For individual energy industries, DHC was a potential competitor. Across Europe the municipally owned utilities and other big companies involved in the CHP/DH business are organisations with long standing experience eager to expand their activities in this area.

To conclude, the UK preference for open coal fires and rejection of central heating were early barriers. The establishment of a widespread network of gas supplies has since been a major obstacle to the further expansion of DH in the UK. It is only now with the threat of oil and gas resources in the UK dwindling, that again there is a focus on the need for new energy resources and a re-think of other technologies. It would appear that more and more local councils are in favour of this type of technology, and together with the governments' recent investment, DHC is now a considered option.

2.4 DHC System Pre-requisites

Certain conditions must exist in order for a DHC system to be viable compared to conventional systems. Heating and cooling load densities (heating/cooling requirement per unit area), should be relatively high. The nature of a DHC system dictates this criterion since it becomes un-economical to distribute energy to sparsely populated areas where distributing piping costs and thermal losses become comparatively high. A relatively high total heating/cooling load is preferred since improved operating efficiencies can be achieved at larger facilities, and since economies of scale favour larger installations.

Energy user candidates that will fill the above requirements are:

- Apartment complexes
- Hospitals
- Universities
- Groups of office buildings
- Hotels
- Factories
- Large recreation and entertainment facilities

Many major cities around the world meet much of their heating requirements through district heating. DHC systems that service areas of the city beyond the high density building zones typically work when adjacent housing densities are fairly high and/or several sources of thermal energy are available. Examples of relatively inexpensive sources of thermal energy are:

- Waste heat recovery from energy-from-waste facilities and from large power generation plants.
- Gas turbine combined cycle co-generation plants.

Without either of these locally available resources a DHC system would probably not be considered as the best option.

2.4.1 Generation

DHC Systems are usually connected to a diverse group of customers with varying load requirements, and must typically accommodate a relatively large total heating/cooling load with potentially wide variations from season to season. As individual customers often experience their peak loads at different times of the day, the central production plants daily characteristic load curve tends to be smoothed out, with the peak demand reduced, compared to the sum to the sum of all the individual peak loads. Therefore, the installed total capacity of a DHC system can be less that that of conventional decentralised systems; a distinct advantage or a district system.

Depending on the total system peak and the average load requirements and the load variations from day to day and season to season, DHC plants of varying complexity can be developed. A relatively simple DHC system might operate a single energy production facility, comprising of an oil or gas filled boiler (heating) and electrically driven centrifugal chillers (cooling). Multiple units may also be selected to more efficiently meet base, intermediate and peak loads, as well as providing standby capacity and increased system reliability.

More complicated DHC systems might operate several different energy production facilities such as:

- Energy from waste normally from municipal, commercial or industrial waste incineration.
- Waste heat from manufacturing plant processes.
- Absorption chillers.
- Heat pumps.
- Coal fired boilers.

Other sources of heat for a DH system could include:

- Geothermal.
- Cement kilns.
- Biomass.
- Solar collectors.

In the case of these more complicated thermal energy production systems, the energy sources selected and the manner in which they are used to depend on:

- Local fuel prices.
- Availability of such alternatives.
- Proximity of the load to such sources.
- Environmental sensitivities.

2.4.2 Distribution Network

In district systems, the thermal energy medium, whether it is hot water, steam or cold water, is delivered to customers via a system of supply pipelines. Having exhausted its energy transfer potential to the user, the medium is then normally returned to the production plant via a return pipeline system. While hot or chilled water is pumped to the users and back to the generation plants through the distribution piping network, steam is delivered to the users under its own pressure. Steam, having given up the usable portion of heat at the user’s location, is typically pumped back to the thermal energy source as condensate. In some cases when steam is supplied to a plant to meet process needs, the user’s process may dictate that the steam may be discharged directly into the process, in which case condensate is not returned to the production source. In other instances, where pipeline installation and maintenance costs are excessive, condensate is not returned to the production facility for re-use, but is wasted. In either case, additional energy and chemicals are required to replace the heat energy that is lost when the condensate is not returned. Four types of distribution piping are generally in use today:

- Single pipe system: this system is only used for stem supply applications with no condensate return. While it features low pipeline costs, this type of system results in comparatively low energy production efficiency and therefore higher costs and emissions.
- Two pipe system: this system used where water or steam is distributed to users in the supply pipe and returned to the thermal energy production source via the return pipe. Two pipe systems provide capability for transferring heating OR cooling at one time.
- Three pipe system: this system’s capability is similar to that of a two pipe system, but the additional supply pipe is provided for, and dedicated to, meeting the domestic hot water (DHW) requirements. The three pipe system has therefore been developed in recognition that DHW is required during both heating and cooling seasons.
- Four pipe system: although the most expensive system, this approach provides the greatest flexibility since two pipes are dedicated to cold water (supply and return). This system is necessary for application where both heating and cooling are provided from the central source and are required during either the heating or cooling season.

There are no direct environmental benefits associated with DHC distribution systems when compared to a conventional or non-district system. Due to the extensive burying of pipe that is required with a district system (a mostly non existent requirement of a conventional system), there are disadvantages. These disadvantages include; during excavation for burying or pipe repair and maintenance when leaks develop in the distribution piping, potential for localised traffic congestion, and general inconvenience to pedestrians and motorists. These factors in most instances are out weighed by the potential benefits of a district heating and cooling system.

Heating and cooling pipes are used to link buildings together to form a district energy network to distribute the thermal energy from a decentralised energy generation station. Traditionally the pipe work used in these networks is buried in the ground and pre-insulated. The costs associated with this are high and if possible the networks should be laid within buildings i.e. underground car parks.

Heating networks typically fall into two categories, low temperature (a flow temperature of around 80^{o}C) and high temperature (a flow temperature of between 100^{o}C to 120^{o}C) [2], although there are temperatures in between these and each network must be designed to be compatible with the connected buildings and take into account the local landscape. If possible, the use of a lower temperature network is recommended as this significantly reduces heat losses, increasing the energy that can be used for low temperature sustainable energy sources, and lower cost piping systems can be designed. For lower temperature systems which operate with flow temperatures that are below 95^{o}C it is possible to utilise plastic pre-insulated pipe work which is manufactured in rolls of up to 100 metres. Above this size, or where the use of plastic pipe is not possible then typically 12 metre lengths of pre-insulated steel pipe work are used with bonded insulation which contain alarm wires to detect moisture. For cooling networks the pipe systems described above also apply, but to reduce costs new and innovative materials are available. It is important to consider that as cooling networks traditionally operate with a much lower temperature difference between flow and return, pipe sizes are much larger than those for the same heat load, which typically operates with a temperature difference of more than five times that of a cooling network. This issue has a considerable impact on network costs and spatial planning.

2.4.3 Heat Demand

The amount of heat which is required by each consumer can vary greatly according to:

- Prevailing standard of thermal insulation
- Life style and personal habits of particular consumers
- Local climate conditions
- System of temperature control
- Whether heat supply is metered or not
- Holiday Pattern

Given adequately insulated dwellings, the maximum heat demand shown in Table 2 is likely to arise. Each person in a housing estate draws off about 40 litres of hot water per day at an average temperature of 50^{o}C (122F). It is therefore necessary to budget for an annual hot water supply per individual consumer of 14.6m^3 at an average temperature of 50^{o}C(122F) or pro rata. This base load should vary only slightly over the year.

Type of Consumer	Maximum Heat Demand (W/m^3 of building volume)	Average Annual Heat Demand (MJ/m^3 of building volume)
Small House	80	430
Block of Flats	45	245
School	60	325
Factory	35	190
Offices	60	325

Table 2: Example of heat demands for different building types [1]

University buildings and hospitals are heavy consumers of heat. Their maximum demand is likely to be of the following order:

Type of Consumer	Maximum Heat Demand (W/m^2 of floor area)
Art Department (with workshop)	260
Science Department (including laboratories)	300
Hospitals	400

Table 3: Table of consumers with large heat demands [1]

These figures are widely available in the form of general cases and energy benchmarks for the purposes of analysis. To achieve highly accurate heat demand profiles, all of the factors listed on the previous page must be taken into account. The addition of multiple heat demand profiles to one model, or scheme, will determine its feasibility.

2.4.4 Storage Options

Thermal Energy Storage (TES) offers the potential for economic and indirect environmental benefits. TES was developed in response to the nature of typical cooling and heating load demands experienced by district energy production systems. Most systems, regardless of scale, are characterised by a period during the day when the demand is quite low and other peak periods when demand rises considerably. The energy demand required to meet the sum of the simultaneous peaks requires additional installed thermal energy production capacity with the resulting increases in capital and operating costs and may stress the local utility's resources, discouraging expansion of existing DHC systems. As the daily peak demand is short-term and the thermal energy production equipment that is provided to meet such demands is used infrequently, utility rates are often considerably higher for peak loads to provide incentives to the users to reduce their short term peak loads.

The principle behind TES is to produce surplus quantities and store thermal energy during periods of low demand and subsequently utilise the stored energy to meet peak demands. The thermal energy storage may simply be hot or cold water and ice. With the demand curve reduced, the hourly production varies less, and this means that the energy production equipment can be reduced in size and still be capable of meeting the lower maximum capacity, and can operate closer to a peak efficiency point throughout the day.

DHC systems are well suited to incorporating TES. In general, compared to individual building systems, DHC systems have more flexibility to reduce installed capacity by using TES, without losing system reliability, and are more capable of covering the higher capital costs and distributing the recovery of such costs over longer periods. In addition, since district systems normally cater to a diverse group of users with varying peak load requirements, the DHC system's characteristic load curve tends to be smoothed out, with the result that the total TES capacity requirements are proportionally lower than if TES was considered at individual building level.

On the district cooling side, thermal storage systems use ice formations and storage technology can be used to reduce refrigeration capacity and meet short term peak demands. As with the heat storage system, with the ice subsequently melted and cooling capacity released when demands peak.

2.5 Energy Production Alternatives

A very promising thermal source being used more and more is combined heat and power (CHP), or cogeneration. Energy from a cogeneration plant is normally extracted in one or two ways; heat is produced and used in a process while exhaust heat from the process is used to drive a turbine and produce electrical power, or conversely electric power is first produced and exhaust heat from this production is then recovered for other uses. Although system efficiencies depend on the overall energy production capacity and the type, capacity efficiency of the individual cogeneration components, typical cogeneration energy conversion efficiencies can be as high as 85 – 90%. This compares favourable with typical electric power generation facility efficiencies of 30-35%. The efficiency of the cogeneration plant is only high if all of the waste heat associated with the electrical power production facility is utilised. This can be the case with DHC facilities utilising heat from cogeneration plants for heating purposes and/or when absorption cooling systems are used for cooling purposes. Absorption systems use steam or hot water to pressurise and vaporise the refrigerant and the refrigerant, after condensation and expansion, chills the cooling system re-circulating water.

DHC systems do not need to restrict themselves to heat from central heating plants. District systems, because of their centralised and arterial nature, are well suited to becoming energy dealers, collecting thermal energy from whatever sources have waste heat or unused capacity that is available, and distributing the thermal energy to wherever is needed.

An example of a district heating and cooling system, acting in an energy dealer capacity and enabling waste heat, is through the extraction of heat from waste water using a heat pump system. Possible applications include community and industrial waste treatment plants. With such applications, during heating periods, heat would be extracted from the waste water using heat pumps. The heat pump converts the low temperature heat extracted to a temperature that can be used in heating applications. During cooling periods, these same heat pumps, operating in reverse, extract heat from the space and/or equipment being cooled and transfer the heat collected into the waste water. Another suggestion for district cooling applications is the utilisation of, as a thermal energy source, cold lake or river water. Depending on the capacity of the source and depth at which the cold water is extracted, the temperature of the water remains at a relative constant cold temperature. Such a system, requiring pumping through the distribution and heat exchanger systems, use as little as 5% of the electricity used by electrically driven chillers. This project is known as the Deep Lake Water Cooling (DLWC) project.

2.6 Emission Considerations

A wide variety of fuels are used to at DHC plants including varies grades of oil and coal, natural gas, refuse and other bio-fuels such as woodchips, peat and straw. The combustion of these fuels may produce environmentally hazardous products of combustion thus flue gas cleaning devices and other emission reduction measures are often incorporated. Such measures are usually required under strict legislation, before approval to operate a facility is granted. Examples of pollution control equipment used at DHC plants include [4]:

- Acid gas scrubbers – these systems usually use hydrated lime to react with the moisture, Sulphur Dioxide (SO), and other acid gases in the flue gases discharged from the combustion system. With such systems, the lime-acid gas-water vapour reaction products are efficiently collected by electrostatic precipitators as particulate matter. Bag filters are also used in many applications to capture the particulate matter as well as the acid gas scrubbing reaction products.
- Conventional oil / gas boilers utilising low Nitrogen Oxide (NO), burners to reduce emissions are very common
- Flue gas recirculation to reduce NO has also proved effective.
- Other emission control or reduction techniques that can be introduced with district energy systems include the optimisation of combustion efficiency reducing Carbon Dioxide (CO_2) and hydrocarbon emissions through the use of modern computerised combustion control systems, and the utilisation of higher quality, lower emission producing fuels.

2.7 De-centralised Energy Production

With the exception of some larger boiler plants, most conventional facilities are usually too small to permit staged energy production (through the use of multiple units or different energy resources). For systems having multiple boiler and/or refrigeration units, staged energy production can be used to meet base, intermediate and peak loads, allowing the energy production equipment to operate at near maximum efficiency. Such capability is typical to DHC systems. Conventional systems that utilise a single piece of equipment (must be rated for peak loads) operate most of the time at partial loads. Depending on the class of equipment used, this may result in dramatic reductions in operating efficiency.

Conventional systems are faced with high costs if pollution control equipment is required, due to a lack of suitable low cost pollution control technologies being available for smaller applications. This creates disincentives to incorporate such equipment. In the case of households and small commercial business, it is completely impractical to incorporate pollution control equipment that could achieve the low emission levels experienced by DHC systems. The potential environmental benefits of DHC systems are attributable in part to the above differences between district systems and conventional systems, but will be discussed in more detail in a later section.

2.8 System Component at the User’s Location

With DHC systems, the integration of the generation and end use thermal energy transfer functions can utilise indirect and/or direct connected distribution systems:

Direct systems do not have isolated subsystems. Instead, hot or chilled water, or steam from the production source is distributed directly through the customer’s radiators or air handling equipment. *Indirect systems* incorporate heat exchangers at both the energy production location and at the user’s location, therefore the generation, distribution, and energy utilisation subsystems are effectively isolated from each other. Another indirect system option uses heat exchangers at the end user only, thereby isolating the generation and distribution systems from the user subsystem. This arrangement is common for steam generation and distribution systems.

Although direct systems were at one time the more prevalent of the two systems, indirect systems are now becoming the preferred approach. This is due primarily to several inherent advantages associated with indirect systems including:

- Greater production against surge induced radiator damage at the customers' end, due to a surge in protection provided for the distribution system and by the pressure isolating heat exchangers.
- Lower make-up water treatment costs due to much less probability for extensive leakage in indirect systems.
- Greater flexibility, as indirect systems can accommodate to a much higher degree users of various sizes and having varying pressure requirements.
- Ease of control since two of the basic operating points are essentially independent in an indirect system.
- Ownership of generation and distribution systems can be separated when necessary or desirable.

2.8.1 Changing User behaviour

As mentioned in the *Abstract* for this thesis, an environmentally sustainable future is as much about user behaviour as it is about new and greener technology. This small sub-section is aimed at identifying the importance of user behaviour, and can relate to the system component at the users location. A system that can relay feedback based on usage levels, make recommendations on energy saving methods and technologies, and possibly offer some kind of incentive will always provide optimum results. Usually the optimum level costs much more but should be considered essential and recommended for new potential installations.

2.9 Combined Heat and Power (CHP)

For most small-scale CHP applications three factors dominate economic viability. These are:

- The capital cost of the installation
- The potential number of operating hours per year
- The relative costs of 'bought in' electricity and gas (or fuel oil)

If any of these variables are not favourable, then a particular CHP scheme may become non-viable. Given that fuel can be unstable, the last point is of particular importance. If for example, the unit cost of mains electricity should fall or the cost of gas rise, there will come a point when a particular CHP unit ceases to be economically viable. Other lesser factors which may influence the economic performance of a CHP scheme are:

- The heat to power ratio of the particular CHP plant
- The difference in maintenance costs between a CHP scheme and a conventional scheme
- The cost of having mains electricity as a back-up system in case of breakdown or maintenance

Given these costs, it is important to undertake a full economical appraisal of any proposed CHP scheme. Two areas that form the basis of any appraisal are *CHP Turbine Systems* and *CHP Sizing* and information is given on each of these in the next two sections.

2.9.1 CHP Turbine Systems

The choice of CHP turbine for any district scheme will vary due to several factors including size, local availability, and use. Below is a selection of turbines that are typically used in different application, showing their characteristics, advantages and disadvantages.

Back pressure turbines have the following features [1]:

- *Capacity* – up to 100MW
- *Characteristics* – Designed mainly for supply of heat with electricity as by product
- *Advantages* – Cheap and can use unconventional fuels such as refuse, excellent overall thermal efficiency
- *Disadvantages* – Fixed heat/electricity output ratio; Poor electricity yield in operation; Expensive for small units.
- *Main issues* – To cover base load of heat for large systems; useful in connection with refuse incinerators

Back pressure turbines with condensing tail have the following features [1]:

- *Capacity* – up to 100MW
- *Characteristics* – Designed mainly for supply of heat with electricity as a by-product, but able to vary output ratio of heat/electricity
- *Advantages* – Excellent thermal efficiency for obtaining heat, but able to obtain electricity at reasonable efficiency when heat load is low
- *Disadvantages* – A very high basic heat demand is always needed for this turbine to efficiently. At very low heat demand electricity production is uneconomical. This turbine is more expensive than a basic back pressure turbine.
- *Main issues* – To cover base load of heat for large systems where fluctuations in demand are expected. It is unwise to dimension such turbines to cover an excess of 50% of the expected peak demand.

Condensing turbines with district heating extraction (ITOC) have the following features [1]:

- *Capacity* – up to 700MW
- *Characteristics* – Designed mainly for power production but permits take-off of steam at around 1 to 1.5 bars pressure for district heating purposes
- *Advantages* – steam adjustment can adjusted instantaneously between and the maximum of about 20% of turbine output. Existing condensing turbines can be modified at moderate cost. Efficiency of electricity production is very high.
- *Disadvantages* – Limitation of quantity of heat which can be abstracted without adversely affecting running of turbine
- *Main issues* – Most common of all the district heating turbines for large schemes. Able to act as a control valve to balance heat output and heat requirements. Used for nuclear district heating schemes and others where relatively long supply lines are used.

Gas turbines have the following features [1]:

- *Capacity* – up to 100MW (open cycle) and 130MW (combined gas and steam)
- *Characteristics* – Designed for putting into operation at very short notice to supply peak electricity. Combined with heat exchangers and small back pressure turbine to step up electricity supply and to obtain waste heat for district heating purposes

- *Advantages* – Suitable for a very small group heating undertakings and for small power take-off. High electric and overall thermal efficiencies
- *Disadvantages* – Expensive in capital investment and maintenance charges. Open-cycle gas turbines require high grade fuel, while closed cycle turbines are even more expensive than open-cycled turbines. Difficult to vary heat/electricity ratio
- *Main issues* – Supplying heat and electricity to very small schemes. Useful as a peak station for the supply of both heat and electricity

Diesel engines with waste heat extraction have the following features [1]:

- *Capacity* – up to 20MW
- *Characteristics* – Diesel engines extract heat from (a) exhaust, (b) cooling jacket, and (c) oil coolers to supply either steam or hot water.
- *Advantages* – Making the best use of prime fuel when electricity is being generated in small quantities by diesel engines, by application of CHP principle
- *Disadvantages* – Use very expensive fuel. Capital outlay quite prohibited for larger installation. Poor overall thermal efficiency. Heat/electricity output ratio invariable
- *Main issues* – Supply of heat and electricity to small heating schemes. Often used in conjunction with supply of chilled water for refrigeration purposes.

2.9.2 *CHP Sizing*

To size any CHP plant, the technical and economical requirements of a particular site must be taken into consideration. Through the establishment of a detailed database concerning heat and electrical demand profiles, a methodology for the size of CHP can be developed based on the following considerations:

Base load – A CHP unit is designed to provide base load electrical, or thermal output, with any shortfall being supplemented by electricity from the grid or hot water/steam from boilers. Figure 2 on the next page illustrates an example of this; the dark blue area representing the base load thermal energy, and the blue and light blue areas representing the extra capacity the plant would need using boilers to meet peak demand. Due to the relative prices of fuel and electricity, electrical base load sizing is more common. The most cost effective solution may be to size above base load, as indicated by the red line on the graph, even though this might involve some waste heat removal.

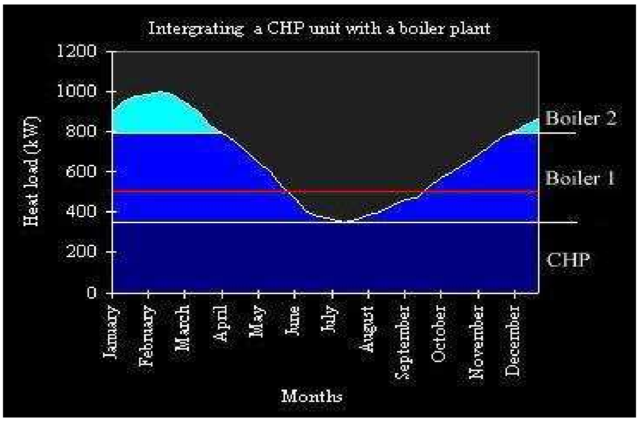

Figure 2: CHP Sizing Example

Load lopping – The types of CHP units in the market today have the ability to modulate, which means they are able to constantly change their output in order to meet changing demand. When load lopping, the CHP unit is operated to match the output of heat/electricity with the demand for heat/electricity during periods of maximum demand. When the electrical demand causes the output to be modulated it is important to take into account the occurrence of heat removal from the system into the atmosphere via heat exchangers.

Electricity Export – The CHP is operated to provide excess electricity that can be exported to the grid or other users with the recovered heat being used on site or partly dumped.

Variations – It may be that in some circumstances, variations such as plant sizing for heat load at the average heat load during times of peak electricity tariff rate is the most beneficial option.

Multiple and Single Units – A series of units can operate in cascade to meet the energy demand at any one time. This involves one unit meeting the base load meeting the base load and smaller units generating as and when required. Figure 3 on the next page illustrates how this can be achieved. Single CHP units are usually the preferred option due to the lower maintenance and installation costs, and higher electrical generation efficiency when operating at full power. In some situations the use of multiple units is advantageous as there is a higher guarantee of emergency supply cover and electricity maximum demand cost saving during maintenance work.

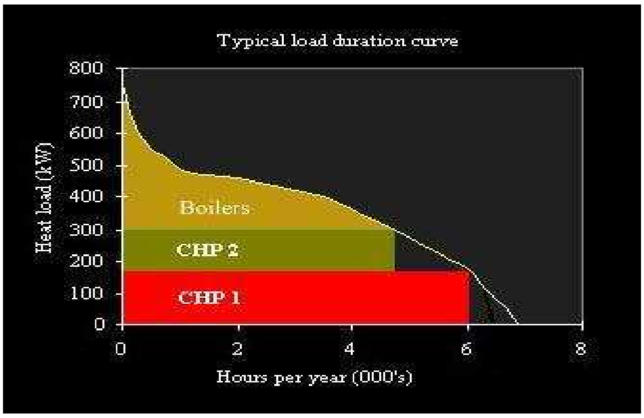

Figure 3: Example of Multiple CHP unit

To summarise the CHP unit specification is dependant on the following:

- Maximum electrical output required
- Thermal heat to electrical power ratio
- Fuel type used and cost
- Grade of heat required
- Utilisation and availability
- Maintenance requirements, operational and capital costs
- Environmental considerations (e.g. exhaust emissions, vibration and noise)

2.9.3 Case Study – Glasgow Hutchesontown Development, UK

Hutchesontown is a small scale development of over 1000 homes built in the 1960s and located a mile south east of Glasgow city centre [27]. Around half of the residents live in four 23 storey tower blocks, together containing 552 one and two bedroom flats; the remainder in four storey deck-access flats. The estate is owned and managed by Scotland’s national housing agency, Scottish Homes.

Like many multi-storey housing developments built at the time, the Hutchesontown homes suffered from poor thermal performance, made worse by open balconies, very exposed position and expensive-to-run off-peak electric storage heating systems. The resulting cold and damp conditions led to widespread condensation and mould related problems in the homes and considerable discomfort for residents. Eventually, the area was designated an Estate-based Strategy Area and Scottish Homes began a programme of investing in the regeneration of the estate.

Adding District Heating – An earlier feasibility study had demonstrated that district heating would reduce energy use and give tenants more control than electric heating. Therefore, a new gas-fired district heating system formed the centrepiece of the refurbishment. A new boiler was built with capacity to serve all the housing in Hutchesontown. Initially, just two boilers were installed to serve the first block. Underground heating mains were installed to carry hot water from the boiler house to the base of the block. The steel pipes were insulated with foam and incorporated a further protective layer and an automatic leak detection system. Another, small plant room was created at the base of the block to house a heat exchanger, where heat is transferred from the primary water circuit to water circulating within the block. Hot water is then pumped to supply the new wet radiator heating systems installed in each flat.

Individual heating systems are controlled by a card operated payment device which also incorporates a programming facility for heating and domestic hot water. Room and cylinder thermostats were also installed, as in conventional central heating systems. Each dwelling has a meter that records the amount of heat and hot water being used and which forms the basis of the payment system. The payment units are installed in all flats and allow residents to pay for their heating as and when required.

In addition to the new district heating system, the entire block was over clad with a new weatherproof skin incorporating extra insulation. Windows were replaced with double glazing and open balconies enclosed to form conservatories. Tennant involvement was a major feature of the whole operation, from the initial survey through to design and installation work. Scottish Homes is now evaluating the option of installing one or more CHP units in the central boiler house as future phases of the work progress. A financial summary of the project is shown below [27]:

Cost: The total cost of the heating system refurbishment amounted to £3,200 per dwelling. Total Cost- £3.2M

Savings: Average bills for the new community system are estimated to be £3.50 per week (£182 a year), a dramatic reduction from charges of up to £700 a year by some residents for partial electric heating. Homes with the new system are also much more comfortable.
Payback: The average payback can be calculated by dividing the investment per dwelling by the annual saving per dwelling which equates to a payback of 17.82 years. The actual payback will generally be lower due to other council and government grants that are not shown.

2.9.4 Case Study – Southampton District Energy Scheme, UK

Southampton City Council has shown its commitment to sustainable development by employing an innovative approach where DHC it is very much part of the city's infrastructure. This includes large-scale schemes and smaller, stand-alone schemes. They view DHC linked to CHP or other environmentally friendly sources as the best way to provide heating, and where relevant, cooling.

The Southampton District Energy Scheme was established in 1986 [22] and began life as a government backed geothermal project. After the project was abandoned, the council took it upon themselves to source a utility company that partnered them in developing this resource. From initially serving one customer in the mid-80's the district energy scheme has grown to more than 40 commercial and public sector customers and hundreds of households by 2003. It now produces over 70GWh of energy a year, providing low cost heating, hot water to private and social housing, hotels, offices, council administration buildings, a hospital, retail developments and a leisure complex. At present Southampton's District Energy Scheme has employed some of the newest technology and a host of ground-breaking features. The most important development has been the addition of the combined heat and power (CHP) generators to the geothermal network.

2.10 Geothermal Energy

Geothermal energy is generally heat from the Earth and is clean and sustainable. Resources of geothermal energy range from the shallow ground to hot water, and hot rock found a few miles beneath the Earth's surface, and even deeper to the extremely high temperatures of molten rock, called magma.

Almost everywhere, the upper 10 feet of the Earth's surface maintains a nearly constant temperature 10^oC and 16^oC. Heat pumps can tap into this resource to heat and cool buildings. A geothermal heat pump system consists of:

- A heat pump
- An air deliver system
- A heat exchanger
- A system of pipes

In the winter the heat pump removes heat from the heat exchanger and pumps it into an indoor air delivery system. In the summer, this process is reversed, and the heat pump removes from the indoor air into the heat exchanger. The heat removed from the indoor air during the summer can also be used to provide a free source of hot water.

2.10.1 Case Study – Reykjavik, Iceland

District heating in Reykjavik began in 1930; when a 3km pipe was built from a hot spring area in the city to a school house, the national hospital and 60 house dwellings [22]. By 1970 nearly all the houses in Reykjavik were receiving hot water for heating. Today Orkuveita Reykjavikur serves roughly 150,000 people or 99.9% of population of Reykjavik and five neighbouring communities. This accounts for 58 percent of the population. 95% of the entire population is now powered by district heating and cooling due to the availability of the naturally occurring geothermal hot springs.

Due to the high content of gases and minerals at the high temperature area, water and steam are used to heat fresh water. The total capacity of the district heating is about 780 MW and the cost of the geothermal energy is low compared with burning of a fossil fuel due to the hot springs being more commonly found in Iceland and the technology has been established for many years. In Iceland DHC has reduced the emission of greenhouse gases dramatically, decades before the international community began contemplating such actions. In Iceland, geothermal energy has economical and environmental advantages which alternative energy sources can not compete with. Figure 4 demonstrates a well establish district heating network.

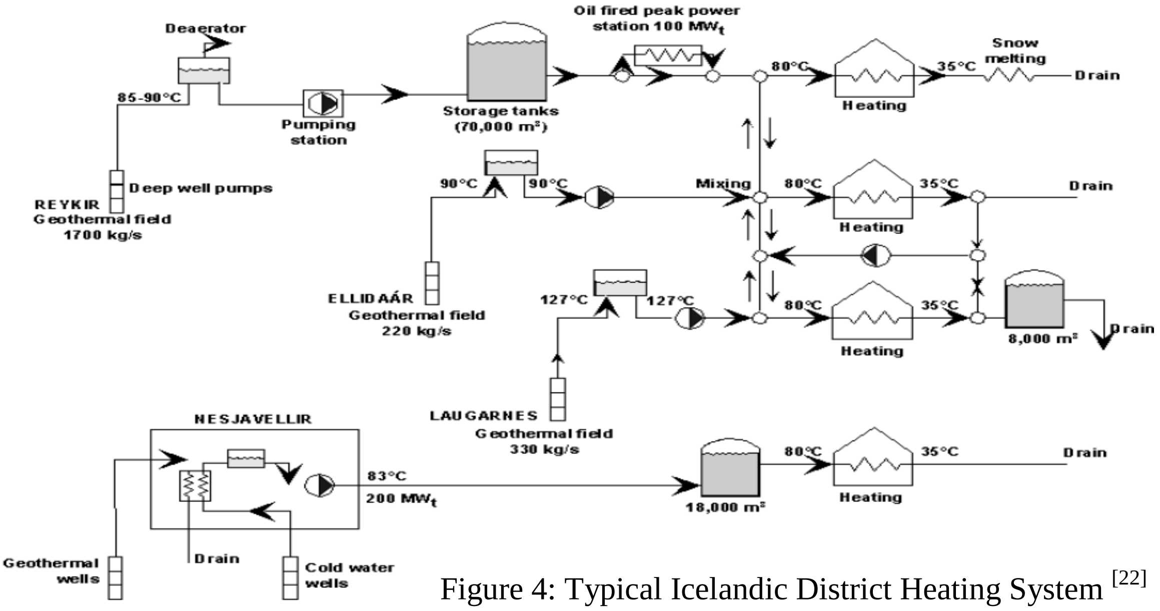

Figure 4: Typical Icelandic District Heating System [22]

2.11 *Waste Management and Heat Recovery*

In many applications there is potential for recovering heat energy that would otherwise go to waste. This chapter describes the various heat recovery technologies and examines the theoretical principles behind each. Before investing in such a technology it is important to first consider some general issues:

- *Is there a suitable waste heat source?* It is important to establish that the source is capable of supplying a sufficient quantity of heat, and that the heat is of good enough quality to promote good heat transfer.
- *Is there a market or use for the recovered waste heat?* It is important to have a use for any waste which might be recovered. In many applications there may be no demand for the heat that is available, with the result that a large quantity of heat energy is dumped. In other situations there may be a long time lag between waste heat production and the demand for heat. Waste heat therefore cannot be utilised unless some form of thermal storage is adopted
- *Will the insertion of a heat recovery device actually save primary energy or reduce energy costs?* Often the insertion of a heat exchanger increases the resistance of the fluid streams, resulting in a fan or pump energy consumption

rising. Heat energy is therefore replaced by electrical energy, which may be produced at an efficiency of less than 35%.

- *Will any investment in heat technology be economic?* Heat recovery devices can be expensive to install. It is, therefore, essential that the economical payback period be determined prior to any investment undertaken.

If a decision is made to invest in some form of heat recovery device, then the next logical step is to select the most appropriate system. There are a wide variety of heat recovery technologies, which can be divided into the following broad categories:

- *Recuperative heat exchangers:* where the two fluids involved in the heat exchange, are separated at all times by a solid barrier.
- *Run-around coils:* where an independent circulating fluid is used to transport heat between the hot and cold streams
- *Regenerative heat exchangers:* where hot and cold fluids alternatively across a matrix of material.
- *Heat pumps:* where a vapour compression cycle is used to transfer heat between the hot and cold streams

2.11.1 Case Study – Vienna, Austria

The district heating network in Vienna supplies around 240,000 dwellings and 5000 industrial customers [2] with district heating energy used for space and water heating purposes. Waste incineration, surplus industrial heat and cogeneration accounts for 97% of the total heat output.

Incineration of Wastes – the network is connected to four separate installations: three community waste facilities and one hazardous waste facility. Around 60% of the waste output from the population of Vienna is treated in incineration installations. This represents just less than 500,000 tonnes a year that is used to produce energy. The heat output from waste incineration accounts for 22% of total district heat production.

Industrial Heat Recovery – Another form of renewable supply of energy is the use of industrial surplus heat. In Europe there is a huge potential for this to be used but despite that it is still very much unused. In Vienna, the use of the surplus heat from the Fernwärme Wien refinery is used in a district heating network. The refinery produces a number of products from crude oil. The number of by-products with significant energy content made it possible to build a district heating pipe to the refinery to make use of this otherwise wasted energy.

In Vienna, the base load for district heating is ensured using waste and guarantees an efficient and sustainable supply of energy. During the colder time of the year, CHP installations are running and only in peak demand times, heat only boilers are used. 97% of heat is based on heat from waste incineration and CHP. The savings compared to in-house boilers were estimated to be around 68%. A recent study by the Austrian Federal Environmental agency found that the CO_2 emissions from the Fernwärme Wien refinery per MWh used energy are about 132 $kgCO_2$. This figure compares to 256 CO_2 per MWh from an average gas boiler. This illustrates the high environmental benefits of district heating.

In the future Fernwärme Wien plans to commission a biomass plant within a year, as well as a new incineration plant, and also considering re-powering of an existing CHP plant. The future of sustainable energy production in Vienna looks very promising and demonstrates the potential savings that can be made from waste management and heat recovery as part of a DHC network

2.12 Solar Energy

Solar energy technologies use the sun’s energy and light to provide heat, light, hot water, electricity, and even cooling, for homes, businesses, and industry.

There are a variety of technologies that have been developed to take advantage of solar energy and use within a district energy scheme:

- Photovoltaic (PV) Systems
- Solar Hot Water

- Solar Electricity
- Passive Solar Heating and Lighting
- Solar Process Space Heating and Cooling

2.12.1 Case Study – Crailsheim, Germany

From the total energy production in Germany, 7% originates from renewable sources and under that heading, solar energy is steadily growing with an output of 270 MW [13]. The solar project in Crailsheim is one of four groundbreaking projects in Germany and is an example of using solar energy on a large scale. In this project, the city of Crailsheim works with many specialist institutions; thermodynamics and thermal technology, solar, and gas to ensure the project is a success and provide a benchmark for future developments.

The first step in this project involved installing photovoltaic devices on existing buildings over an area of 1040 km^2, distributing heat across 10km into a newly built area. In the second step of the project, the collector fields were installed on walls of building for noise reduction, covering an area of 7000m^2. It was established that this project would cover 50% of the heat demand from the new development.

2.13 Biomass Energy

Biomass is produced from organic materials, either directly from plants or indirectly from industrial, commercial, domestic or agricultural products. It is also known as ‘bio-energy’ of ‘bio-fuels’ and it does not include fossil fuel.

Biomass falls into two main categories:

- Woody biomass includes forest products, untreated wood products, and energy crops.
- Non-woody biomass includes animal waste, industrial and biodegradable municipal products from food processing and high energy crops. Examples include rape, sugar and maize.

Biomass energy is cost effective and sustainable when a local fuel resource is used, which results in local investment and employment, and also minimises transport miles to the users location.

2.13.1 Case Study – Maribo-Sakskøbing, Denmark

In Denmark, straw is available from every agricultural zone. Around 11.9PJ of straw was used in 2003, amounting to 1.4% of gross energy consumption [9]. Straw is used as a supplementary fuel (co-firing) in large scale CHP plants and as the sole fuel in smaller CHP plants or boiler stations. Waste heat from the CHP plants and the heat produced in the boiler stations are used in district heating.

A small CHP plant based on straw is the Maribo-Sakskøbing CHP plant. The plant was commissioned in 1999 and the electricity produced equals the consumption of around 10,000 households, whereas the heat produced covers 90% of district heating supplied in Maribo-Sakskøbing. The 40,000 tonnes of straw used by the plant are delivered by local farmers and the ashes from the combusted straw are then returned to the farmers, to be used as fertiliser.

Straw is a very efficient energy source with 89% of the energy used. Out of this 29% goes to electricity production and 60% goes to heat. This very efficient use of the fuel provides clear environmental and efficiency benefits. The emissions of CO_2, SO_2, and NO_x are considerably reduced through the combined production on electricity and heat. A further advantage is that straw emits less sulphur and nitrogen than fossil fuels like coal and oil. A final advantage is that straw is CO_2 neutral since the carbon dioxide emitted is equal to the carbon dioxide it consumed while growing. The heat produced is sold to two district heating utilities in the twin towns of Maribo and Sakskøbing, around 140km south of Copenhagen.

District heating offers many environmental benefits to the Danish society. Around 60% of all households are connected to district heating grids; 75% of the heat is waste heat from CHP, a further 12% comes from waste incineration, 6% is biomass burned in boilers and 3% is industrial heat waste. The remaining 4% is mainly natural gas, and also oil, used in peak load and spare capacity boilers. The average annual cost for heating a house with district heating is one-third lower than heating with oil, and one-fifth lower than heating with natural gas.

2.14 Nuclear energy

Nuclear energy is very much a viable energy source for use within a district heating system. At first glance there is an immediate reaction against this type of technology, but nuclear energy would work similarly to any type of CHP plant producing both electricity and heat.

Sooner or later (possibly sooner) the world's resources of fossil fuels (oil, coal, and natural gas) will come to an end. Preparation for the escalating costs of such fuel resources which will eventually become intolerably expensive. District heating methods should also adapt to the usage of alternative energy sources. Unlike major schemes of harnessing solar energy, nuclear power has already proved itself to be a viable method of providing energy, with production costs lower than those which apply to fossil fuel. Its recent record shows that it is safer, cleaner and more desirable from the environmental point of view than power and heat production by fossil fuels.

Nuclear power is therefore ideally suited for the supply of heat and power by means of ITOC turbines but the following properties of atomic power plants require special consideration:

- They are usually very large, delivering an enormous and constant supply of steam.
- For reasons of safety nuclear power stations are located at maximum distance from urban centres.
- The fuel costs are quite negligible, but the capital costs of building a nuclear plant are huge.

2.14.1 Case Study - Holland

Plans for a nuclear combined heat and power plant in Holland [10] were only recently presented to the industry, the energy sector and the press. The partners collaborating in the Inherently Safe Nuclear COGENeration project are the Netherlands Energy Research Foundation (based in Petten), Stork NUCON (Amsterdam), KEMA (Arnhem), the interfaculty Reactor institute (Delft), and ROMAWA (Voorschoten). These organisations have started a design study to develop a safe and efficient nuclear combined heat and power plant incorporating two technologies which have demonstrated their practical effectiveness, the High-Temperature Reactor and a plant which produces both electricity and heat.

2.15 Wind, Wave and Tidal Energy

Recently in the UK there has been a push for renewable technologies, and some see it as the solution to future energy problems. The advantage of wind and wave energy above conventional fuel energy generation is that the source will never run out. The technology is still in its early ages but there is potential for it to contribute to a significant percentage of the UK’s energy demands. Unfortunately at current levels of production, these renewable technologies could never completely replace conventional fuel energy production. Wind turbines are the most advanced technology, cheaper than alternative renewable technology, but wind can be very unpredictable, and can not guarantee a continuous and steady flow of energy generation. Wave and tidal have the potential to generate energy on a similar scale to wind energy but the technology is still at an early stage, and costs are very high. As energy demands in the world increase it would be impossible, at this stage for renewable energy to replace fossil fuels, and in some cases, meet the extra demand.

3 *Case Study Development*

This section is aimed at introducing the case study and reviewing the potential that Glasgow as a city has to introduce sustainable technology on a large scale. The case study is split into two parts; one confirmed development, and one hypothetical situation where any district scheme developed would incorporate both but take into account the time period between each development. The following areas will be covered in this section:

- Glasgow City Centre
- Government and Glasgow City Council Initiatives
- Case Study Development

3.1 *Glasgow City Centre*

Glasgow is Scotland's largest city and the fourth largest in Great Britain. It lies on both banks of the River Clyde in the western part of a heavily populated central belt. Glasgow forms the heart of Scotland's major commercial and industrial area, called Clydeside. This area, extending along the River Clyde from Glasgow to about Greenock, is the centre of its shipbuilding industry including ship-repairing and marine engineering facilities. Varieties of other industries are located in and near Glasgow including; rail, chemicals, electronic equipment, whiskey, processed foods, and textiles. Glasgow and other port facilities along the River Clyde make up Scotland's chief port, one of the busiest in the UK. The city is served by a network of railways, highways and an international airport.

Glasgow's most historic building is Glasgow Cathedral, also known as Saint Mungo Cathedral, dating from the 12th century. The University of Glasgow, founded in 1941, is the city's oldest and largest institution of higher learning. Other institutions include the University of Strathclyde and the Royal Scottish Academy of Music and Drama. Other major central buildings include; Kelvingrove Art Gallery, Mitchell Library, and the Royal Theatre.

Table 4 on the following page illustrates a breakdown of the building and facility types in Glasgow City Centre. This table demonstrates the potential for sustainable development in Glasgow, and specifically DHC due to the high content of varied building types.

Building Type	*Quantity (unless specified)*	*Percentage*
Residential:		
Number of Dwellings	291,474	
- Owner occupied Houses		49%
- GHA Houses		25%
- Other Social Rented Housing		15%
- Private Rented Houses		11%
Transport:		
Mainline Rail Terminals	2	
Bus Stations	1	
International Airport	1	
Underground Stations	1	
Education:		
Secondary Schools	29	
Primary Schools	171	
Universities	3	
Further Education Colleges	11	
Nursery Schools	91	
Retail:		
Main district Shopping Centres	2	
Areas of Retail Commercial Development	5	
Local Shopping Parades	170	
Office/Business:		
Total Office Floor space	2,314,219 sq m	
- City Centre	1,445,844 sq m	63%
- Out-with City Centre	868,375 sq m	37%
Health and Social:		
General Hospitals	10	
Community Health & Care Schemes	5	
Sport and Leisure:		
Local Parks	74	
District Parks	12	
City Parks	5	
Indoor Sports Arena	1	
Indoor Sports Centres	7	
Swimming Pools	5	
Council Owned Pitches	295	
Community Libraries	34	
Environment:		
Local Nature Reserves	6	
Local Sites of Importance for Conservation	39	
Sites of Special Landscape Importance	214	
Sites of Special Scientific Interest	5	
Vacant and Derelict Land Sites	851	

Table 4: Building and Resource Review of Glasgow City Centre [24]

The potential is shown in each division of the table. Examining just the *Office and Business* section, the city centre has almost 1.5 million square metres off office space, where the majority will be powered by conventional means. In the *Residential* section, there are around 300,000 homes in the city centre. The potential given the right location for DHC could provide massive environmental benefits. The next section will look at the effect of government influence and the initiatives the council has already invested in.

3.2 Government and Glasgow City Council Initiatives

Government targets will always influence the decisions made at a local council level, and often when big goals are set by the government, there is an even greater incentive to invest time and money to reaching these goals. The government have four long-term goals for energy policy in the UK [16]:

- To put the UK on the path to reducing carbon dioxide emissions by 60% by 2050
- To maintain reliable energy supplies
- To promote competitive markets in the UK and beyond
- And to ensure that every home is adequately and affordably heated.

The first goal relates directly to global warming and the pollutant gas emission CO_2 that is a bi-product of fossil fuel generation, and was brought about by the Kyoto Protocol. Global Warming experts state that carbon dioxide is one of the main greenhouse gases that have caused the heating of the planet. As fossil fuel plants have been around for hundreds of years the technology is cheap, available and the reason why most countries use this method of energy generation. The Kyoto Protocol was adopted in Kyoto, Japan, on the 11th of December 1997 and entered into force on the 16th of February 2005. It is an international agreement linked to the United Nations Framework Convention on Climate Change. The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialised countries and the European Community for reducing greenhouse gas (GHG) emissions. These targets amount to an average of 5% against 1990 level over the 5 year period 2008-2012. Recognising that developed countries are principally responsible for the current high level of GHG emission in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations.

The other long-term goals have been brought about by the UK's increasing dependency on importing fossil fuels and look at reducing energy supply and demand. In the UK, over the last ten years, the amount of oil imported from other countries, mainly Russia, has increased from <1% up to around 32% [4]. This dependency raises other issues surrounding security of supply and future availability.

It is these main reasons that the government has development a green campaign to raise awareness of these issues and put in place objectives that will influence the way people live their life and the future generations.

In Glasgow, a number of schemes have already been put in place as part of its 'Environmental Strategy and Action Plan' which began in 2005. They have developed a set of environmental indicators that will set targets for the community and quantify the changes that have been made. The types of indicators are as follows [24]:

- *Economic Indicators,* jobs, investment, free school meals
- *Social Indicators;* school leaver destinations, homelessness, child care
- *Environmental Indicators;* recycling, cycle routes, pollution, traffic growth

On the face of it, this project would be primarily investigating environmental behaviour, but the nature of the project, economic and social behaviour provide just as much importance. The indicators, in general, cover a relatively small number of issues, but the report detailed in *1.2 Project Background* indicates the new levels of sustainability the council would like achieve.

Other initiatives set up by the council that have a direct effect on environmental behaviour are the Carbon Management Programme and the Sustainable Development Group. The Carbon Management Programme was developed in partnership with the Carbon Trust, with the target of reducing current CO_2 emissions by 20% by 2013. This equates to approximately a cut of 8,000 tonnes of CO_2 per year which will be achieved through a range of energy efficiency, transport and recycling projects. The Sustainable Development Group's main role is to deliver advice, recommendations and guidance for the mainstreaming of sustainable development into council policy and project across the city. Some of the recent individual projects in Glasgow, in areas such as energy and sustainable construction, are listed below [24]:

- White Cart Water Flood Prevention Scheme
- Glasgow Strategic Drainage Plan
- Pre-12 Primary Schools Renewal Programme
- Glasgow Bridge and Port Dundas Canal reconnection

3.3 *Case Study*

Last year Glasgow won the right to hold the Commonwealth Games in 2014 and this gives the city of Glasgow a unique opportunity to showcase its commitment to sustainability by developing a plan for a large scale project that will be used by thousands of people from all over the world.

The main aim of the case study is to develop an energy profile for a specific case study set in Dalmarnock on the outskirts of Glasgow city centre. Using this energy profile, a hypothetical district heating with optional cooling model can be developed. The case study is an important factor in the research, in that it is a new development attempting to use only sustainable buildings. As previously mentioned, the energy model is split into two sections:

- Care Home
- Commonwealth Games Village

The care home for 138 rooms has been given planning permission and will begin construction early 2009. A map of the area (Figure 5) is shown on the next page. The Care Home has been highlighted in yellow. A second Care Home, also shown in yellow has been allocated on the map. This development has not yet been confirmed but would be an identical development to the first Care Home. As part of the energy model, both situations will be analysed, determining the best possible outcome for the development.

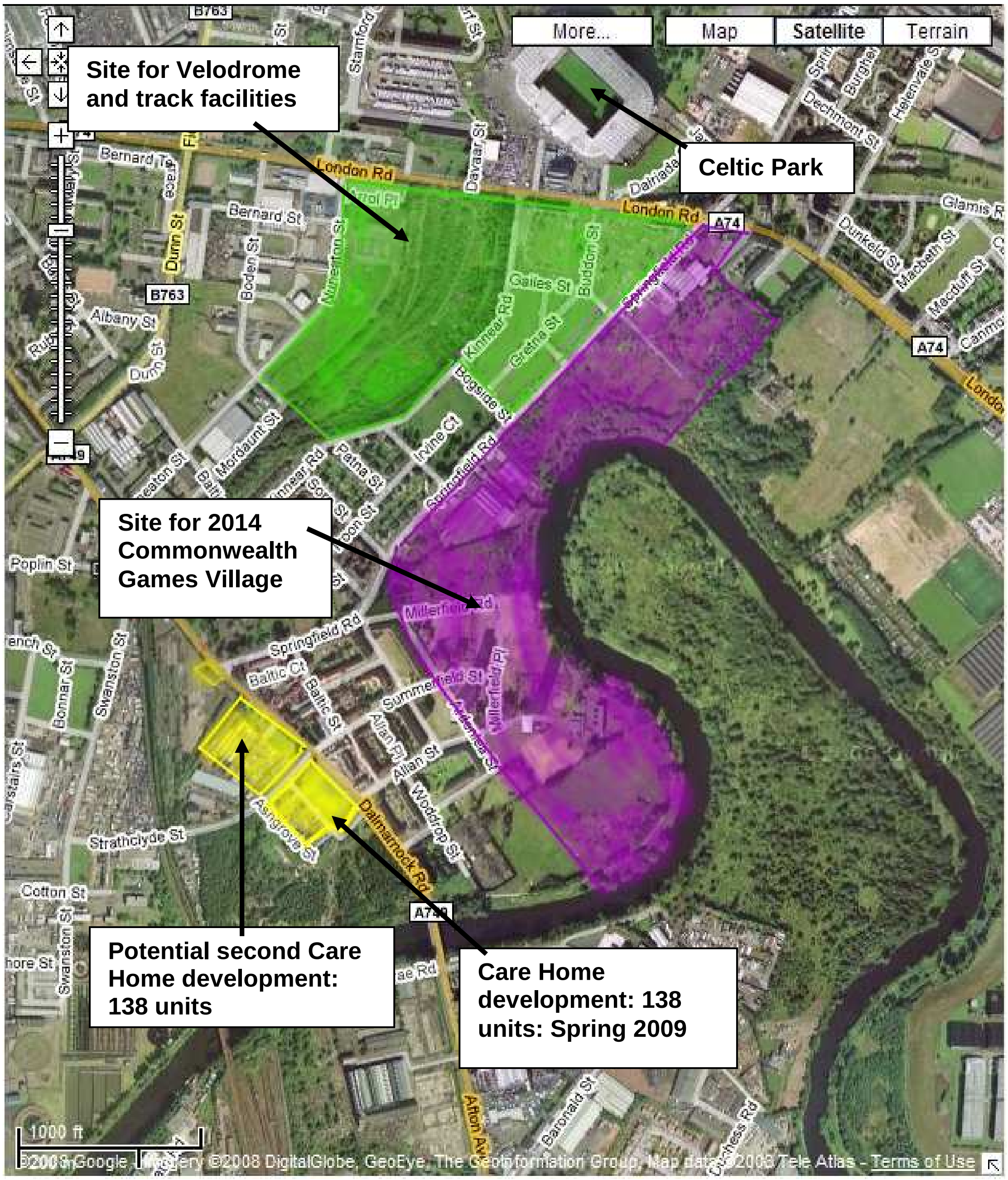

Figure 5: Commonwealth Games Village and Care Home Development Map [28]

The second development can be seen as the purple shaded region in figure 5. This purple region covers the boundary for the Commonwealth Games Village including space for the 600 sustainable homes to house the athletes and officials for the duration of the games. Post-games it is expected the village will be turned into a neighbourhood and further housing units built.

To understand the design of the Commonwealth Games Village Figures 6 and 7 illustrate the potential development from and 3-D and aerial view respectively:

Figure 6: 3-D view of artists' impression of Commonwealth Games Village [28]

Figure 7: Aerial view of artists' impression of Commonwealth Games Village [28]

4 Environmental and Economic Study

In the previous section, the main components of DHC systems were discussed. In this section, the potential environmental benefits and economical implications of DHC systems are identified considering all environmental impacts.

4.1 Environmental Impacts Associated with Heating and Cooling Systems

With the exception of solar or electric heating and cooling systems that utilise only power produced by hydro or thermonuclear power generation facilities, the thermal energy required for heating and cooling purposes is produced by systems that require the combustion of fossil fuels. The production process creates products of combustion which are emitted to the atmosphere at elevated levels via stacks or towers. Emissions associated with thermal energy production, include among many others, oxides of sulphur, nitrogen, and carbon. Such emissions contribute both locally and globally and result in negative environmental impacts such as global warming, acid rain and poor air quality. In addition, chilled or cooling water production systems use electrically driven compressor chillers that require refrigerants such as chlorofluorocarbons (CFC's). These chemicals are thought to be the primary contributor to ozone layer depletion in the upper atmosphere. Recent technological advances have removed certain CFC's, so it is therefore important to research the required refrigerant in each case to reduce any harmful emissions.

With heating and/or cooling systems, some electric power is required to operate fans, pumps, cooling system compressors, and in some cases, heating coils. Such power is typically generated by hydro, nuclear, fossil fuel fired power generating plants, or a combination of all three. In the case of nuclear power plants, disposal of radioactive wastes and releases of radioactive material into the air and water systems during process occurrences are a major source of concern. Even hydro-electric power stations are being identified as possible sources or pollution problems, and environmental impacts, that result from the loss of agricultural, wildlife habitat, forest lands, flooding and impacts that results from the build up of the concentration of mercury in the environment upstream of hydro dams. Thermal power generation plants also discharge large quantities of waste heat to the environment from the steam turbine condensing system area of the plant.

Taking into account all of these impacts, it is apparent that heating and cooling systems that minimise the quantity of fuel and electrical power required to meet the users needs will result in reduce negative impacts on the environment. The combustion process and refrigerant based thermal energy systems represent the most prevalent systems used throughout the industrial world from household level up to major power production plants. While DHC plants are not immune to the production of pollution causing emissions, the nature of operation of these plants is such that significant reductions in the pollutants emitted can be established, compared with other widely used alternatives.

4.2 Potential Environmental Benefits Associated with DHC Systems

Potential environmental benefits are derived, partly due to the difference between district and conventional systems and partly due to stand-alone features of DHC systems.

4.2.1 Partial Load Efficiency

In general, DHC plants operate at higher efficiencies under partial thermal load conditions, compared to conventional systems. Conventional systems typically employ only one boiler and one refrigeration unit. While such units must be rated for peak seasonal and hourly loads, they actually operate most of the time at much lower partial loads. Operation at these lower loads can, depending on the class of equipment used, result in much lower operating efficiencies. District systems on the other hand, with multiple units can optimise over plant efficiency by selectively operating fewer units at or near maximum efficiency during partial load conditions. DHC systems that compromise several different types of thermal energy generation plants optimise plant and system efficiency by utilising the thermal energy sources with the highest energy conversion efficiencies for base and other partial load conditions. The sources with the poorer conversion efficiencies can then be used to meet peak loads. In the end, improved efficiency means use of less fuel for the same amount of energy produced which in turn results in the conservation of fossil fuels, reduced emissions, improved air quality, and reduced use of refrigerant in cooling applications.

4.2.2 DHC Integration with Power Generation

District systems are well suited to combine with electric power production facilities forming a CHP or cogeneration plant. The mixture of these two energy production schemes results in a substantial improvement in overall energy conversion efficiency since the district heating schemes can effectively utilise the otherwise wasted heat associated with the electric power production process. A district system meeting much or all of its load requirements with wasted heat from power generation facilities will have a positive environmental impact as fuel consumption within the community is reduced considerably. Conservation of fossil fuels and a reduction of combustion related emissions are resultant direct benefits of a DHC system.

4.2.3 Biomass Combustion

Biomass combustion is considered by many as a means of zero production of CO2 when combined with reforestation. The underlying principle is that by burning biomass, CO is released but with reforestation the CO is absorbed in the new growth provided rates of each activity are balanced.

4.2.4 Limited Number of Emission Sources

The centralised nature of DHC energy production plants results in a reduced number of emission sources in a community. This introduces the potential for several direct benefits:

- Large facilities are much more likely to incorporate sophisticated state of the art pollution controls technologies that individual buildings, particularly; households, commercial establishments, and small industrial complexes. TO incorporate such equipment on a small scale basis, due to the general lack of low cost effective pollution control equipment, is normally impractical. In comparison, therefore, large scale district systems, which in many cases have included best available control technology, are capable of significantly reducing the emissions to the environment on an equivalent energy production basis.
- The exhaust towers, characteristic of large energy production facilities, are relatively high and therefore the exhaust gases that are discharged from the tower

are well mixed with large volumes of the ambient are before the pollutants can reach the surrounding population, structures or plant life. The resultant improved dispersion introduces the benefit of minimising low level pollutant concentrations compared to the numerous lower towers of a non-district system. While local air quality can benefit significantly from DHC, the long range pollutant transport is subject of continuing debate. While high stacks are an effective means of discharging pollutants, they do permit the pollutants to migrate long distances. However, the problems associated with these dispersed pollutants are still related more to the total quantity of pollutants that are emitted into the atmosphere.

4.2.5 Superior Operating and Maintenance

Large centralised plants, such as DHC facilities, typically use better operating and maintenance practices than small individual building systems. Large facilities have trained staff, as well as sophisticated computerised monitoring equipment available to continuously monitor system operations ensuring performance specifications are being met on a long-term basis. When such specifications are not met, prompt maintenance can be administered, or operating changes or upgrades introduced, as necessary. Regularly scheduled maintenance is a normal function of facilities of this scale.

With large DHC systems, the incentives to maintain a high level of operability, with little downtime or drop in operating efficiency, are economically based and are often critical to maintain the overall viability of a plant. Individual building systems can not always afford complicated and continuous monitoring equipment, or to upgrade existing obsolete equipment, or employ permanent maintenance staff. The result is many such operations deteriorate because of poor maintenance, with operating efficiencies subsequently dropping well below optimum levels. A larger, well maintained, high efficiency facility translates directly to reduced fuel consumption which, in turn, results in conservation of fossil fuels and reduced emissions. Higher operating efficiency of the combustion process, where parameters such as temperature, combustion air and fuel input levels, residence time, etc. are closely monitored, also impacts emission production in that the concentration of certain pollutants produced, particularly CO_2 and NO_x, is reduced.

4.2.6 Technical Upgrades

Centralised DHC facilities permit developing thermal energy production and emission reduction technologies to be adopted at the earliest possible date. Such technology improvements usually have significant positive environmental benefits. Examples of such developments include:

- Retrofitting boilers with low NO_x burners, where flue gas recirculation or selective catalytic reduction techniques to reduce NO_x levels.
- Flue gas heat recovery scrubber systems to minimise SO_2 emissions, while at the same time improving the thermal efficiency of the system, further reducing emissions.
- Plume abatement techniques to reduce the vapour plumes associated with cooling towers.
- Implementation of CFC refrigerant substitutes with lower or no ozone depletion potential in chillers.

With DHC systems, new technologies can be implemented at much reduced cost and much more practically, even when compared to the same emission reduction effort being achieved at an equivalent number of conventional facilities.

4.2.7 Higher Design Efficiencies

In many cases, the relatively high capacity equipment associated with DHC facilities inherently operated at higher efficiencies than that of similar lower capacity units. This is particularly true of large centrifugal refrigerators which have coefficients of performance (COP’s) of more than 5.0. This compares with the smaller units, such as those installed in individual buildings, which have COP’s in the range of 3.0 to 4.0. The COP is the ratio of the refrigerating effect or cooling capability of the unit to the power input required to achieve this capability. COP provides a means of comparing the performance of various refrigeration units.

4.2.8 Other Environmental Benefits

There are many indirect environmental benefits of DHC plants which may not have as much impact as the benefits described previously but are worth stating:

- The noise associated the operation of heating and cooling equipment is concentrated at a single source with a centralised facility. Sophisticated noise control measures to minimise noise impacts on the surrounding neighbourhood can be applied more practically and cost effectively at a central facility than at numerous individual buildings
- With the concentration of fuel sources oil storage at central facilities, the potential risks associated with leakage are reduced since centralisation implies elimination of multiple smaller oil storage containers which will deteriorate with time and lack of supervisory care. Storage containers at central facilities are more likely to be regularly inspected for leaks or deterioration
- For liquid and solid fuels associated with DHC systems, the reductions in fuel use identified previously will indirectly reduce vehicle emissions associated with fuel shipment as the requirement for delivery such fuels will also be reduced.
- Where local air quality is a significant problem, the type of fuel burned can be upgraded in many DHC applications, with significant environmental benefits. A plant burning coal or even relatively clean burning fuel oil can reduce its emissions simply by converting the operation to natural gas firing. Without DHC alternative fuel options are impractical in most communities.
- Considering cooling systems in a DHC system, the conversion from CFC’s is simplified and a practical option. The use of cooling water from local rivers or lakes with cooling towers is a realistic alternative with DHC systems.

The flexibility offered by DHC systems to pursue such environmentally beneficial alternatives is virtually non-existent with decentralised systems with their multitude of small units and owners

4.3 EU Directives Influencing DHC

Directives are used by the European Union as a method to harmonise the national legislation in its member countries.

‘Directives define the framework under which member states must implement EU decisions within national legislation. The EU commission prepares the directive and when the Council of Ministers has approved a new directive, the member states have 2 years to make the necessary changes in their national legislation. This is known as transposition or transposing the directive. The creation of the internal market within the European Union has resulted in a large number of directives and a number of these are relevant to the DHC and CHP sector.’ [26]

4.3.1 Current Directives

The Cogeneration (CHP) Directive 2004/8/EC [26] -

The purpose of this directive is to increase the efficiency and improve security of supply by creating a framework for promotion and development of high efficiency cogeneration of heat and power on useful heat demand and primary energy savings. The directive achieves this through:

- Establishment of harmonised efficiency criteria for cogeneration to include year of manufacture and fuel type
- Guarantee of origin of electricity from high efficiency cogeneration. This enables producers to demonstrate that electricity they sell is produced from high cogeneration.
- Requiring member states to establish potentials for high-efficiency cogeneration.
- Ensuring support schemes for cogeneration are based on useful heat demand and primary energy savings
- Addressing grid access and tariff irregularities for high efficiency cogeneration

Energy Performance of Buildings 2002/91/EC [26] –

The purpose of the directive is to promote the improvement of the energy performance of buildings within the EC taking into account outdoor climatic and local conditions as indoor climate requirements and cost-effectiveness. The directive achieves this through:

- Ensuring member states adopt a methodology at a national or regional level for calculating the energy performance of buildings (SBEM in the UK)
- Setting of energy performance requirements based on the above methodology.
- Requiring that new buildings above 1000m^2 be considered for the technical, environmental and economic feasibility of using alternative energy systems such as CHP, DH and/or Cooling, or decentralised renewable energy systems.
- Requires that major refurbishment of existing buildings above 1000m^2 meet minimum energy requirements where technically, functional and economically possible.
- Requiring the production of an energy performance certificate when a building is sold, constructed or rented.
- Requiring the inspection of boilers and Air-Conditioning systems on a regular basis

Procurement of Utilities 2004/17/EC [26] -
Coordinating the procurement procedures of entities operating in the water, energy, transport and postal services sector.

Procurement of Public Works, Supply and Services Contracts 2004/18/EC [26] -
Coordinating the procedures for the award of public works contracts, public supply contracts and public service contracts.

Emissions from Large Combustion Plants 2001/80/EC [26] -
The setting of limits for emissions of certain pollutants into the air from large (>50MW thermal input) combustion plants.

Incineration of Waste 2000/76/EC [26] -
The setting of limits from waste incineration and co-incineration plants.

4.3.2 Future Directives

Directive on Energy End Use Efficiency and Energy Services [26] -

The European Commission has issued a proposal for a directive on Energy End Use Efficiency and Energy Services. The directive aims to enhance the cost effective and efficient end use of energy by:

- Providing targets, mechanisms, incentives and frameworks to remove existing market barriers and imperfections to allow the efficient end use of energy.
- Developing a market for energy services and the delivery of energy efficiency programmes and measures to end users.

Key points in the directive include:

- The introduction of a mandatory target for the annual amount of energy to be saved in the public sector attributable to energy services, energy efficiency programmes and other energy efficiency measures.
- The removal of barriers to ensure that distributors and/or retailers selling electricity, gas, district heating and/or heating oil:
    - Promote energy efficiency
    - Refrain from measures that impede delivery of energy services
    - Provide information on end-use customers to enable proper design of energy efficiency programmes.

4.4 Sustainable Building Design

As new building regulations come in to effect and mandatory technical assessments are needed before a new or old building is passed fit for development, it is important to carry out a study into the impact of sustainable building design on DHC. Sustainable building design would appear to have a negative effect on DHC as the energy demand must be high for a scheme to be implemented, and by introducing sustainable housing, the demand would drop, forcing the network to expand, resulting in increased costs. However, this is not always the case. In order for a successful DHC system to be implemented, sustainable building factors are taking into account at very early planning stages. The network of a District Heating scheme, as discussed before, will always require a mix of different energy demands from various building types. Sustainable building design exists as the future of sustainable living, and because of this, the technology of a DHC network will always look to advance according to market and housing trends. In April 2007 the Code for Sustainable Homes replaced Ecohomes for the assessment of new housing in the UK. The code is an environmental assessment method for new home and contains mandatory performance levels in 7 key areas including [26]:

- Energy Efficiency and CO2 emissions
- Water efficiency
- Surface water management
- Household waste management
- Pollution
- Use of materials
- Ecology

The scoring system for the code has six levels. Each level is made up of appropriate mandatory minimum standards together the appropriate number of flexible standards. Code assessments are carried out in two phases:

- An initial assessment and interim certification at the design stage – based on drawings, specifications and commitments
- A Final assessment and certification after construction – based on a design stage review and confirmation of compliance including site records and visual inspection

The Building Research Establishment Environmental Assessment Method (BREEAM) is the UK’s leading resource for sustainable building design and assesses each of the 7 key areas [26]:

Energy Issues – CO_2 emissions, low energy lights, metering, ‘A’ rated goods, energy management.
Health – Heating, lighting, air quality, noise.
Management – Best practise commissioning, policies implemented at top level management, effective used and maintained operating manuals, operational environmental management system.

Transport – The location of development, parking and cycling facilities, access to public transport and local amenities, implementation of travel plans.

Water – Water efficient appliances, water metering, leak detection systems, water butts.

Materials and Waste – Materials with a low embodied energy, buildings where part or all of an existing building is re-used, responsibly resourced materials, use of recycled materials

Land use and ecology – Brownfield or rededicating a contaminated site, ecological enhancements, protecting or endangering ecological features, building footprint.

Pollution – Refrigerants and insulation with a low global warming potential, space heating with low NOx emissions, building in a low flood risk area and attenuation of surface water run off, good practice in terms of oil interceptors/filtration in car parks and other risk areas.

From the list above, it has been shown that developing home to a certain standard goes beyond the four walls of a house and takes into account many other factors. It is important to assess these factors in order to achieve a high standard of complete sustainability.

4.5 Building Energy Design Modelling Packages

The most widely adopted procedure for analysing energy in building in the UK is using Standard Assessment Procedure (SAP). SAP 2005 [26] is adopted by government as part of the UK national methodology for calculation of the energy performance of buildings. It is used to demonstrate compliance with building regulations for dwelling (Section 6 [26] for Scotland) and to provide energy ratings for dwellings.

New and future regulations will make it compulsory for modelling packages to carry out energy assessments before a building is granting planning permission. This will aid in the development of new standards and more sustainable buildings.

5 System Description and Modelling

This section of the project will describe the construction of four demand profiles for four separate simulations. The constructed demand profiles are imported into a university developed modelling package, Merit. A description of Merit is given in the next section. Following on will be a section on half-hourly data; the basis of constructing a profile. Finally both model descriptions are examined and an explanation given about their form and structure.

5.1 Merit Programming

Merit is a University of Strathclyde developed programming tool, allowing the user to analyse the potential of certain technologies against various demand profiles taking into account local climates. Creating a demand profile requires the selection of location parameters, manufactures' specification of renewable technologies and weather data to simulate power production. At this point the input parameters can be altered so that the required output demonstrates maximum efficiency. Normally to do this the point at which the capacity of the required energy storage system becomes minimum while the capacity factor of the renewable system is at its maximum.

5.2 Half-hourly Energy Data

Electronic data electricity consumption measured every half hour is available from energy suppliers for most significant buildings/sites. This type of high accuracy data is also available on a real-time basis from an automatic meter reading system source, allowing real-time analysis with automatic exception reporting.

A spreadsheet is an ideal tool for analysing half-hourly suppliers' data and can be programmed to produce weekly plots. By analysing these spreadsheets on a week to week basis; identifying changes, trends, differences and similarities is possible. Immediate analysis of half-hourly data should include:

Base loads – high base loads at night would indicate plant being left on or a fault. Base loads should be viewed as absolute values (kW) as a proportion of daytime consumption.

Night/Weekend differences – significant differences between weekday nights and weekend day/night consumption could indicate plant being left on unnecessary during weekday nights.

Peak operational hours – excessive consumption during hours leading up to full daytime consumption and falling away from it e.g. 06:00 – 09:00 and 17:00 – 20:00.

Profile shape: unusual changes from day-to-day and week-to-week may indicate poor control. Changes with season and switching major plant on should be apparent.

Spikes, peaks and troughs – unusual step changes and spikes in consumption may indicate erratic plant control.

Occupancy – above all, compare the profiles to actual occupancy patterns of the building.

5.3 Model Description: Residential Care Home

The following information has been sourced on the Care Home Development:

- Each development consisting of 137 rooms
- 4 individual dwellings per development
- 4 dwellings; A1, A2, and B having 5 floors and C with 6 floors
- Buildings will be built to a sustainable homes standard (BREEAM or equivalent)
- Total floor area of approximately 8000 sq m

Using sustainable buildings standards, assumptions can be made regarding typical electricity and heating loads. Energy standards are available from the Chartered Institution of Building Services Engineers (CIBSE), specifically, section 20 of the CIBSE Guide F on Energy Efficiency. For Care Homes, CIBSE proposes the following data is used:

Energy Type	**Typical Practise Annual Demand (kWh/m^2)**	**Good Practise Annual Demand (kWh/m^2)**
Thermal	**492**	**390**
Electricity	**75**	**59**

Table 5: CIBSE Care Home Energy Benchmarks [23]

For the purpose of analysing a new sustainable care home, the good practise data in Table 5 will be used for the model.

Figure 8: Care Home development plans

A development drawing of the Care home is shown above in figure 8. The four proposed buildings A1, A2, B, and C have been identified. Buildings A1 and A2 are identical, with B of similar style but different internal dimensions. Building C is a much larger building catering for larger rooms and facilities. The exact dimensions of each building are shown in table 6:

Building	Number of Rooms	Total Floor area (m2)
A1	27	2101
A2	27	2101
B	27	1908
C	56	3716
Total	137	7726

Table 6: Care Home Building Statistics

5.3.1 Scenario 1

The first scenario consists of the initial Care home that has been granted permission for construction. The static load profile has been developed on a excel spreadsheet based on attributes previously stated in the model description and is shown below in figure 9:

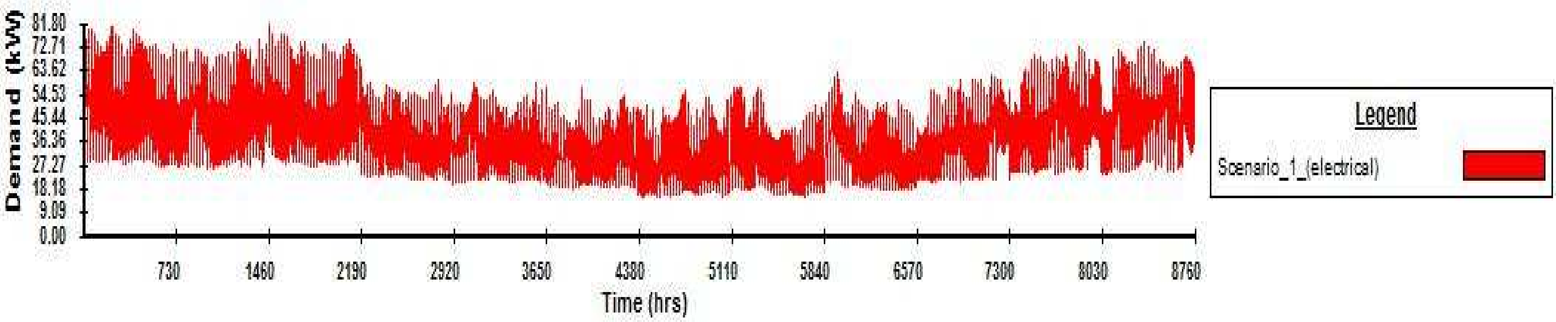

Figure 9: Scenario 1 Electrical Demand Profile

Figure 9 and 10 are based on the ‘Good Practise’ annual demand and a static load profile attributable to a care home in home Glasgow. Below in Figure 10 is the thermal load profile for the Care Home.

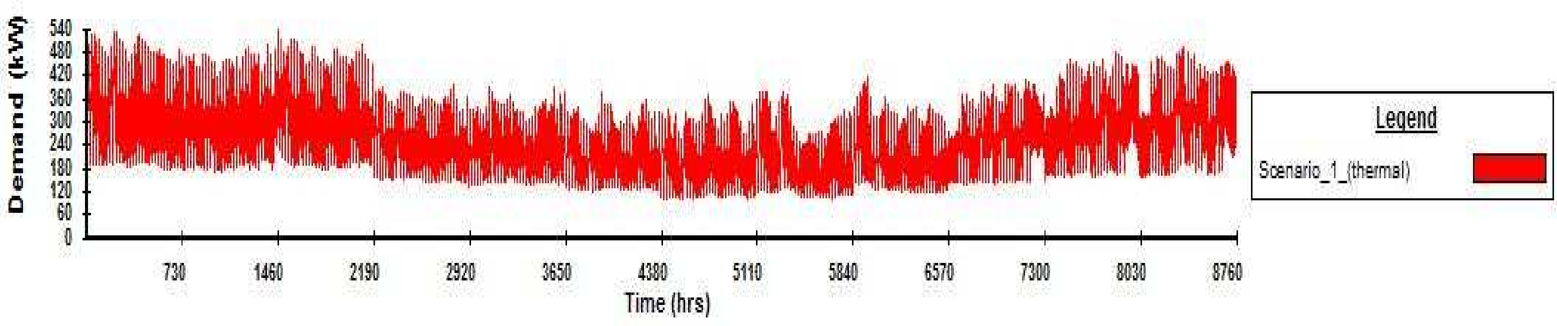

Figure 10: Scenario 1 Thermal Demand Profile

After using the Merit to import the model, the following simulations were carried out:

- CHP sizing to electrical base load
- Integrating renewable technologies and storage

5.3.2 Scenario 2

The second scenario includes the second Case Home development, identical to the Care Home in Scenario 1. Below in Figure 11 is the electrical demand profile for the second scenario.

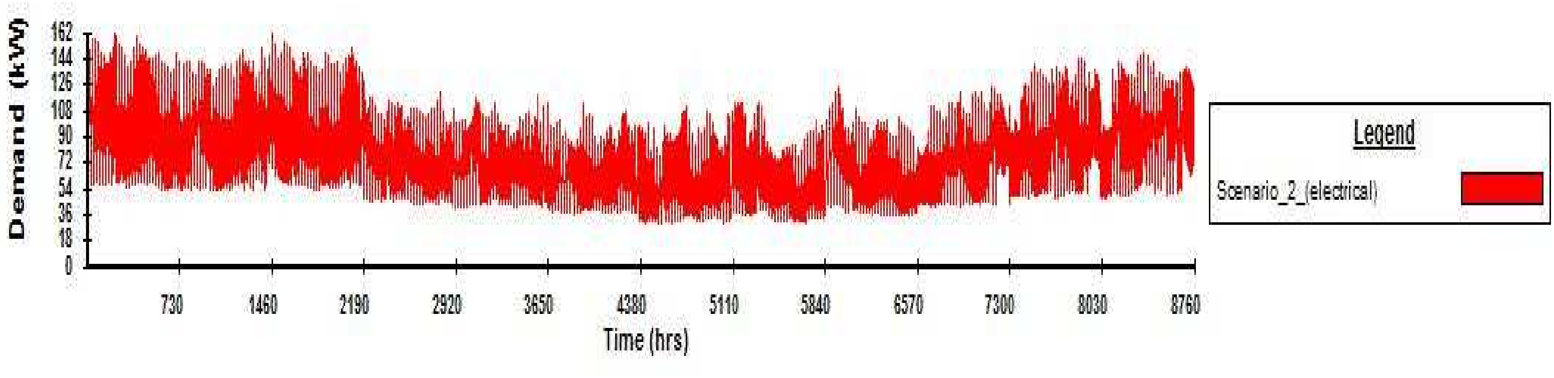

Figure 11: Scenario 2 Thermal Electrical Profile

Figure 12 illustrates the thermal demand profile for the second scenario and the following simulations were completed on Merit:

- CHP sizing to electrical base load
- Multiple CHP simulation
- Integrating renewable technologies and storage

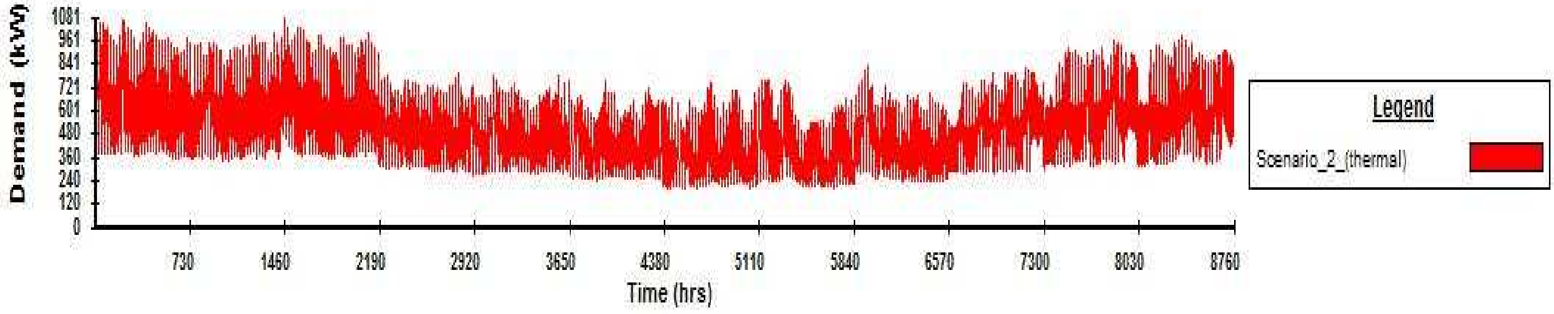

Figure 12: Scenario 2 Thermal Demand Profile

These simulations were aimed at determining if a district scheme would benefit this type of building, and any subsequent developments. The next section will describe the model description of the Commonwealth Games Village and discuss the development of the model, and scenario 3 and 4.

5.4 *Model Description: Commonwealth Games Village*

With the Commonwealth Games coming to Glasgow in 2014, the second development consists of a Commonwealth Games Village that will begin construction in autumn 2010. Its main purpose is to house athletes and officials for the duration of the games. The development will be used only for a few weeks as a games village before being sold as residential homes. This development is part of a complete re-generation of the Dalmarnock site. Post games the residential zone will be refitted to become a fully integrated neighbourhood. Temporary training facilities used for the games will be removed and further residential buildings eventually built.

Therefore, as well as the two Care Home scenarios, two residential scenarios will be analysed with the intention of using DHC for the entire development. The following information is available for the Commonwealth Games Village development:

- Must provide accommodation for 6,500 athletes and officials within 300 residential units
- Space for a 100 new homes after the games
- Maximum of 2 athletes/officials per room
- Buildings do not rise above 4 storeys
- Housing types allowed
  - 4 storey 2-3 bedroom apartments
  - 2 storey 2-3 bedroom terrace houses
  - 2 storey 2-3 bedroom semi-detached houses
  - 3 storey 2-4 bedroom townhouses
  - 2 story 3-4 bedroom detached houses

This information will be used to generate a hypothetic model that will aid in the investigation into using DHC on a large-scale in Glasgow. Again using standards provided by CIBSE, table provides data on typical energy use in sustainable residential buildings.

Energy Type	Good Practise Annual Demand (kWh/m^2)
Thermal	**60**
Electricity	**40**

Table 7: CIBSE Residential Energy Benchmarks [23]

In order to set a demand profile using the data, a hypothetical situation was developed using an excel spreadsheet. As required in the brief, the Games Village must house around 6,500 people and consist of 300 units. A set of types of building types were listed and with these constraints the following configuration was found:

Building Type	Floor Area (per dwelling)	Number of Occupants (per dwelling)	Number of Buildings	Total Number of Athletes and Officials	Total Floor Area (m2)
4 storey 3 bedroom Apartments	94	24	122	2928	11468
2 storey 3 bedroom Terrace Houses	100	12	20	240	2000
2 Storey 3 Bedroom Semi-detached Houses	100	12	18	216	1800
3 Storey 4 Bedroom Townhouses	120	24	122	2928	14640
2 Storey 3 bedroom Detached Houses	100	12	18	216	1800
Total			***300***	***6528***	***31708***

Table 8: Commonwealth Games Village Hypothetical Construction

Again using the residential data from CIBSE benchmarks and the configuration in Table 8 two demand profile scenarios 3 and 4 will be constructed:

- Scenario 3: Two week period of Commonwealth Games
- Scenario 4: Post Games Neighbourhood

5.4.1 Scenario 3

Figure 13 below illustrated the structure of the 3rd scenario. This scenario only takes into account the 1st model with only one care home, and the Commonwealth Games Village. As the Games village is only in operation as a Games village the load profile has been generated as a residential Zone. For the duration of the games it could be assumed the load profile would be of one similar to a local hotels load profile. Scenario 1, the Care Home, can be seen in figure 13 as the red load profile. The green load illustrates the Games Village profile, and finally the yellow profile illustrated the total demand consumption of each day throughout the year in kW.

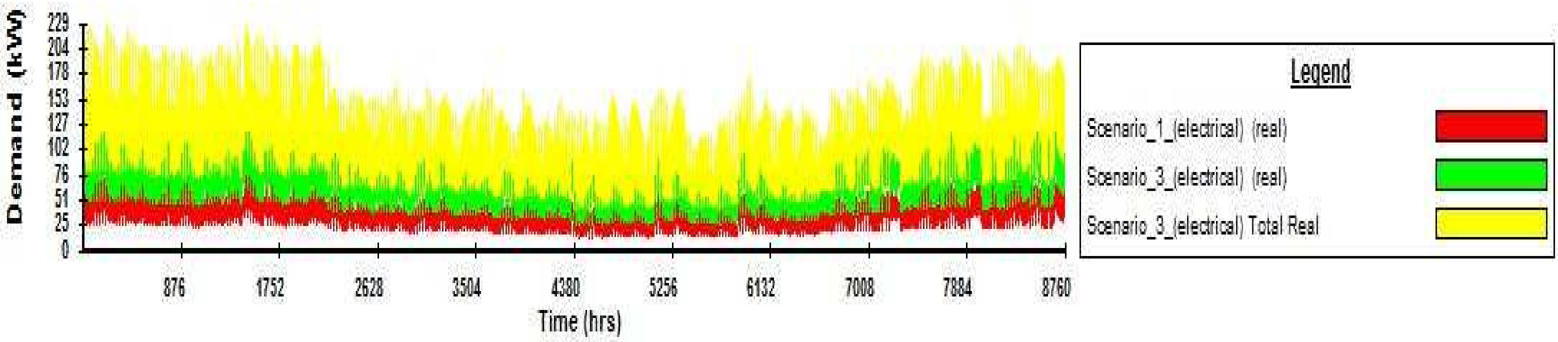

Figure 13: Scenario 3 Electrical Demand Profile

Figure 14 illustrates the thermal demand profile for the 3rd simulation. As discussed above the individual thermal load profiles are made up of the red and blue sections on the graph and the total demand thermal load profile is shown in brown.

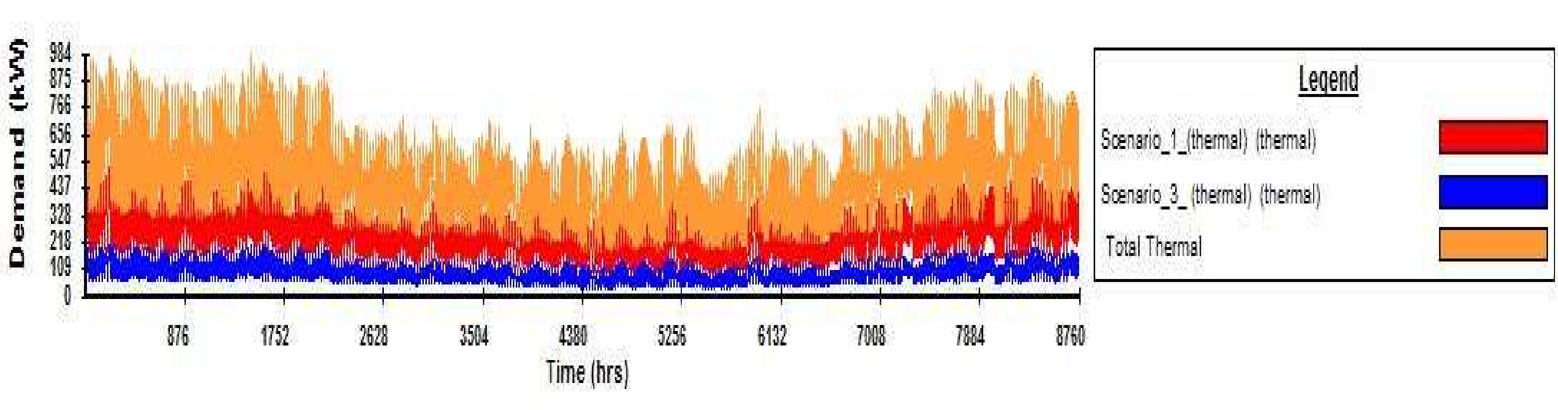

Figure 14: Scenario 4 Thermal Demand Profile

5.4.2 Scenario 4

The final scenario takes into account a post games development including the following attributes:

- 100 residential units, accommodation for 2000
- Same style of housing to the games village
- Homes built to same standard

Taking this into account a similar configuration to Table 8 was found with a hundred extra homes being used. Figures 15 and 16 illustrate the hypothetical electrical and thermal demand profiles:

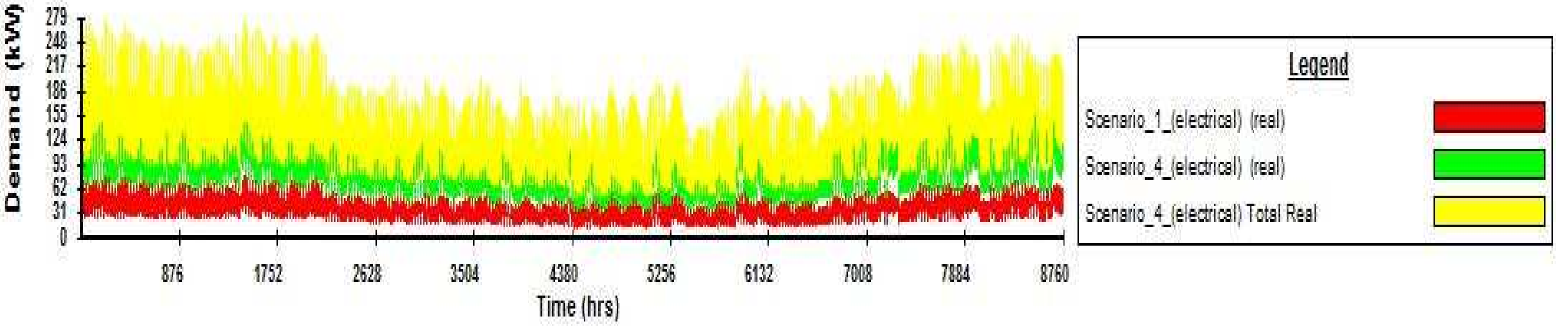

Figure 15: Scenario 4 Electrical Demand Profile

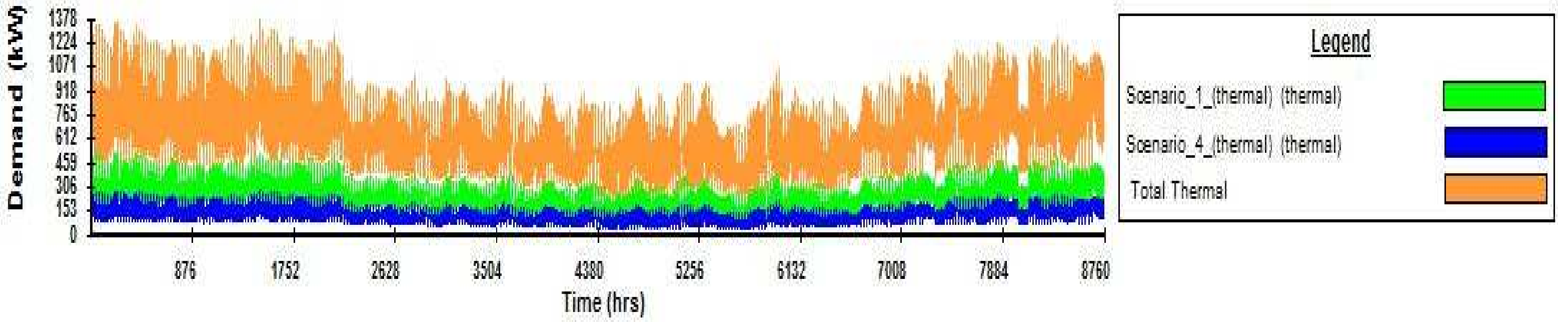

Figure 16: Scenario 4 Thermal Demand Profile

5.5 Model Description and Assumptions

As illustrated in each scenario section, the demand profile has been specified in each case, and therefore it remains to simulate these scenarios against different supply options. The nature of this project is to look at a district scheme with the development of CHP as the main energy resource, and other smaller integrated renewable technologies.

The next section will discuss the boundary conditions that have been set for each model and the matching section will explain the demand and supply simulation.

5.5.1 Boundary Conditions

For the simulations in Merit, a Glasgow climate data set has been selected. This data will increase the accuracy of the result taking into account local weather conditions. Figure 17 illustrates the climate data profile for Glasgow:

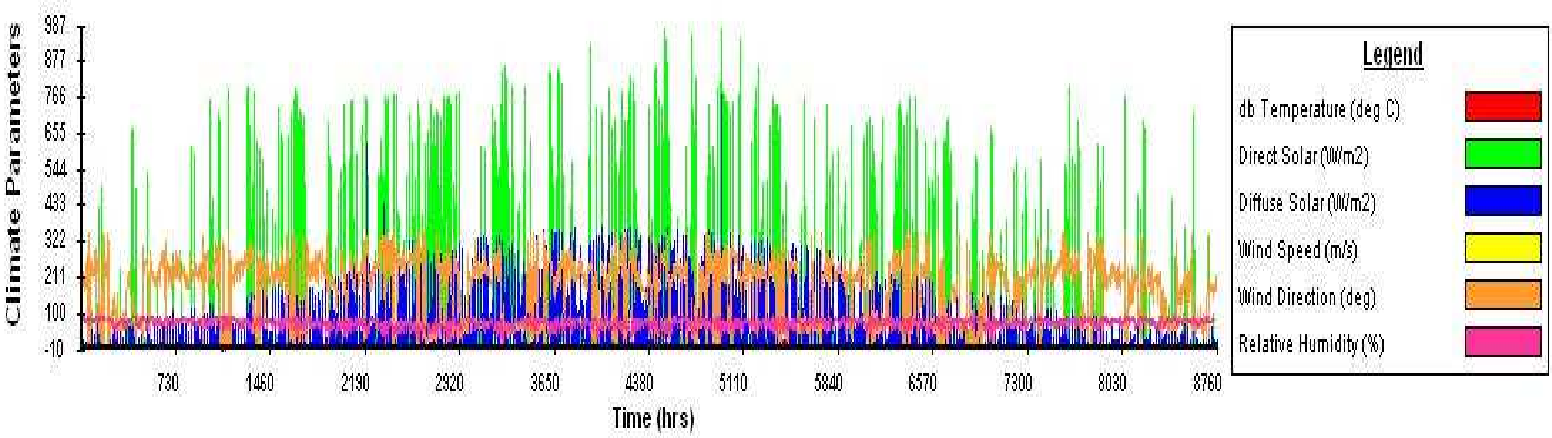

Figure 17: Glasgow Climate Data Profile

The climate data file includes the period of simulation, from 01/01/2003 till 31/12/2003. The climate file for Glasgow is part of the Merit database.

5.5.2 Matching

This part of the simulation simply involves matching the demand profile with several supply options. Matching allows different configurations of supply technologies to be simulated at the same time, providing the user with the ability to try many combinations resulting in a high percentage match. A major advantage is the ability to simulate realistic scenarios before the construction stage, and subsequently saving energy and money.

The best match outcome will receive following attributes

- the highest correlation factor
- the smallest inequality coefficient
- the highest level of energy production
- the highest efficiency

The results also indicate any surplus or deficit energy, which allows the user to modify other model characteristics that might improve the results.

5.6 *Integrated Renewable Technologies*

Due to programming restrictions, the only renewable technologies available to analyse on Merit were photovoltaic (PV) panels and wind turbines. The most commonly integrated to a district scheme are PV panels and discussed earlier in the thesis. Climate conditions in Glasgow are not the ideal circumstance for PV panels in this case, but as the entire development is new, it is worth investigation the integration of PV panels as part of the simulations.

Wind is a better resource in Glasgow due to high occurrence of strong winds in the area, but the problem wind energy is the lack of consistency with energy generation. This does not make it an ideal resource in a district scheme, but the commercial benefits of having a wind turbine as part of the Commonwealth Games Village are high, and for this reason, will include the addition of 1 of 2 wind turbines as part of the simulations.

Tables 9 and 10 give technical details of the Wind Turbines and PV Panels, respectively, used in the simulations:

Name	Proven 6kW
Turbine Hub Height (m)	11
Rated Power (kW)	2.5
Power Factor	0.8
Swept Area (m^2)	4.91
Reference Air Density (kg/m^3)	1.23

Table 9: Wind Turbine Technical Data

Name	110 Mono: Siemens S
Cell Type	Monocrystalline
Nominal Power (kW)	110
Panel Height (m)	1.32
Panel Width (m)	0.66
Tilt (degrees)	45
Orientation	South - East

Table 10: PV Panel Technical Data

The CHP units chosen for analysis in Merit consisted of two differently sized and operated machines; Capstone C60kW and Jenbacher 256kW. The following information was available on both machines, shown in Tables 11 and 12:

Name	Capstone C60
Operation Mode	Follow Electrical Demand
Engine Type	Synchronous
Rated Power (kW)	60
Minimum Power (kW)	5
Power Factor	0.98
Electrical Efficiency	0.92
Thermal Efficiency	0.95

Table 11: CHP Capstone C60 Technical Data

Name	Jenbacher
Operation Mode	Follow Electrical Demand
Engine Type	Synchronous
Rated Power (kW)	212 - 526
Minimum Power (kW)	30
Power Factor	0.98
Electrical Efficiency	0.92
Thermal Efficiency	0.95

Table 12: CHP Jenbacher Technical Data

Both CHP units were selected after carefully examining the electrical load profiles of each simulation. The Jenbacher unit allows different rated power outputs to be input into the program, giving various levels of thermal generation, resulting in the best possible solution for each model.

6 Results and Recommendations

The results displayed in the section will conclude the Merit analysis of the four scenarios, and the recommendations will summarise the findings of the researched based aspect of this report. It is the hope that this preliminary study and results will benefit future research, and a more in-depth analysis of DHC in Glasgow.

6.1 Results

The subsequent sub-sections will list the results for each simulation. Only a section of results have been selected that best explain the interaction between supply and demand in each model scenario.

6.1.1 Scenario 1

The first scenario, a Care Home development returned the following results after simulating the model in Merit. Tables 13 and 14 display the electrical and thermal demand simulations, while figure 18 illustrates one scenario graphically:

Scenario	Supply	Auxiliary	Total Demand	Total supply	Match
Scenario 1A	NULL	Capstone C60kW	349.49MWh	339.53MWh	95.28%
Scenario 1B	2 x Wind Turbine 6kW	Capstone C60kW	349.49MWh	311.42MWh	96.26%
Scenario 1C	2 x Wind Turbine 6kW + 300 PV	Capstone C60kW	349.49MWh	283.76MWh	96.70%
Energy Delivered	**Energy Surplus**	**Energy Deficit**	**Average Efficiency**	**Electricity Efficiency**	**CO2 Emissions**
339.53MWh	0.00kWh	9.75MWh	83.55%	23.19%	224.27g/kWh
342.72MWh	0.00kWh	6.60MWh	84.86%	22.58%	209.76g/kWh
344.00MWh	155.82kWh	5.34MWh	84.38%	21.67%	195.51g/kWh

Table 13: Scenario 1 Electrical Simulation Results

Scenario	Supply	Total Demand	Total Re-supply	Match	Energy Deficit
Scenario 1C	Capstone C60kW	2.31GWh	771.49MWh	48.37%	1.54GWh

Table 14: Scenario 1 Thermal Simulation Results

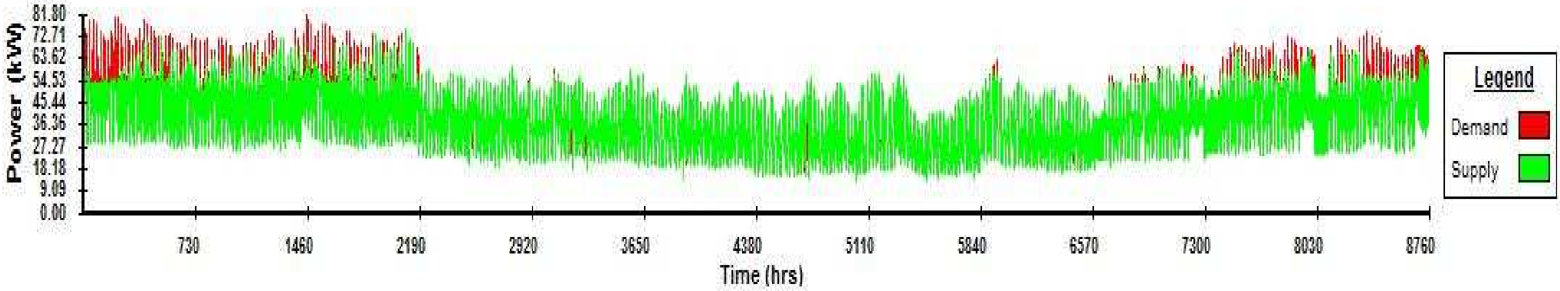

Figure 18: Scenario 1C Electrical Demand and Supply Profile Match

6.1.2 *Scenario 2*

The second scenario included a second identical Care Home development and returned the following results after simulating the model in Merit, shown in Tables 15 and 16. To compare the addition of a second care home the same settings for scenario 1 were kept before simulating a bigger CHP unit and multiple units. Figure 19 illustrates the first simulation, 2A:

Scenario	Supply	Auxiliary	Total Demand	Total supply	Match
Scenario 2A	2 x Wind Turbine 6kW + 300 PV	Capstone C60kW	698.98MWh	446.83MWh	78.02%
Scenario 2B	NULL	Capstone C60kW x 2	698.98MWh	921.35MWh	82.16%
Scenario 2C	2 x Wind Turbine 6kW + 300 PV	Capstone C60kW x 2	698.98MWh	893.65MWh	81.66%
Energy Delivered	**Energy Surplus**	**Energy Deficit**	**Average Efficiency**	**Electricity Efficiency**	**CO2 Emissions**
507.23MWh	0.00kWh	190.84MWh	78.80%	24.74%	143.48g/kWh
679.06MWh	238.86MWh	17.65MWh	145.59%	58.96%	157.31g/kWh
685.01MWh	266.24kWh	12.23MWh	141.31%	62.80%	159.05g/kWh

Table 15: Scenario 1 Electrical Simulation Results

Scenario	Supply	Total Demand	Total Re-supply	Match	Energy Deficit
Scenario 2C	Capstone C60kW x 2	4.62GWh	1.93GWh	55.24%	2.69GWh

Table 16: Scenario 1 Thermal Simulation Results

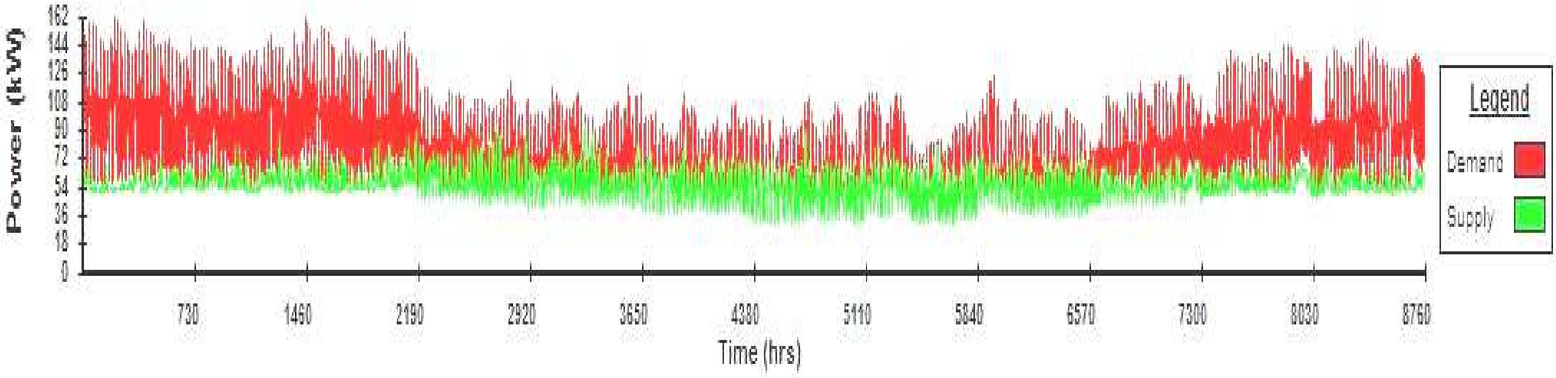

Figure 19: Scenario 2A Electrical Demand and Supply Profile Match

6.1.3 Scenario 3

Adding the Commonwealth Games village in the third scenario returned the following results shown below in tables 17 and 18. Figure 20 shown on the next page is an example of using CHP together with PV and Wind technology as a district scheme:

Scenario	Supply	Auxiliary	Total Demand	Total supply	Match
Scenario 3A	2 x Wind Turbine 6kW + 600 PV	Capstone C60kW x 2	981.61MWh	929.99MWh	85.19%
Scenario 3B	NULL	Jenbacher 212kW	981.61MWh	974.86MWh	98.20%
Scenario 3C	2 x Wind Turbine 6kW + 600 PV	Capstone C60kW x 2	981.61MWh	887.26MWh	98.51%
Energy Delivered	**Energy Surplus**	**Energy Deficit**	**Average Efficiency**	**Electricity Efficiency**	**CO2 Emissions**
875.26MWh	0.00kWh	138.64MWh	150.42%	54.59%	107.81g/kWh
974.75MWh	0.01kWh	6.55MWh	33.32%	58.96%	541.11g/kWh
976.69MWh	3.47kWh	4.68MWh	33.57%	62.80%	504.13g/kWh

Table 17: Scenario 3 Electrical Simulation Results

Scenario	Supply	Total Demand	Total Re-supply	Match	Energy Deficit
Scenario 3A	Capstone C60kW x 2	3.26GWh	1.97GWh	69.45%	2.69GWh
Scenario 3C	Jenbacher 212kW	3.26GWh	2.13GWh	75.24%	2.69GWh

Table 18: Scenario 3 Thermal Simulation Results

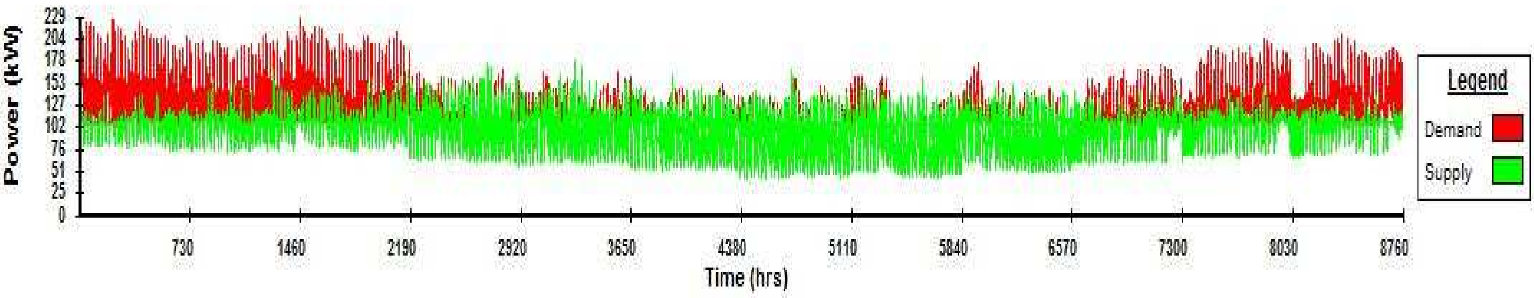

Figure 20: Scenario 3A Electrical Demand and Supply Profile Match

6.1.4 Scenario 4

Scenario 4 is the final completed scheme including; one care home, the commonwealth games village as a regular neighbourhood, and a post games housing development. Tables 19 and 20 show the results from each simulation and figure 21 illustrates the demand profile against one CHP unit sized to the base load.

Scenario	Supply	Auxiliary	Total Demand	Total supply	Match
Scenario 4A	2 x Wind Turbine 6kW + 600 PV	Jenbacher 212kW + Capstone C60kW x 1	1.19GWh	1.17GWh	97.77%
Scenario 4B	2 x Wind Turbine 6kW + 600 PV	Jenbacher 212kW	1.19GWh	1.07MWh	95.66%
Scenario 4C	2 x Wind Turbine 6kW + 600 PV	Jenbacher 160kW + Capstone C60kW x 1	1.19GWh	1.07GWh	90.04%
Energy Delivered	**Energy Surplus**	**Energy Deficit**	**Average Efficiency**	**Electricity Efficiency**	**CO2 Emissions**
1.17GWh	0.00kWh	17.66MWh	30.58%	8.16%	338.30g/kWh
1.16GWh	0.01kWh	28.99MWh	32.58%	10.04%	476.63g/kWh
1.07GWh	0.01kWh	120.60MWh	50.07%	20.67%	308.98g/kWh

Table 19: Scenario 4 Electrical Simulation Results

Scenario	Supply	Total Demand	Total Re-supply	Match	Energy Deficit
Scenario 4C	Jenbacher 106kW + Capstone C60kW x 1	3.57GWh	1.91GWh	67.58%	1.66GWh

Table 20: Scenario 4 Thermal Simulation Results

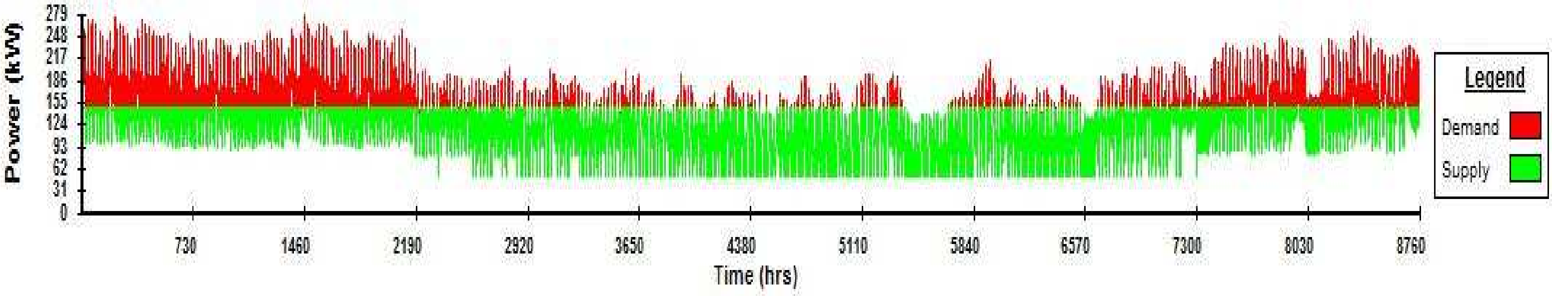

Figure 21: Scenario 4C Electrical Profile Match – Base Demand Only

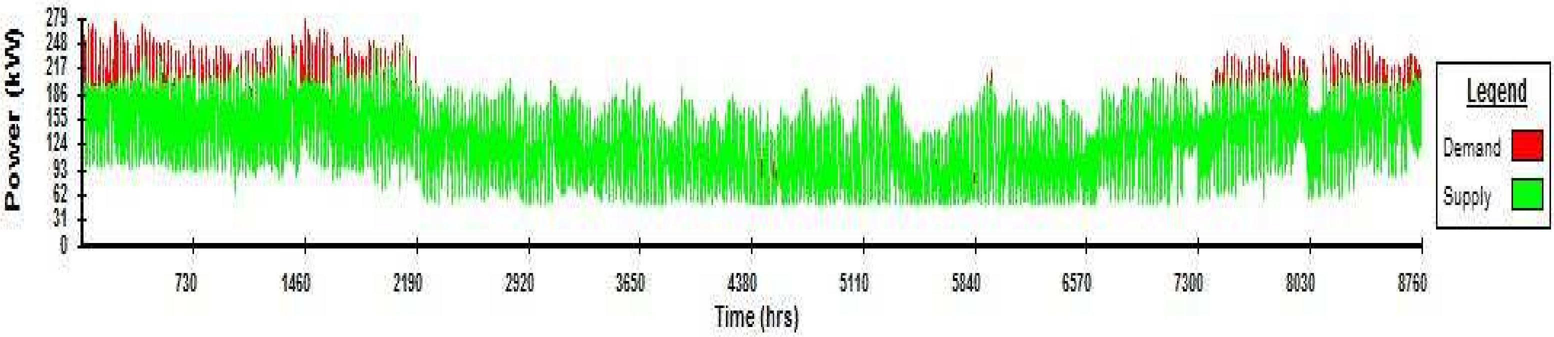

Figure 22: Scenario 4C Electrical Demand and Supply Profile Match

6.2 *Results Discussion*

The main purpose of the simulations is to understand the potential for CHP on a large scale providing electricity and heat to a number of customers. The section will discuss the results of each scenario and conclude any lesson learnt.

Scenario 1 matched a demand profile from a new sustainable care home against 3 possible supply options. The results showed a good match between the electrical demand profile and the CHP supply profile, with each simulation returning a match of over 90%, and an average efficiency of over 80%. The electrical efficiency is on the low side, but would be improved if some sort of demand side management technology is implemented. The thermal demand profile only returned a match of 48%; this is due to the large heating requirement of a residential care home. In the case of sizing the CHP for this development, while the electrical demand could be met by the CHP and renewable technologies, a secondary CHP or conventional system would need to be set up to meet the total requirement of the building. Even by increasing the CHP unit to increase the heat to power ratio produced similar results; a shortage of thermal load.

The second scenario returned similar results. By doubling the demand profile, the increase in difference between the peak demand and base load meant it would be harder to match one CHP unit to the entire electrical demand profile and still maintain the same level of efficiency. The addition of a second CHP unit, and other renewable technologies increased the match results, from 78% up to 82%, and increased the thermal match result in scenario 1 up to 55%. Again the results illustrate an example of an unbalanced district scheme.

In the third scenario the hypothetical electrical thermal demand model for the Commonwealth Games village was added to the first care home development for simulation. The addition of the village reduces the thermal to electrical demand ratio, making CHP a viable option. Also by having, generally, a greater demand, larger and multiple CHP units could be modelled, increasing the heat to power ratio for the scheme. The results show again a high match percentage for each electrical demand simulation. The increased capacity of the CHP and the use of multiple units results in a higher percentage match shown in table 18. The reduction in efficiency of the systems should be noted due to the high peaks and troughs of the system. With no demand side management the CHP engine will be running during periods of low energy demand, reducing the efficiency of the entire system.

The last model demonstrates the final stage development of the post games village and care home. Results indicate a similar pattern to the third model with high match percentages for both electrical and thermal demand profiles, but a low efficiency. Figure 21 illustrates the base demand met by one CHP unit, and figure 22 illustrates 2 machines sized for the base load and peak demand loads with renewable generation added to the model in the form of PV panels and wind turbines. This model demonstrates the future potential for this type of system in Glasgow and emphasises the importance of matching supply and demand. The results are by no means an accurate technical analysis as there are other sources of energy that could not be simulated, and will be discussed in section 6.2.1, but provides a preliminary feasibility study on this particular development.

6.2.1 Further Investigation Discussion

As discussed in the previous section, some kind on demand side management or storage capacity would improve the efficiency of the district scheme. The addition of the village improved the system practicality and demonstrated the potential of this kind of design. Further investigation into supplying heat and electricity to temporary games buildings including; restaurants, shops, offices, training facilities would be beneficial to the research of this scheme, and by adding additional load profiles, a smoother demand profile could be found, and subsequently, this would improve the efficiency of the model.

Due to data constraints a cooling model could not be developed, but the additional of a cooling energy profile would increase the demand during the summer months, undoubtedly reducing the difference between the base and peak loads, therefore again increasing the efficiency of the system.

6.3 Recommendations

The set of preliminary recommendations have been split into seven sub-sections due to the different aspects of DHC. Although the technology has been around for a while it is hoped that the recommendations provide additional information on the technology and key elements of that would be required for any feasibility study:

- Technical Design Guidance
- Project Checklist
- CHP Checklist
- Financing
- Load Profiling
- Future Proofing
- Further Research

6.3.1 Technical Design Guidance

The design of a heat network is critical, as it represents a significant capital investment and incurs ongoing operational costs. The type of buildings that are proposed for connection to the heat network and the specifications for the scheme therefore require attention.

The cost of installing the heat network depends on four factors:

- The design operating temperature and pressure
- The complexity of services
- The length of the network
- The peak heat demand

The network can be split into three levels

- The branches and connections to supply
- The distribution heat network
- The transmission heat network

As an example, in Denmark, district heating systems are so large that there is often a transmission system with high temperature and high pressure, transporting the heat to heat exchanger stations for distribution at low temperature and pressure. For most proposed schemes in the UK, it is unlikely that there will be a requirement a transmission heat network as the area for the scheme generally is small and the heat is supplied from a local source. Clusters of small district heating schemes can be connected together and supplied by a larger transmission network from a single point. Anchor loads such as public sector and community buildings and campuses can also form the basis for schemes. This is how many of the Danish large schemes developed over time.

6.3.2 Project Checklist

The project checklist provides a detailed list of the key elements that should be considered before venturing into any project:

Consumer type consideration:

- Public sector housing
- Public sector non-housing
- Private sector housing
- Private sector non-housing
- Future third party connections

Scheme Type:

- District Heating
- District Cooling
- CHP – Power to grid
- CHP – Power sold over private network
- Boilers only – provision for future CHP

Construction Scope:

- Energy centre
- Buried heating pipe-work
- Buried cooling pipe-work
- Electrical distribution
- Internal distribution systems
- Consumer interface units
- Heat emitters

Scheme distribution network:

- Energy centre
- Buried heating pipe-work
- Buried cooling pipe-work
- Electrical distribution
- Internal distribution systems
- Consumer interface units
- Heat emitters
- Existing boilers/chillers and other plant at each consumer

Billing and Metering:

- Consumers charges based on consumption metered at boiler house
- Consumers charges based on consumption metered at dwelling / consumer
- Consumers charges fixed
- Credit risk for non payment

Future Third Party Buildings:

- Future third party included in agreement
- Profit share from third party connections

6.3.3 CHP Checklist

CHP is considered to a major component of a DHC scheme and this checklist has been set up to consider its feasibility in a new system:

Find the annual heat and power requirement - CHP is ideal for buildings heat and power together for more than 4000 hours a year.

Know the electrical load profile - It is important to understand the base load profile rather than the mean or peak. This will ensure that the system will run efficiently.

Know the heat demand in kW and degrees C - CHP configurations vary widely according to the amount of heat required and the temperature it is required at. Some engine manufactures will offer engines with much higher jacket heat recovery temperatures than others.

Know how much the current cost are for heat generation – By knowing the billing figures, a precise cost comparison demonstrating the potential savings to be made from each CHP system.

If in doubt, go small – A CHP that is too large for the application won't save, whereas a CHP that is too small, although slightly less that it otherwise would.

Understand lifecycle cost – The cheapest CHP solution identified during the procurement may not necessary be the cheapest to run over a period of time.

Track record – There are many existing CHP systems that under perform, so it is important to find a supplier with a good track record.

Purchase an operations and maintenance service contract – Buy an Operation and Maintenance contract at the same time as the installation; this will guarantee the systems performance.

Listen to the supplier – Understanding where money needs to be spent and where to economise to ensure a product that will perform and is cost effective. It is important to check specifications prepared by anyone who does not own, operate or manage CHP's

Renewable grants and funds – The viability of CHP can vary according to these payments. The internet is always a good source for this type of information.

6.3.4 Financing

Security and risk must be addressed in order to finance new infrastructure, regardless of whether it is a public or private sector project. This will impose specific requirements on a project. The key issues to be addressed are likely to include:

- Developer contribution – Avoided utility costs or a connection charge per property
- Developer agreement – Transfer of assets to an ESCO if they are installed by the developer
- Heat supply contracts – Public sector buildings will provide additional security and covenant strength
- Fuel supply contract – Index linked fuel prices based on a minimum 5 year contract and good covenant
- Insurance – CHP, boiler plant and heating network quality standards and warranties
- Due diligence – Quality of engineering and design specifications
- Property lease clauses – Preventing changes to heating systems by leaseholders / freeholders
- Revenue recovery – Contractual agreement with specialist metering / billing company
- Maintenance – Local agreement with oversight by M&E contractors

Public sector buildings can act as important anchor loads to provide security to finance providers. Security is usually geared to around 50% of the value of any loan facility, providing a debt: equity split of around 70:30. However, public sector heating connections could be used to secure a larger debt facility.

Energy Service Companies (ESCO) are private companies whose services can be used to deliver varying levels of input to district heat and power schemes and other types of energy service contracts. Typically these services include project design, capital finance, construction, management, fuel purchasing, billing, plant operation, maintenance, long-term replacement and risk management. ESCO's typically provide capital finance to projects on the basis of bankable long-term energy supply contracts with their customers.

6.3.5 Load Profiling

Residential load profiles for hot water tend to have pronounced morning and evening peaks. To maximise the benefits CHP would need to serve enough residents and blocks that it became viable to install a large thermal store (hot water tank) to meet demand at peak times. The thermal store would allow the CHP units(s) to run throughout the day, maximising electricity generation and charging up the store to meet peak demand.

A mix of uses alongside would help create daytime loads reducing the need for thermal storage and making CHP more viable. Uses such as larger public sector sites, commercial offices and hotels create a flatter more consistent load profile.

Heat generated by a CHP unit in summer can also be utilised to supply chilled water for cooling, delivering a further 5-10% saving in CO_2 emissions. Office buildings, hotels and hospitals are all likely to have substantial chilling loads, and associated electrical demand to run compression chillers. Heat can be used to drive absorption chillers.

Absorption chillers are driven by heat rather than electricity. Although they have a higher capital cost than vapour compression, they have lower running costs and enable CHP operators to generate revenue from heat that otherwise be wasted.

6.3.6 Future Proofing

Phases of development may be carried out by different developers, particularly if there is horizontal mix of uses. If developments are to be 'future-proofed' for connection to district heating then each phase must be designed to be compatible with and optimise the overall operation of district heating.

As a minimum, new blocks of residential development should be should be specified with 'wet' space heating systems supplied by communal boilers in order that they can be connected to a district heating network in the future. This creates a specific need for guidance on common standards and requirements. The common standards and requirements for future proofing form part of strategic heat planning guidance. This approach has been adopted by the London Borough of Barking and Dagenham [2] which is seeking to develop a town centre district heating network.

6.3.7 Further Research

Identifying the areas of research in DHC will maintain the progressive nature of the current research into this field. While DHC is a growing option alongside other conventional methods of generating heat and electricity, there are improvements that could be made in order for a more complete and recognised technology.

Current broader issues include:

- Centralised versus decentralised DHC systems and how these specification work together.
- The interrelation between the electricity production and heat demands. Operation of the respective grids

In terms of production, the following areas are recommended for research:

- Renewable/biomass CHP production
- Optimal regulation for large scale integration of solar thermal application in district heating in relation to heating and domestic hot water use.
- Pre-feasibility studies evaluating the local geological conditions (temperature levels, water availability) in order to use geothermal energy for DHC
- Designing and optimising the integration of geothermal energy in DHC systems.
- Designing and optimising the combined use of geothermal and solar thermal in DHC systems
- CHP gas turbines and use of combined solutions such as solar pre-heating

- Development of new application for long term heat storage with reduced heat losses
- Design and use of short term heat storage
- Improved utilisation of waste heat and incineration in relation to cooling applications and optimisation of the operation of waste incineration plants

In the area of transport, distribution and customer installations the following areas are recommended for research:

- Decentralised heat generation and integrated systems
- Reduction of operating costs and maintenance costs by improvements to piping and joints
- Development of new pipeline structures and components, which will enable cost reductions
- Development of technologies for low density areas; reducing heat losses and return temperatures
- Development of intelligent substations
- Development of renovation methods for district heating networks
- Optimisation of the DHC system with the focus on the dynamics between components; production, distribution, substations and customer installations
- Broadening the use of district heating by new household application and assessing its impact of customer installations

Another area of research includes the Cooling feature of DHC:

- Absorption cooling – improvement for district heating use; supply and return temperatures, size reduction of the absorption cooling installations
- Assessing possibilities regarding the use of ‘surplus heat’. Solar thermal applications in combination with district cooling
- Development of district cooling technology by using the existing infrastructure in DH networks
- Integration of district cooling equipments in existing buildings
- Development of small absorption chillers (10kW) for single family homes

On the subject of exchanging knowledge an extensive research network would be required including scientific journal, annual conferences, website, textbooks, training workshops and student exchanges. Demonstrating the DH technology used in other countries, including elements not currently present in the UK market would broaden the knowledge and awareness of DHC and its capabilities.

With these expected improvements, the following impacts are possible:

- *Improved cost effectiveness* for district heating grids. E.g. standardisation of customer installations (substations), developing new pipes and component structures and technologies which reduce cost for construction works.
- *Extensive integration* of combustible renewable technology, surplus heat from industrial processes, geothermal and solar heat and free cooling resources (e.g. deep sea water)
- *Increased efficiency* by integration of district cooling technology
- *Increased end use efficiency* due to permanent interconnection between the customer and the heat supplier. This would enable data collection about the customer behaviour regarding heat consumption and possible advices regarding end use efficiency measures.
- *Reducing primary energy consumption and energy import dependency* as the result of all the described measures.

7 Conclusions

The aim of this project is to provide Glasgow City Council and other associated companies with a preliminary investigation into the impact of introducing district energy schemes to Glasgow on a large scale. This was successfully completed by breaking down the objectives into several categories; environmental, economical, historical, and technological.

The first objective of the project involved investigating a district scheme and its main components, while researching several case studies dependant on each type of technology. This section demonstrated the involvement of several supply technologies, brought together to form one district scheme; adding to the complexity of the research.

Districts energy schemes have never had a popular image in the UK, and it was felt that it would be important to understand the reasoning behind the lack of advancing technology. A commonly thrown about comment in the UK is that, ‘the technology is too expensive’, and then someone might ask, ‘why is the technology so widely used in other countries?’ Well the reasons behind this go back more than 50 years, and the decisions made over this period have a significant contributing factor, and although the technology *can* be expensive, learning from these decisions will have an impact on future decisions.

With the research mainly based on factual events and technical research, the addition of analytical results from a case study based in Glasgow would improve the findings of the project. The case study consisted of a new Care Home being built in early 2009, and the Commonwealth Games Village beginning construction in 2010. Both developments would be built to a sustainable home standard and the electrical and thermal demand profiles would require developing accurate data. The final models were developed in Excel and imported to a university developed modelling package, Merit, and found that although initial scenarios based on just Care Homes showed a large deficit in thermal generation against demand, the addition of the Village provided a more viable and sustainable option, and revealed the potential for implementation of district energy on this scale. The introduction of *more* sustainable (reduced consumption) living in Glasgow should not be seen as a deterrent to district heating, and in fact, it should be seen as an integrated knowledge base to work with district schemes.

The final project objective presents a record of recommendations and further areas of research based on the technical research of the project. It is hoped that this can be used to aid in any potential development of a district energy scheme. As the project is based on a preliminary investigation, the results should act as guidance and as a benchmark in terms of future investigation. The areas of further research are an essential aspect of the recommendations, and by implementing, could change district energy technology within the energy market from a random environmental occurrence to a widely accepted and available energy generation technology.

District schemes will definitely have its part to play in the future of energy generation, and should be considered as one of the best alternatives to conventional generation. District schemes will always require some form of fossil fuel, but the reduction in CO_2 itself, justifies the inclusions of the technology as part of a sustainable future in Glasgow, and throughout the UK.

It seems as though this may be one of those points in history of district energy where a decision is made that could influence the way we live our life; maybe not immediately in the UK, but hopefully in Glasgow, and the knock on effect could lead to a better standard of sustainable living.

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