Ground Source Heat Study

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Final Report

Prepared by

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Project 410 – West Midlands Ground Source Heat Study

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TNEI Services Limited

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West Midlands Ground Source Heat Study

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Executive Summary

TNEI were contracted by the Government Office for the West Midlands to investigate the potential for the exploitation of ground source heat from groundwater using heat pumps throughout the West Midlands Region. To add value to the study Birmingham City Council have commissioned TNEI to undertake more site specific work in order to consider the suitability of new developments planned for the Eastside area of Birmingham for the application of heat pump technology. This summary provides a brief overview of the information contained in this report and is intended to direct those interested in the more technical aspects of the study to the relevant sections.

How heat pumps work
Heat pumps can be used to extract low grade heat from water within the ground or from the ground itself to provide space heating. Conversely, a heat pump can be operated in reverse to extract heat from buildings and provide cooling. Although a heat pump requires an input of electrical energy for its operation, the heat output from the heat pump can be in the range of 3 to 6 times the electrical input (this is known as the coefficient of performance or COP). Therefore heat pumps are energy efficient devices and can help to reduce carbon emissions because under most circumstances, less fuel would be consumed producing their supply of electricity than that which would be required to produce an equivalent heat output by conventional means. Heat pumps generally require little maintenance, requiring about as much maintenance as a refrigerator.

Factors affecting economic performance
The COP of a particular heat pump system relates to its operating cost and it is important to compare this with the operating costs of an alternative conventional system when assessing the likely economic benefits of any scheme. Factors which affect the COP of the system and hence the operating cost include the use of a low temperature heating system (which minimises the temperature lift required by the heat pump).

The demand for cooling in addition to heating increases the utilisation of a heat pump system and allow it to compete with the capital costs of a conventional systems where both a conventional boiler and a chiller would be required. The ratio of the electricity price to the alternative fuel price has obvious implications for running costs and there is evidence to show that this ratio is converging to improve the economic case for the use of heat pumps. In terms of costs of a heat pump installation, most installers use a rule of thumb of £1000 per kW installed (i.e. this covers capital and installation costs).

An additional factor which must be considered when assessing the performance of a heat pump system which uses groundwater, is the cost involved in pumping groundwater from the borehole to the heat pump. TNEI would recommend that in general, pumping should not undertaken from depths of greater than 50m below ground level.

Heat Sources for Heat Pumps
Low grade heat can be extracted from water within rock formations underground by drilling boreholes, from the ground itself and from surface water bodies such as lakes rivers and canals. It is also possible to extract heat from beneath mud flats. Whichever heat source is preferred, it is important that this lies close to the point of end use to avoid excessive heat losses.

The heat exchanger systems associated with heat pumps can be configured in various ways, they can be open (where water is abstracted and passed through the system) or closed (where a heat transfer fluid is circulated in sealed pipes which are submerged in the heat source). The systems can also be configured vertically using boreholes or where space allows a horizontal array of heat exchanger pipes can be buried adjacent to the development to be heated. Heat pumps are a proven technology and the case studies section of this report highlights a number of different schemes which have various configurations and make use of several different heat sources.

Suitable Developments for Heat Pumps

This study has ranked the most suitable developments in which heat pumps could be used, this is provided as a prioritised list in Section 2. The suitability of the development relates to many of the economic factors stated above. TNEI have proposed that the most suitable developments are those which have a demand for heating and cooling on a daily basis throughout the year. Such developments include; hospitals, hotels, and museums (especially where temperature controlled environments are required). Developments less suitable for heat pumps include domestic properties which have low occupancy and where cooling is unlikely to be required.

The suitability of a development for the implementation of heat pump technology also depends to some extent on the drivers for the project. For example some installations may not always be undertaken to provide the best economic performance. Instead other factors may affect the choice of a heat pump system such as the ability to undertake a novel installation which may be eligible for grant funding and as in one of the case studies detailed in Section 4 to reduce running costs for tenants.

Areas of the West Midlands Region Suitable for heat pumps using groundwater

The regional study has highlighted areas of the West Midlands where groundwater conditions are suitable for use as a heat source for heat pumps. Approximately one quarter of the West Midlands Region is underlain by a Permian and Triassic sandstone formation which is capable of bearing sufficient quantities of water (i.e. it is an aquifer) at shallow enough depth to be exploited by heat pumps. The study has also delineated areas served by the Transco gas network. Areas which are off gas and have suitable groundwater conditions have been highlighted as likely to provide the most technically feasible and economic potential heat pump installations.

The study has shown that the Unitary Authorities of Warwick, Worcestershire, Staffordshire, Shropshire, Telford and Wrekin have areas which have potential for the development of heat pump systems. Therefore any new developments proposed in these areas could be checked against the map provided in Section 6 to determine whether they are likely to plot on the aquifer and then investigated in more detail to determine their suitability.

Other areas that are off the mains gas network and where groundwater conditions are not suitable could still use heat pump technology, however closed loop vertical or horizontal systems such as those highlighted in the case study section would be appropriate for these sites.

The Eastside Case Study

An investigation into the planned developments in the Eastside area have shown that there are various possibilities for this area. The area has access to canals, the River Rea and shallow groundwater all of which provide suitable heat sources for a heat pump. Shallow groundwaters in this area of the city have arisen because of a reduction in the amount of water being abstracted from the sandstone aquifer. This is due to changes in industrial usage and also tighter legislation surrounding groundwater extraction.

British Waterways were contacted about the possibility of using canals as a heat source and they are very keen for canals to be used in this way. They are especially interested in the potential for using canal water to provide heating for the planned development at Typhoo Basin. The Mailbox development in Central Birmingham already has a cooling system which uses canal water.

The type of developments being planned for Eastside such as hotels and leisure facilities mixed use housing and commercial and also the City Library are the types of development where the most economic performance of a heat pump system can be expected.

General recommendations

TNEI would recommend that some effort is made towards raising awareness of what heat pump technology has to offer amongst developers, architects and planners. Heat pumps although seen as novel in the UK are a proven technology and are commonplace on the continent. Heat pumps being an energy efficient device have the potential to improve the sustainability credentials of a particular development.

Given current fuel prices, TNEI would recommend that off gas areas (or buildings which are as yet unconnected to the gas mains) are targeted initially because heat pump technology competes well with alternative fuels such as electricity, oil and LPG.

Developments best suited to this technology are those which have high hours of usage and also those which have a demand for heating and cooling.

Several developments at Eastside should be targeted with respect to using this technology so that they provide a working showcase of heat pump technology that can be used to market the concept to other developers. The potential for using a heat pump within a particular development should be considered at an early stage so that certain elements of building design (e.g. the installation of a low temperature heating system) can be easily incorporated.

Within the wider West Midlands region, new developments which are planned for areas which lie on the major aquifer that underlies about one quarter of the region and also that correspond to off gas areas should be assessed as to whether they could make use of heat pump technology. Areas which are off the aquifer but off gas could make use of horizontal or vertical closed loop systems.

1. Introduction

1.1 History of Heat Pump Development

Although there has been a recent upsurge in interest surrounding heat pumps they are not a new technology. There was rapid growth in the development of heat pumps in the early 1970s in response to the oil crisis. Therefore heat pumps represent a proven technology and are capable of meeting the heating and cooling needs of many different types of development. The current interest in the use of heat pumps is driven by a desire to improve the energy efficiency of developments and to reduce carbon emissions. There are also indications that anticipated rises in the price of mains gas relative to electricity will begin to provide favourable economics for heat pump installations. Heat pumps are widely used on the continent however, the most prolific application for heat pumps in the UK to date has been in commercial buildings with the chemicals and food and drink sectors now appreciating the benefits of using heat pumps to cool their products whilst using the extracted heat to supply office spaces.

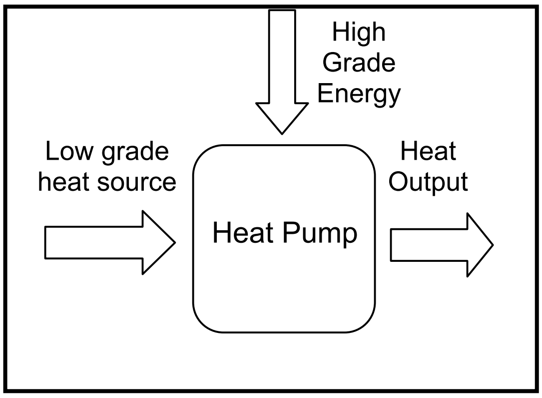
1.2 How a Heat Pump Works

A heat pump works by extracting heat from a low grade (i.e. low temperature) heat source such as water within rock formations underground (groundwater) which in the UK is usually at 10-15°C or alternatively heat can be extracted from the ground itself which will also be at temperatures of 10-15°C). The heat pump then produces a more useful, higher temperature output (typically 40 - 50°C) which can then be circulated through a low temperature heating system. To upgrade heat in this way, the heat pump requires an input of energy which is usually electricity (Figure 1). A vapour compression cycle is the most common form of heat pump process and a schematic of this cycle is shown in Figure 2. In this cycle, electricity is the high grade energy input and it is used to drive the compressor. The cycle takes place in the following sequence:

- Heat exchange from the low temperature source takes place in the evaporator. This part of the cycle is kept at low pressure and the refrigerant boils at low temperature as it absorbs heat from the source.
- The vapour then passes to the compressor where it is discharged at a higher pressure and temperature (this part of the process consumes electrical energy).
- The vapour then enters the condenser and heat exchange with the sink (i.e. heat output stream) causes the vapour to condense and release heat. Because the pressure is higher than in the evaporator the condensation temperature is also higher.

The high pressure liquid discharged from the condenser is then expanded through a valve. The liquid vaporises and its pressure and temperature reduce to the starting condition in the evaporator.

Figure 1 Schematic diagram of a heat pump system



1.3 Efficiency of a heat pump system

The efficiency of a heat pump is referred to as the “coefficient of performance” (COP). It is the ratio of heat pump output to power input (often measured in kW) as indicated below:

$$\text{COP} = \frac{\text{Heat energy output}}{\text{Electrical energy input}}$$

The term “COP” is used rather than efficiency because its value in most practical systems would be in the range 3 to 6 whereas an efficiency value would not normally be greater than one.

It is important to note that in applications where water is actively pumped, the electricity consumed by the heat pump itself and the borehole pump can be of the same order. Therfore, the effective COP of a groundwater system can be rather lower than that indicated by the definition given earlier.

Figure 2 Schematic diagram of vapour compression cycle

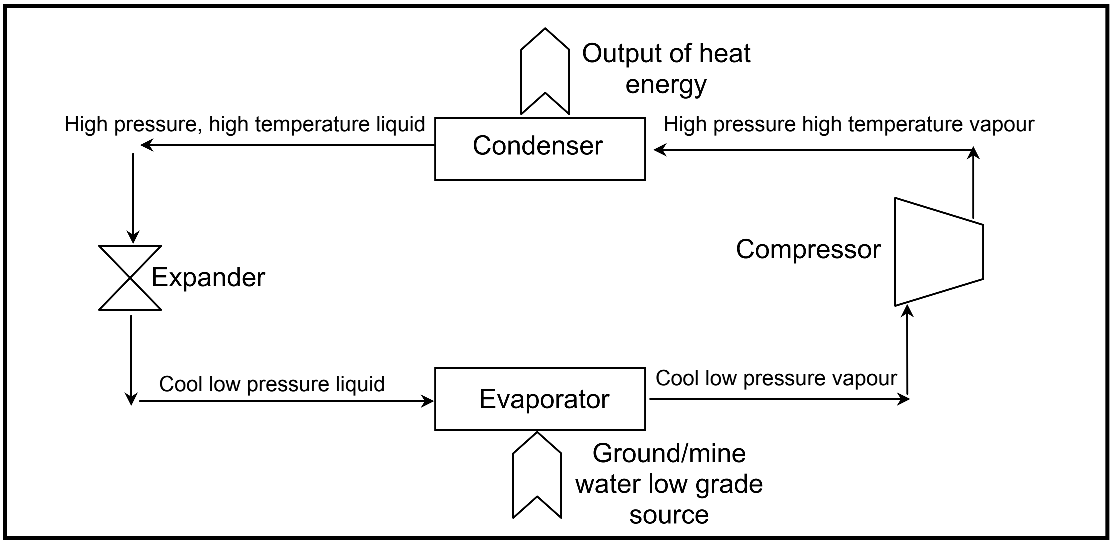


Table 1 was taken from the website of the Swiss heat pump test centre (www.wpz.ch/english) and shows how COP varies over a range of different operating conditions. The table, which is consistent with the basic theory of the heat pump, shows that the best performance is achieved when the temperature difference between the heat source and heat sink is at a minimum i.e. when a relatively low temperature output is produced from a relatively high temperature source. For this reason, heat pumps are better suited to low temperature heating systems such as underfloor heating, radiant panels and wall grid heating.

A heat pump and a refrigerator are thermodynamically equivalent. Both absorb heat at a low temperature and reject it at a higher temperature. With a refrigerator, the main interest is in the low temperature performance but it is the heat output which is of importance in a heat pump. It is possible to alter the operation of a heat pump so that advantage is taken of its cooling effect and this allows the system to switch between a heat output or a cooling output suitable for air conditioning or comfort cooling.

Table 1 COP values of heat pumps under various operating conditions(After Swiss heat pump test centre www.wpz.ch./english)

	Temperature output of 35° C			**Temperature output of 50° C**		
Temperature of heat source	Lowest COP	Average COP	Best COP	Lowest COP	Average COP	Best COP
5°C	4.0	5.0	5.8	2.9	3.3	4.2
10°C	4.5	5.5	6.8	3.3	3.8	4.5
15°C	5.0	6.2	7.0	3.6	4.2	5.0

1.4 Heat Pump Maintenance Requirements

Heat pumps do not require frequent maintenance as they have very few moving parts. Their reliability is similar to that of a fridge, the usual point of failure being the compressor. They do not require servicing such as oil top-ups in the same way that combined heat and power engines do and are unlikely to require annual servicing such as is required with conventional gas and oil boilers. There should be no need to clean the water sides of the evaporators and condensers provided that the water quality is compatible with the heat exchanger (this would be determined prior to installation). Any maintenance that is required should be undertaken by qualified refrigeration/heat pump service engineers. In an industrial or other non-domestic setting, larger capacity heat pumps may require annual inspections.

1.5 Further Information about Heat Pumps

Table 2 provides some contacts which may provide useful sources of further information:

Table 2 Useful contacts for further information

Name	**Phone No.**	**Web Address**
UK Heat pump Network	Environment and Energy Helpline 0800 585 794	http://www.heatpumpnet.org.uk/
UK Heat Pump Association	0118 940 3416	http://www.feta.co.uk/hpa/
Green Consumer Guide	N/A	http://www.greenconsumerguide.com/domesticll.php?CLASSIFICATION=180&PARENT=54
Energy Saving Trust Heat Pump Fact Sheet	N/A	http://www.est.org.uk/schri/downloads/ground.pdf
Clear Skies – potential funding for heat pumps	Helpline 08702 430 930	http://www.clear-skies.org/
Environment Agency – Abstraction Licences	Contact Regional Office	http://www.environment-agency.gov.uk/?lang=_e
British Geological Survey – Geological/Hydrogeological information	Headquarters 0115 936 3100	www.bgs.ac.uk/
TNEI Services – heat pump	0191 233 9300	http://www.tnei.org.uk

(and renewables) consultancy		

2 The Economic and Environmental Issues

2.1 Factors influencing heat pump performance

A heat pump producing one unit of heat output, in a good application, would use about 0.25 units of electricity compared to between about 1.1 and 1.4 units of gas in a boiler. On this basis, the financial savings would range from 0.15p to 0.85p per unit of heat output. This would result in annual savings ranging from approximately £13.00 to £74.00 per unit heat output if the system operated for 24 hours per day, seven days per week for the whole year. By any normal investment appraisal criterion, an investment of £2000 to save £13.00 per annum would be regarded as very unsatisfactory. The same investment to save £74.00 would be regarded as acceptable by some organisations but it is certainly not good.

The example illustrates the difficulty of justifying heat pump use on an economic basis. It also indicates the important factors affecting economic acceptability which, in turn, allow the characteristics of potential applications to be identified (Table 3). This reduction in primary fuel consumption due to heat pump use results in a very important conclusion. Heat pumps will invariably cause less environmental pollution than even the most efficient conventional heating system. To a large extent, the savings which would justify this cost are affected by the relative price of heating fuel, usually gas, and electricity, and by the heat pump's capacity and utilisation (the following sections discuss these factors in more detail).

For open loop systems where heat is extracted from groundwater, the costs associated with pumping this water can also be a very important factor. The factors which favour an economic heat pump installation and the type of development most suited to this technology are described in Section 2.6.

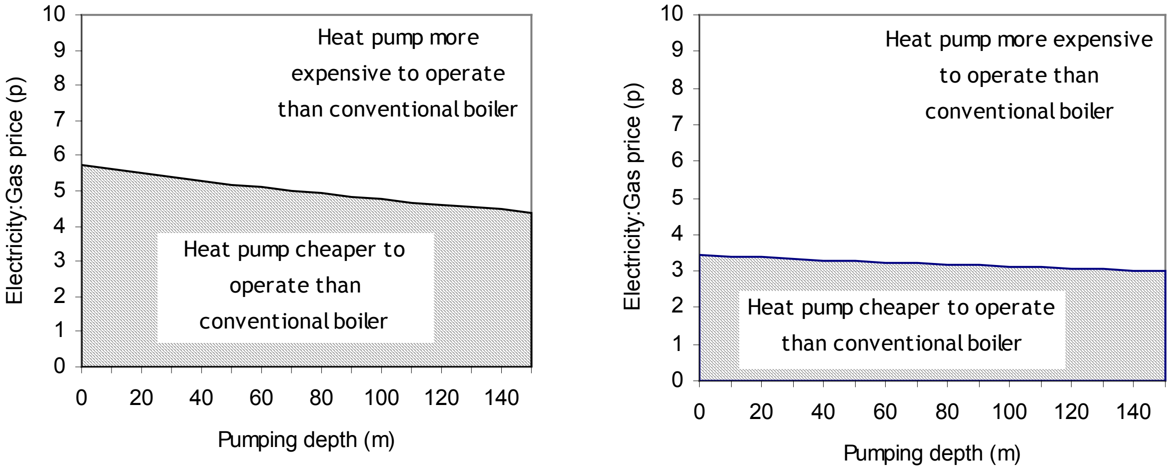
2.1.1 The configuration of the heat pump system

The COP of a ground source heat system affects the operating cost and this must be lower than that of the equivalent boiler if a heat pump has any prospects of being economically attractive. As described in section 1.3, the coefficient of performance of a heat pump will decrease as the required temperature lift increases. Therefore to get the best performance out of a heat pump system, TNEI would recommend that the heat pump system be used in conjunction with a low temperature heating system.

This is explained in Figure 3, where in a conventional high temperature system the heat pump would have to raise water temperature from its ambient value of 10-15°C for circulation at 70-80°C. This represents a temperature increase of 55-60°C. In a low temperature system the heat pump would have to raise water temperature from its ambient value of 10-15°C to 40° – 50°C for circulation through an underfloor heating network or through radiant panels. This represents a temperature increase of 25-40°C. Therefore the COP or efficiency of the low temperature system would be greater than that of the high temperature system.

TNEI has calculated under what circumstances a heat pump would have more expensive running costs than a conventional boiler for both the high and low temperature cases. Figure 3 can be used to make a rough assessment of whether a potential heat pump system which uses groundwater is likely to be economic. Once the electricity : gas price ratio has been calculated and the depth to groundwater is known for a particular site an initial decision can be made as to the likely benefits of using a ground source heat system.

Figure 3 Economics of a potential heat pump installation of (a) low and (b) high temperature heating systems



For example a site where the groundwater is 40m beneath the surface and where the ratio of the electricity to gas price is 4.5, the heat pump would be more economic to operate than a conventional boiler under these circumstances if a low temperature system were used. If a high temperature system were involved, the heat pump would be more expensive to operate than a conventional system.

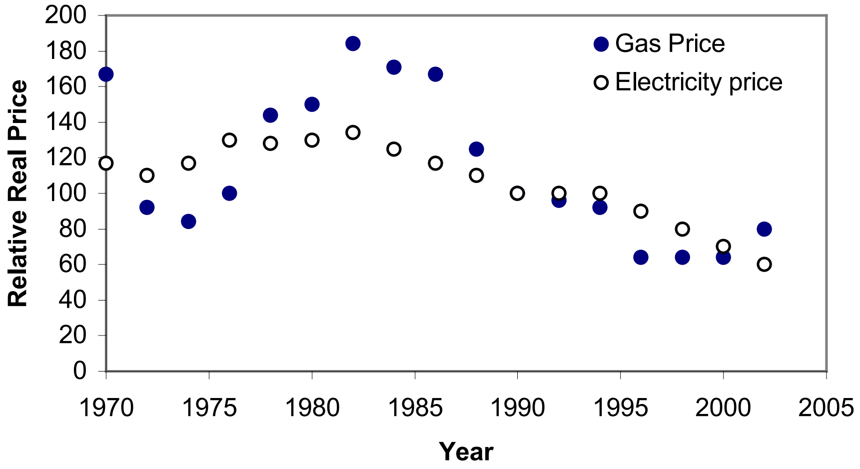
Figure 3 also shows that for the low COP case (Figure 3b), the maximum value of the ratio of electricity to heating fuel price is about 3.5 for any saving to occur. For the high COP case (Figure 3a) the maximum ratio varies from about 5.5 when no pumping is involved to about 4.5 with pumping from 150m. Based on the use of natural gas and mains electricity, the likely range of the electricity to fuel price ratios is about 4.5 to 10. Thus, low COP applications would not result in any financial savings, even without pumping costs, but there are some prospects of savings if a high COP (i.e. low temperature) system could be used.

2.1.2 The Electricity/Fuel Price Ratio

The electricity/fuel price ratio is clearly critical to the economic performance of any heat pump and it is useful to consider the historical trends. Figure 4 shows the relative changes in the real prices of gas and electricity since 1970. Figure 4 shows that electricity to gas price ratio was most favourable to heat pumps in the early 80s but it rose steadily and was least favourable in the 1990s. The change reflects the perceived value of heat pumps. General interest in heat pumps was highest in the early 80s but combined heat and power (CHP) became the “advanced” energy system of choice during the 90s. In contrast to a heat pump, CHP is economically attractive when the fuel price is low and electricity prices are high. However, Figure 4 shows some evidence of a reversal in the trend of the price ratio (the gas and electricity prices are converging) and, if this were to be sustained, it is reasonable to speculate on a justifiable, growing interest in heat pumps.

The cost of a unit of electricity is typically 5p to 6p compared to around 1.5p for gas and a heat pump costs about £200 per kW of heat output more than a conventional boiler.

Figure 4 Relative Real Prices of Gas and Electricity (Prices = 100 in 1990)



2.1.3 The Demand for Cooling

The economic prospects of a heat pump system are improved if advantage can be taken of the heat pump's capability to work in reverse and produce a cooling stream for air conditioning. The improvement in the economic case depends on the extent of air conditioning use relative to its capacity, which would normally be based on heating requirements. However, as an example for the high COP case, the maximum electricity to fuel price ratio could be extended from about 5.5 to 7.5 with no pumping requirement. If a particular development had identified a need for cooling, the economics of a heat pump system would be improved with respect to capital costs. Due to the fact that the heat pump can be reversed to meet cooling demands there would be no requirement to purchase additional cooling devices such as chillers.

2.2 Investment Appraisal

The analyses and results described in Section 2.1.1 and 2.1.2 consider only whether a heat pump would result in lower operating costs. This is an important factor in heat pump assessment but, if an installation is carried out for economic benefit, the reduced operating costs must be high enough to justify the capital investment. Unfortunately, heat pumps are expensive. They are typically about four times the cost of a conventional boiler and, therefore, high levels of saving are required if the cost is to be justified using normal investment criterion.

It is important to stress that heat pumps are generally effective in conserving energy and reducing atmospheric pollution. Most practical designs would produce benefits in these areas even if their operating costs were unfavourable. Some installations proceed on this basis. One such example is the Lumphinnans site (see case studies in Section 4) where the drivers for the installation were the need to reduce heating bills for the tenants and also to provide an innovative scheme which would attract both grant funding and publicity.

Even if a strong weight is given to conservation and environmental issues, some attention would normally be given to economic matters. It should be clear from the previous sections that a satisfactory system needs a high coefficient of performance and the opportunity to provide air conditioning can be highly beneficial. Utilisation is a further critical feature which affects economic performance. Clearly, the longer the system operates, the greater the annual saving for the same capital investment.

2.3 Types of Development Suited to Ground Source Heat Technology

Table 3 shows the type of development that may benefit from heat pump technology and ranks the type of demand based upon utilisation and a need for cooling. A high coefficient of performance, the other key factor, is most likely to be satisfied in a new development because an appropriate low temperature heating system can be installed conveniently. However, new buildings can also be insulated to a high level which reduces the total demand and, hence, the scope for saving. For this reason, the best prospects for an economically attractive installation may well be within an old building that could conveniently accommodate a low temperature heating system.

Table 3 Approximate Economic Ranking of Heat Pump Opportunities

Rank	Type of Demand	Examples
1	Heating and/or cooling demand for most of the day for most of the year	Hospitals, Hotels, Museums which need a controlled environment
2	Commercial type heating and cooling	Air conditioned office blocks, shops
3	High, extended heating demands	Swimming pools, leisure centres
4	Domestic or similar heating with high premises occupancy rates	Sheltered housing
5	Commercial type heating	Non-air conditioned office blocks
6	Domestic or similar heating with low premises occupancy rates	Housing complexes with few children and a high proportion of working people

2.4 Indicative system costs

The costs of installing a heat pump system will vary according to the system configuration (the different configurations are detailed in Section 3) therefore this section can only provide a rough idea of the costs of such a system as each case is so site specific. TNEI spoke to several installers who advised that as a rule of thumb, a cost of £1000 per kW installed should be used. Indicative costs for some of the equipment used in a heat pump system have been provided for a horizontal closed loop system and for a vertical open loop system (Table 4).

Table 4 Indicative costs of heat pumps and some associated equipment

System type	Horizontal closed loop	Vertical open loop
Heat pump 7.5 kW (£/kW)	£347	£347
Heat pump 11 kW (£/kW)	£255	£255
Heat pump 11 kW (£/kW)	£200	£200
Heat pump 40kW and above (£/kW)	£150	£150
Underfloor heating (per m^2)	£16	£16
Slinky cost (per m)	£7	N/a
Borehole (per m)	N/a	£40
Abstraction Licence	N/a	£600

3 Ground Water as a Potential Heat Source

3.1 Groundwater as a Source of Heat

Water which resides in the pore spaces and cracks in rock formations beneath the surface is known as groundwater. Different types of rock formation can contain different amounts of water depending upon how porous they are. For example certain sandstone formations can be thought of as a sponge with groundwater occupying pore spaces between rock grains. Conversely crystalline rocks such as granite do not contain pores and are generally not capable of storing much water. Terms relating to how water behaves whilst beneath the ground are explained in Appendix A.

Groundwaters have a huge heat storage capacity and groundwater temperatures are relatively constant all year round (Banks *et al*., 2002). The thermal capacity of a particular groundwater reserve depends upon the volume of water present and temperature and the temperature which it is at. The temperature is controlled by the geothermal gradient (Jessop *et al*., 1995) i.e. the increase in temperature which occurs as you approach the Earth's Core. In the UK, groundwater temperatures are always around 10°–12°C. For optimum utilisation of groundwater, it is essential that the site of end use is in close proximity to the energy source and to achieve this, boreholes can be purpose drilled at specific sites. From the literature and from conversations with the Environment Agency, there presently appears to be a lack of legislation and regulation concerning the exploitation of geothermal resources (these issues are discussed more fully in Section 7). There are several ways in which groundwaters can be exploited to provide ground source heat and these are detailed in the following sections.

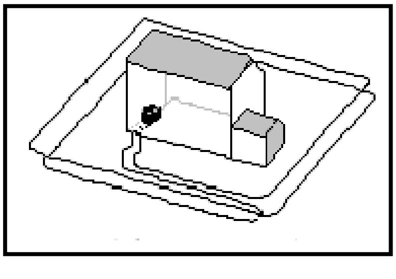
3.2 Closed Loop Systems

In a closed loop system, groundwater is not abstracted, instead the heat transfer fluid (which may be water or a purpose designed refrigerant) is circulated through a sealed submerged pipe, the length and diameter of which depend upon the heating requirements. Installation standards for this type of system have been provided by the International Ground Source Heat Pump Association (IGSHPA) (Huttrer, 1997). This type of system does not involve abstracting water and is useful in rock formations that contain little water (Banks, *et al*., 2002).

3.2.1 Horizontal Closed Loop Systems

These systems are useful for small installations where space is not at a premium as the heat exchanger needs to be buried beneath ground (at a depth of around 90cm) directly adjacent to the deveopment (Figure 5). A helical type of heat exchanger pipe known as a 'slinky' maximises the length of the buried pipe per metre of trench. The 'slinky' system requires a greater length of pipe per ton of thermal energy than conventional horizontal systems. Improved subhorizontal drilling techniques have facilitated the installation of horizontal systems. When the heat exchanger pipe is buried, it is important that there is close contact between it and the backfill material to ensure efficient heat transfer from ground to refrigerant. To assist with this process, 'flowable backfills' i.e. liquid backfills which will flow into the trench and form a close contact around the heat exchanger pipes are often used (Huttrer, 1997).

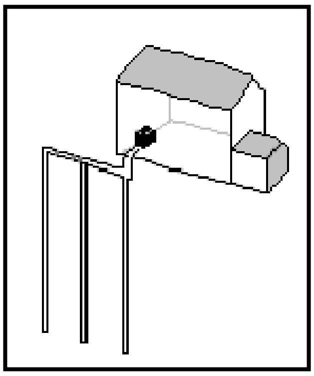
Figure 5 A closed loop horizontal system



3.2.2 Vertical Closed Loop Systems

These systems are useful for small sites where space is at a premium (Figure 6). They also suit sites planned for commercial installations where the soil depth is relatively shallow. Vertical systems generally extend to 160m depth and 40-90m of loop is required per ton of heat exchange. Careful drilling and grouting of the well is required to maximise heat transfer (Huttrer, 1997).

Figure 6 A vertical closed loop system



3.2.3 Surface Closed Loop Systems

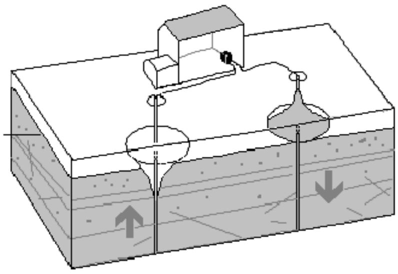
Surface systems exploit water bodies e.g. rivers and lakes which have sufficient depth and volume and also have a significant flow. The need for excavation in the installation of these systems is limited which make these systems inexpensive and efficient. The heat exchanger pipes are floated out into position and then sunk. There is no documented evidence that these systems have any deleterious impacts upon aquatic ecosystems (Huttrer, 1997).

3.3 Open Loop Systems

Surface or groundwaters can be used for these systems which are often favoured for their efficiency and relative low cost (Figure 7). These systems usually require a significant water yield which is of reasonable quality (Banks *et al.*, 2002). The major drawback of open systems is that the heat exchanger can require frequent cleaning to remove chemical precipitates or organic fouling. The use of chemical inhibitors to limit scale deposition with heat exchangers can have consequences for the release of discharge waters from open systems (Huttrer, 1997). Open loop systems can exploit groundwaters in three main ways:

- Total abstraction – where no groundwater is returned to the aquifer following heat extraction – i.e. it may be discharge to surface water courses
- Partial abstraction – where some groundwater is returned i.e. some may be used within the development e.g. for toilet flushing
- Zero abstraction – where all the groundwater is returned to the aquifer following heat extraction

Figure 7 An Open Loop Vertical system



3.4 Standing Column Wells

Standing column wells are used where both the bedrock and water table are near the surface and are most applicable to scenarios where mine water is used and where mine shafts are involved. Standing column wells can be up to 460m deep and the diameter of the well is dominated by the size of the pump. Standing column wells are vertical open systems whereby water is pumped from the bottom of the well and returned to the top (Spitler *et al*., 2002). The temperature of the well is controlled by bleeding off small quantities of water. These systems can also be used to supply potable water. Drilling costs for these systems are generally expensive (as they commonly encounter hard rock lithologies) however the heat exchange capacity of these systems is three-four times better than those of vertical closed loop wells (Huttrer, 1997).

3.5 Compatibility of Groundwater with Heat Pump Equipment

Groundwater may contain contaminants which can cause problems with various components of a ground source heat system (e.g. evaporators, pumps, pipes and heat exchangers. It is important to adequately characterise any groundwater prior to its use in such a system. Quality issues that may arise when dealing with groundwater include:

- Suspended particulates which can abrade or clog components
- Dissolved constituents which may generate salinity or acidity and have the potential to cause corrosion
- Dissolved constituents which may precipitate from solution leading to clogging e.g. limescale or oxides of iron
- Algae or other biological matter which could cause clogging

Although these issues need to be addressed, if present they do not represent insurmountable problems. For example, particulates can be removed using in-line filters, limescale can be avoided using water softners and biological contaminants can be removed using disinfection.

4. Existing Examples of Heat Pump Technology

4.1 Heat pump case studies

As highlighted in Section 1, heat pumps are a proven technology and have many applications. Heat pumps can exploit various heat sources including, groundwater, the ground itself, canals, rivers and lakes, mudflats and even the water contained within abandoned mines. The following examples highlight the versatility of these systems. However it should be noted that the heat pumps installed within some of the examples were chosen for a variety of reasons and may not always have been chosen as the best economic case.

4.1.1 Ochilview, Lumphinnans, Fife

Location:
Fife Scotland
Type of development:
Block of 18 Flats
Facilitator:
Fife Special Housing Association
Open or closed system:
Open loop borehole system
System configuration:
Vertical
Heat Source:
Water from within abandoned coal mines
Rationale behind project:

Fife Special Housing Association (FSHA) had poor uptake throughout their 200 homes at Ochilview in the Lumphinnans area therefore they decided to refurbish the 18 tenement properties (John Gilbert Architects 2001). At the time, the newly formed Housing Association decided to self fund the refurbishment and wanted to incorporate some renewable energy technologies into the project. This was partly to make the system eligible for grants and partly to serve as an exemplar to the region. The housing association had an interest in reducing fuel poverty in the area as the existing flats were previously heated using electric storage heaters which cost the tenants around £600-£700 per year to heat.

System specification:

John Gilberts Architects (1999, 2001) won the contract for the refurbishment with their proposed geothermal system. A borehole was driven and this extracts heat from mine waters within the abandoned workings from a depth of 170m below the site. The mine water has a temperature of 14.5^{o}C and the heat pumps boost the temperature to 55^{o}C. Following heat extraction the mine water is returned (via another borehole) to the mine workings at 3^{o}C. The hot water temperature is boosted with immersion heaters as necessary. Most of the borehole pumping is done at night using an ECO2000 tariff to limit pumping costs. Thermal storage tanks maximise the use of the heat generated in off-peak electricity periods, the project was designed on a 30 year lifespan.

Outcomes:

The entire refurbishment cost £800,000 and it was completed in August 2001. The success of the project has meant that the flats now have a waiting list and the running costs for the flats has been reduced from £600 - £700 per annum to between £110 and £140 per annum

Further info:
http://www.johngilbert.co.uk/resources/geothermal.html

4.1.2 Brancaster Millennium Activity Centre, Norfolk

Location:
Norfolk
Type of development:
Activity Centre retrofitted in historic building
Facilitator:
National Trust
Open or closed system:
Closed loop heat exchanger system
System configuration:
Horizontal
Heat Source:
Mud flats
Rationale behind project:
The Brancaster Millennium Activity Centre is a residential education centre which was opened in 1997 to promote environmental sustainability. The Centre is housed in a refurbished 17th century building. The building was refurbished using sustainable materials and it incorporates several renewable energy technologies. Other renewable technologies have also been incorporated at the centre and include solar hot water, solar PV and a small wind turbine.
System specification:
The centre has a heat pump which uses the adjacent mud flats as a heat source. The heat pump supplies under-floor heating in parts of the building. 1km of plastic piping has been completely buried under the mud flats to serve as a heat exchanger. Brine is circulated through this piping and as it circulates its temperature is raised to that of the mud. The brine then flows into the heat pump where heat is extracted from the brine to the water that is then circulated through an underfloor heating system.
Outcomes: The system provides carbon savings and also provides a visitors attraction
Further info: www.nationaltrust.org.uk/main/news/brancaster_info.pdf

4.1.3 Lee Valley Regional Park, Cheshunt

Location:
Cheshunt, London
Type of development:
Five Lodges and a Reception Block
Facilitator:
Youth Hostel Association
Open or closed system:
Closed system
System configuration:
Horizontal
Heat Source:
Lake
Rationale behind project:
The Youth Hostel Association wanted to create a scheme that is sympathetic to the surrounding landscape of the Country Park and also to create a development that is environmentally friendly
System specification:
The heat exchanger is constructed of a closed loop of coils of high density polyethylene pipe which were floated out and then sunk in the lake which is adjacent to the development. The main office block houses three Viessman water to water heat pumps and each lodge has its own small plant room and heat pump

Outcomes: When compared with oil and natural gas, the system reduces annual CO_2 emissions by 105 tonnes and 47 tonnes respectively
Further info:
http://www.earthenergy.co.uk

4.1.4 Dunston Innovation Centre, Chesterfield

Location:
Chesterfield, Derbyshire
Type of development:
Incubation units for start up offices
Facilitator:
Chesterfield Borough Council
Open or closed system:
Closed loop system
System configuration:
Vertical using borehole
Heat Source:
Ground
Rationale behind project:
The Dunston Innovation Centre in Chesterfield is a low energy building designed for start-up companies and is subdivided into a number of self contained units, with common conference and meeting room facilities. The Innovation Centre was created to promote the concept of sustainable development. Heat pumps are used to meet the heating and cooling demands for this building.
System specification:
The system comprises 32 boreholes situated in a landscaped area behind the building. Each borehole has a polyethylene pipe, grouted in place. The boreholes are manifolded together on to flow and return lines, that are connected to the main ground loop circulating pumps, located in a small ground floor plantroom. Risers take the ground loop water and distribute it via heat pumps on the three floors of the building. Tenants are simply metered for their heating and cooling, using standard meters in each unit.
Outcomes:
Chesterfield Borough Council have made an arrangement that the centre is to be supplied with electricity derived from renewable energy sources. Thus, the heating and cooling of this innovative building, is achieved with no overall CO_2 emissions.
Further info:
http://www.emra.gov.uk/s_d_success/dunton_innovation_centre.asp
http://www.earthenergy.co.uk/chesterfield.html

4.1.5 Buntingsdale School, Shropshire

Location: Market Drayton, Shropshire
Type of development: Infant school
Facilitator: Shropshire County Council
Open or closed system: Closed Loop
System configuration: Horizontal System
Heat Source: Ground
Rationale behind project: Buntingsdale Infant School, Market Drayton, Shropshire is not connected to the mains gas network and formerly had electric storage heating. However this caused overheating problems on days of high solar gain. The objective of this project was to demonstrate the use of a heat pump system in an off gas building.

System specification: A heat pump has recently been installed at the school using funding obtained from the Carbon Trust. The 40kW heat pump has horizontal heat exchanger pipes (which circulate a brine solution) buried beneath the ground in a field adjacent to the school. 50m of pipe were buried in 50 trenches which were 1.3m deep and 1.5m wide. The system has a COP of 3 i.e. the heat output (in kW) is three times the electrical input (in kW).

Outcomes: The school is now equipped with an energy efficient heating system which currently saves around 1-1.5 tonnes of CO_2 emissions per month. Energy consumption figures can be viewed via the Shropshire County Council Website.

Further info:
http://www.shropshireonline.gov.uk/
http://www.thecarbontrust.co.uk/

5. Geology and Hydrogeology of the West Midlands

5.1 Geology

The variety of rocks mirrors the variation in topography and provides the underlying frame for the region (Figure 8). The oldest, hardest rocks occur as isolated outliers in the south Shropshire Hills and the Malvern Hills. To the south west of the region, the Herefordshire area is dominated by the red Devonian sandstone and marls which give rise to the characteristic, deep fertile red Herefordshire soil. To the north of Herefordshire near the border with south Shropshire, the geology comprises of a sequence of old, hard, limestone, shales and sandstones this results in the characteristic ridge and valley scenery.

North Shropshire and much of the remainder of the region is underlain by predominantly soft reddish rocks comprised of a mixture of sandstone and clays. In Warwickshire, central Staffordshire and Worcestershire these heavy clay soils form an essentially pastoral landscape. In the centre of the West Midlands region from Wolverhampton to Coventry, and around the Potteries and Telford, there are exposures of Carboniferous rocks. This sequence includes the coal seams and other economic deposits which have been extensively worked in the past. These economic deposits resulted in industrial growth within the region and the development of large urban centres. The southern most part of the West Midlands Region is composed of Triassic mudstones. The geology of the Central Birmingham area is described in more detail in the case studies section.

5.2 Hydrogeology

A generalised map showing the hydrogeology of the region is shown in Figure 9. The region has been divided into three hydraulic areas:

- Major aquifers with adequate supplies of groundwater
- Concealed/confined aquifers without significant groundwater
- Impermeable rocks with little or no groundwater

This does represent a generalisation and TNEI would recommend that potential sites where ground source heat is being considered be checked on a more detailed geological map (at a recommended scale of 1:10 000, these maps can be obtained from the British Geological Survey – Table 2).

About one quarter of the West Midlands region is underlain by major aquifers. Approximately half of the region is underlain by aquifers which are either concealed or yield small quantities of groundwater. A further quarter of the region is underlain by impermeable rocks which are unlikely to yield substantial quantities of groundwater (Figure 9).

5.2.1 Areas underlain by major aquifers

The northern and eastern part of the region are underlain by a major aquifer. The main parts of this aquifer extend from Shrewsbury to Stoke on Trent, from Newport through Wolverhampton to Kidderminster and from Birmingham northwards towards Cannock (Figure 9). This aquifer is composed of Permian and Triassic sandstones. Discussions with the Environment Agency have revealed that this aquifer can supply variable but productive yields of water throughout its extent.

An investigation of the depth to the water table throughout this aquifer is necessary because the cost of pumping groundwater from deep horizons may affect the economics of any proposed ground source heat scheme. Research previously undertaken by TNEI has shown that water levels should generally not be more than 50m below ground surface for an installation to be economic.

Discussions with the Environment Agency and the consultation of geological maps has revealed that water levels in the Permian and Triassic aquifer within the West Midlands Region is relatively shallow being in the region of 15-20m below ground level and in some areas, groundwater is even shallower.

5.2.2 Concealed aquifers

Approximately half of the region is underlain by concealed aquifers. The fact these aquifers are concealed means that although there is a supply of water within the aquifer it may be limited and it may be relatively inaccessible due to the depths of overlying confining strata. Therefore areas which are underlain by confined aquifers have been discounted from this study.

5.2.3 Impermeable rocks

About one quarter of the West Midlands Region is underlain by impermeable rocks which do not have the capability to store large volumes of groundwater. These rocks may be either crystalline, well cemented or fine grained sediments such as mudstones and shales. These rock types may contain a limited amount of water within fractures in the formation although this would be unlikely to support an abstraction for a groundwater heat pump. There may however be other options for exploiting ground source heat in this type of lithology (see Section 6.3).

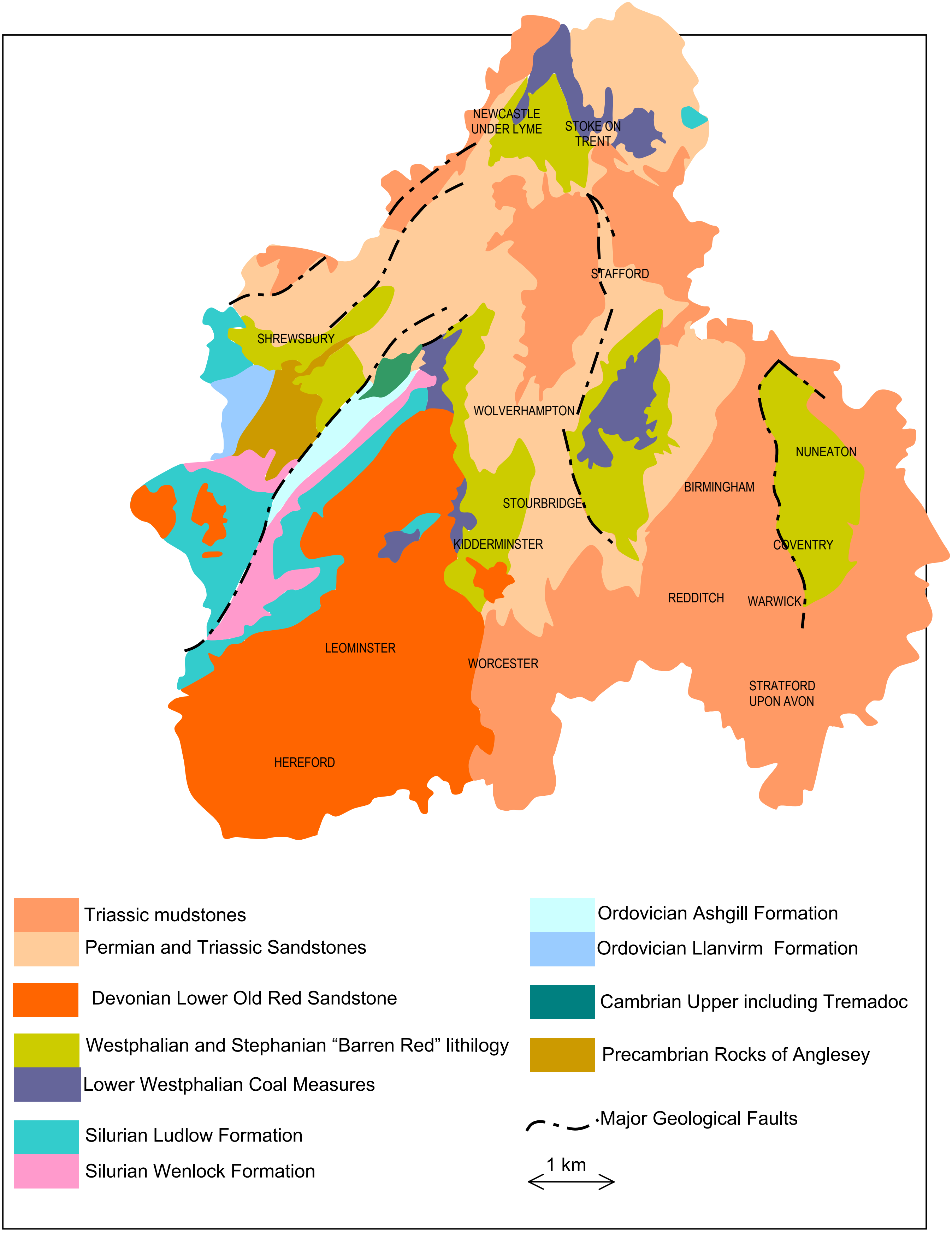


Figure 8 Simplified Geological Map of the West Midlands Region

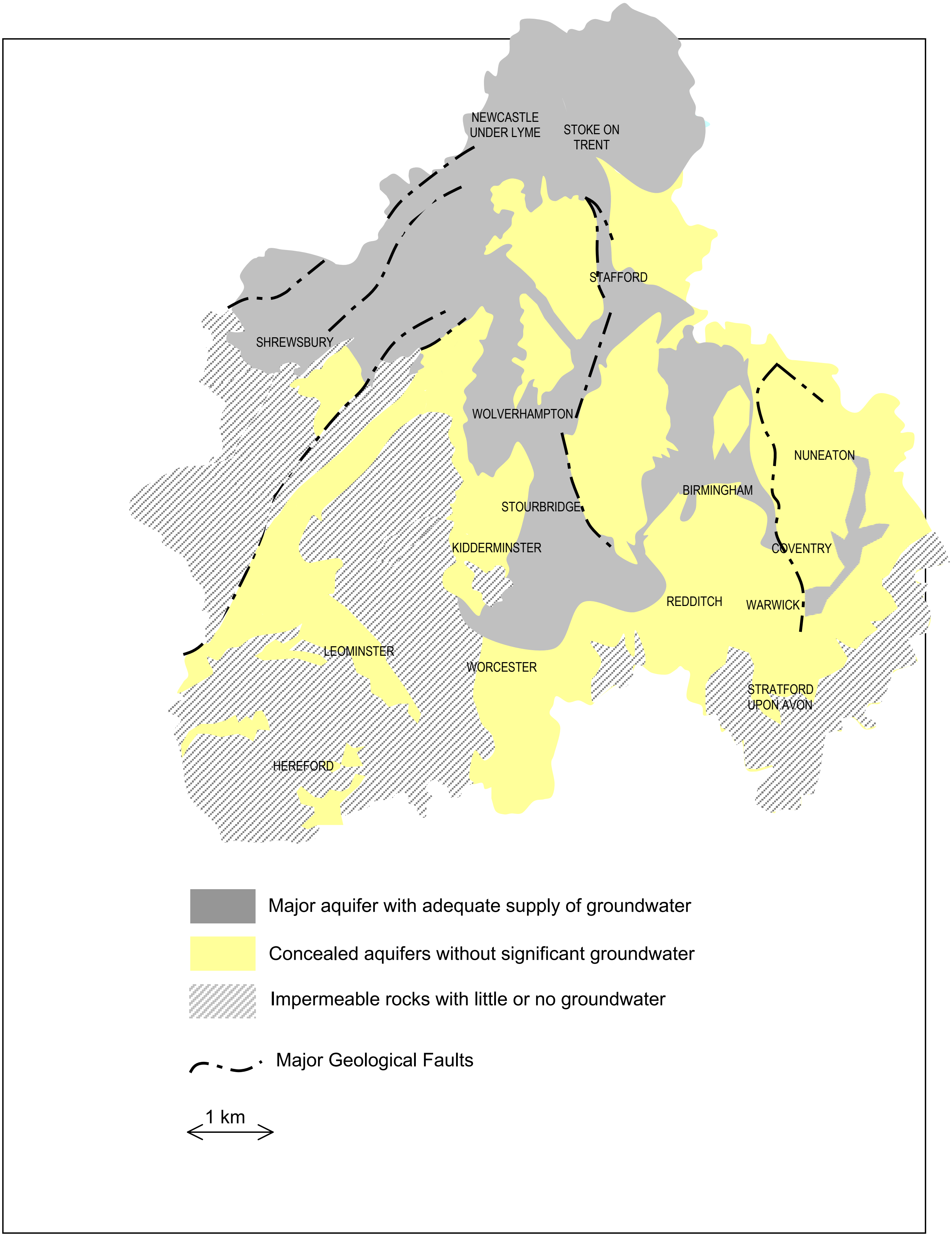


Figure 9 Simplified Hydrogeological Map of the West Midlands Region

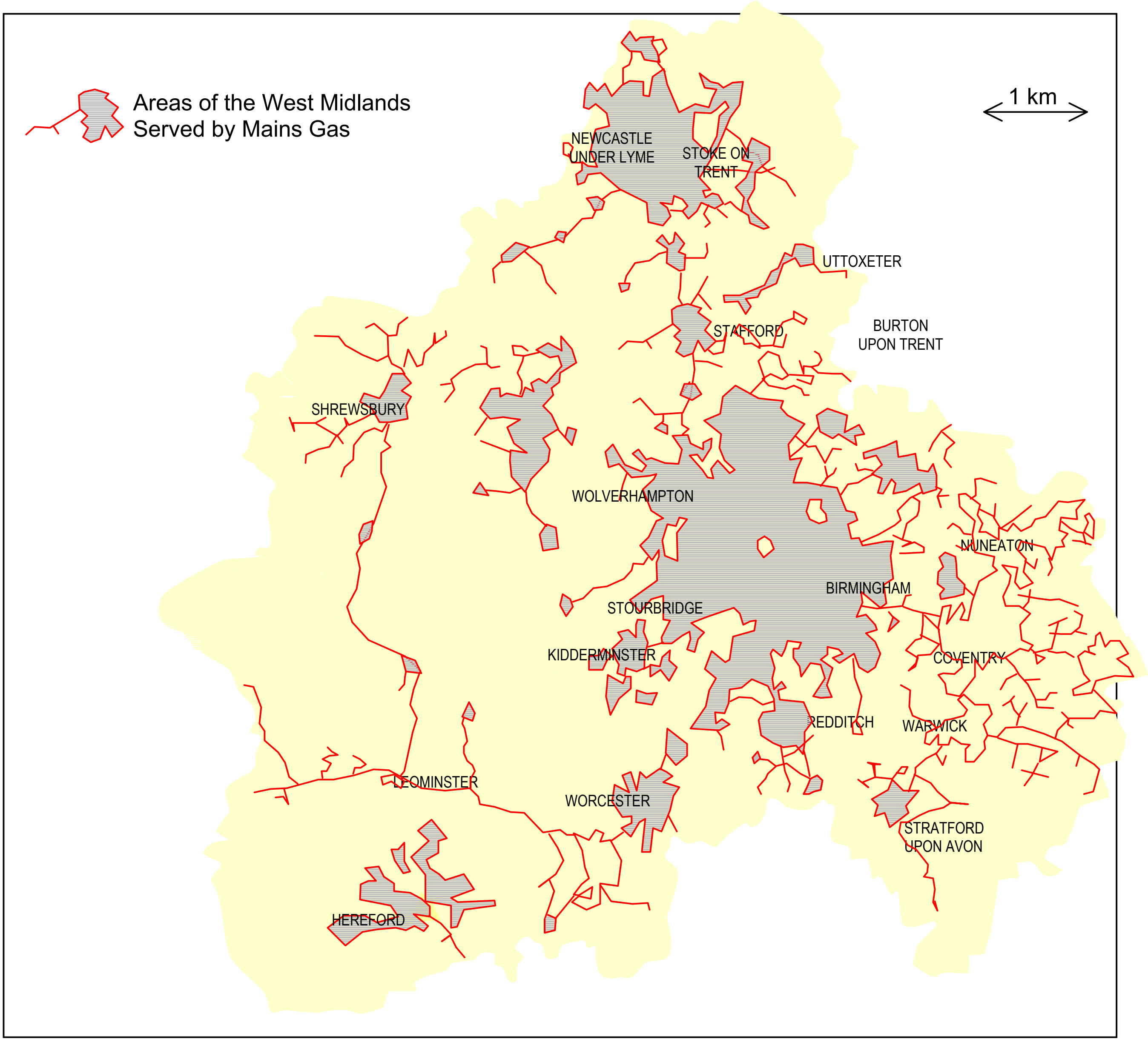
6 Suitable Sites for Explotation of Ground Source Heat

6.1 Acquisition of gas network data

Due to the fact that at the present time, the economics of ground source heat systems favour areas which are unconnected to the mains gas network, it was necessary to correlate areas having suitable groundwater conditions with areas which are off the mains gas network. Transco runs the national gas network and delivers around half of the energy needs of the UK via its 275,000km of pipework.

Transco were contacted in order to provide information about the location of the low, medium and intermediate gas networks in the West Midlands region. Transco have provided a polygon of the network West Midlands Region which is summarised in Figure 10. The gas network highlights the main areas of conurbation in the Region and shows clearly that the central and eastern part of the region is well served by mains gas whereas the western half of the region is less populated and therefore has a less dense network.

Figure 10 Map Showing Transco Network throughout the West Midlands Region



6.2 Sites which are off gas but on the aquifer

Figure 11 represents a combined overlay of areas where groundwater conditions are likely to be suitable for the exploitation of ground source heat and areas which are currently not served by the mains gas network. These areas have the potential to offer the best prospects for ground source heat in the region. Suitable areas have been highlighted to the north and east of Stoke on Trent. There are also large areas extending north and eastwards from Shrewsbury and to the west of Wolverhampton. There are also suitable areas to the south and east of Kidderminster and to the east of Coventry.

The prospects for ground source heat with respect to each Unitary Authority are summarised in Table 5:

Figure 11 Map of the West Midlands Region Detailing areas suitable for Ground Source Heat from groundwater

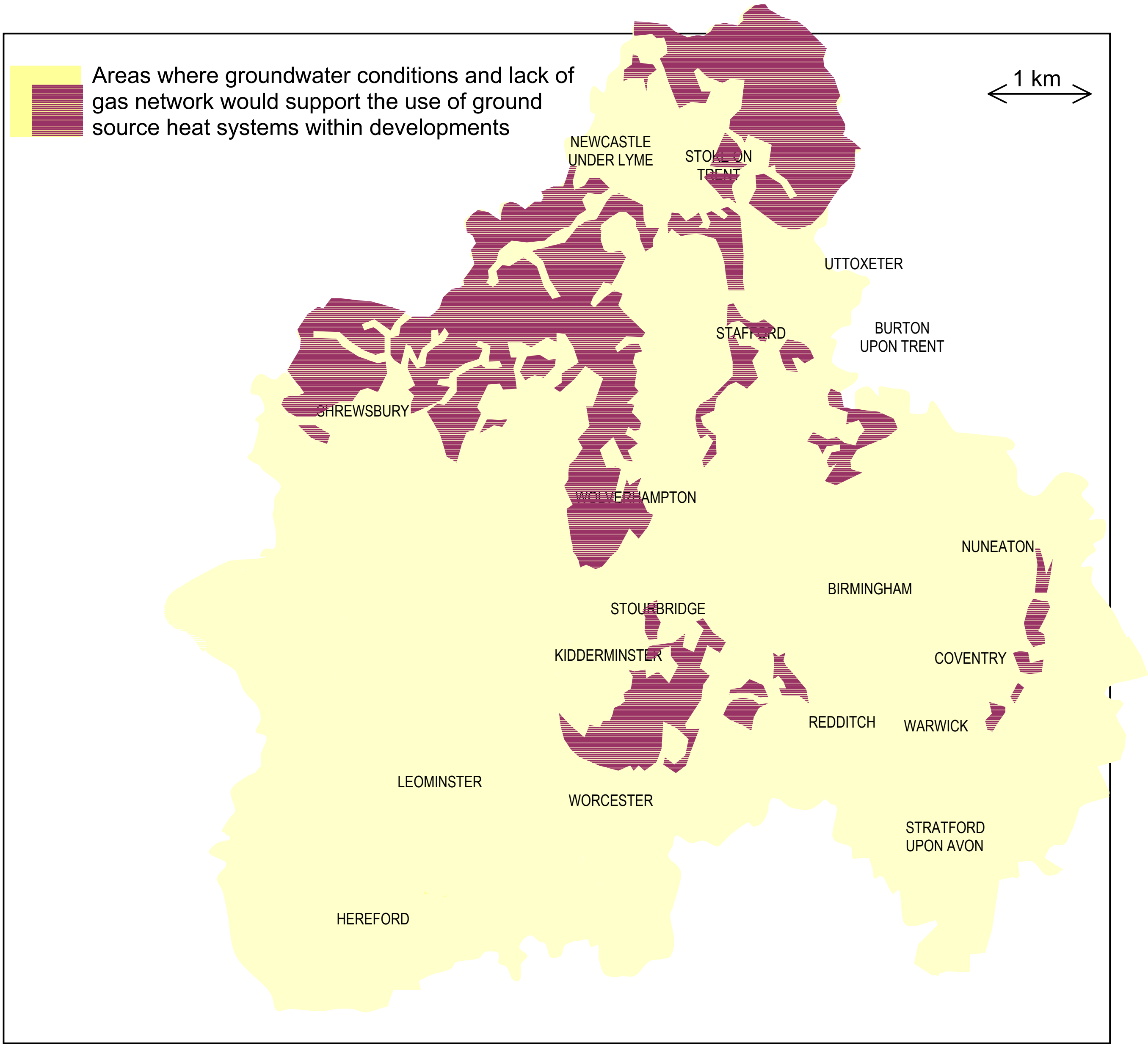


Table 5 Potential for groundwater heat pumps in each Unitary Authority

Unitary Authority	Suitability	Comments
Stoke on Trent	✗	Good gas network
Staffordshire	✓	On Aquifer, with off gas areas
Walsall & Wolverhampton	✗	Good gas network
Shropshire	✓	On Aquifer, with off gas areas
Telford & Wrekin	✓	On Aquifer, with off gas areas
Dudley & Sandwell	✗	Good gas network
Birmingham	✗ ✓	Good gas network, some areas with very shallow groundwater
Solihull	✗	Good gas network
Coventry	✗	Off Aquifer, good gas network
Warwickshire	✓	On Aquifer, with off gas areas
Worcestershire	✓	On Aquifer, with off gas areas
Herefordshire	✗	Off Aquifer

Table 5 gives a rough guide as to which Unitary Authorities need to be made aware of the potential for ground source heat within their ares. Areas where little prospect for ground source heat from groundwater have been identified should not be totally ruled out because there may be an option to install horizontal or vertical closed loop systems which do not require groundwater (see case studies in Section 4). Some of these options are described in the following sections.

6.3 Prospects for other sites

In the following sections some options will be presented for sites that lie outwith the areas highlighted in Figure 11. The success of a ground source heat system within these areas will depend upon the availability of a source of heat other than groundwater and also depend upon the type of development (e.g. new or retrofit being considered).

6.3.1Sites which are on the gas network and on the aquifer

Sites that are connected to the mains gas network and are on the aquifer may still have some potential for ground source heat depending upon the type of development being considered. If a retrofit is considered for a building already served by mains gas then a heat pump system is unlikely to be able to compete with a conventional gas system given the present gas prices. However if a new build development is considered and the building is currently unconnected to the mains gas network then a heat pump installation may compete with the cost of gas connection. Also if there are additional heat sources such as canals, lakes, rivers or the ground the capital cost of a ground source heat system will be further reduced if a borehole is not required.

An example of this is the Central Birmingham area (see Eastside case studies). The area has a dense gas network but the presence of very shallow (within 5m of the surface) groundwater in some areas of the city means that shallow (less costly) boreholes would be required. The presence of the canal network means that buildings on the banks of the canal have access to heat from this water, the lack of borehole in this scenario would further reduce capital costs.

6.3.2 Sites which are off the Aquifer and off the Gas Network

In these cases it is necessary to find an alternative heat source for the heat pump. A good example of an off aquifer, off gas site is Buntingsdale school (see Section 3.1.6) which lies on Carboniferous Geology and is off the mains gas network. At this site, the heat source is the ground and the heat exchanger pipes lie in buried trenches around the site. These systems may not be suitable for large, urban buildings because larger buildings require larger horizontal areas and at some sites space is at a premium. In this case vertical systems would be the preferred option. There are also greater heat losses in closed loop systems which is why systems which use groundwater directly can be more favourable. In urban settings where space is at a premium, closed loop systems can be used in conjunction with vertical boreholes as undertaken at Dunston Innovation Centre (Section 4).

6.4 The GATER Concept

The GATER (Groundwater as a Thermal Energy Resource) concept was outlined in a report prepared on behalf of the BRE (Building Research Establishment) in April 2003 (BRE, 2003). The report was instigated due to concerns about rising water levels in some of our cities, which included Birmingham (see explanation in Section 8). It is envisaged that in future, water will have to be pumped from beneath some of our major cities to prevent ingress into cellars, basements and underground transport and to protect existing building foundations. The report proposed several uses for this pumped groundwater:

- As a heat sink for providing cooling
- As a heat source for heat pump heating systems
- Using groundwater as grey water

The GATER report considers the possibility of pumped groundwater being circulated round cities where it could be tapped into and used for any of the purposes described above. It has been estimated that the cooling capacity of the water that will be pumped from beneath Central Birmingham to avoid ingress into building foundations and basements is around 13MW per annum. It has also been calculated that heat pumps have the potential to extract 21MW of heat from this water per annum.

7. Regulatory Framework for Abstraction of Groundwater

7.1 Abstraction of Groundwater

Permission to abstract groundwater or water from river, lakes and canals should be sought from the Environment Agency (EA) by means of applying for an abstraction licence. Applying for an abstraction licence will entail a cost (usually around £600 for the licence). Where there are plans to abstract water from a borhole, the EA will almost certainly insist that test pumping is carried out at any potential site in order to assess the impact that any abstraction may have on surrounding groundwater reserves (this will entail an additional cost). It will also be necessary to obtain a discharge consent from the EA for any water which may be discharged from the system back into the ground or into surface water features. An abstraction licence / discharge consent will not be required if a closed loop system is used because the groundwater will not be disturbed by this type of system.

7.2 Abstraction of Water from Canals

Some areas within the West Midlands Region have an extensive canal network. The Mailbox development in central Birmingham currently uses water from the canal for cooling its buildings. In order to use water from the canal for planned developments within the West Midlands Region, British Waterways would need to approve such a scheme and an abstraction licence would be required from the Environment Agency.

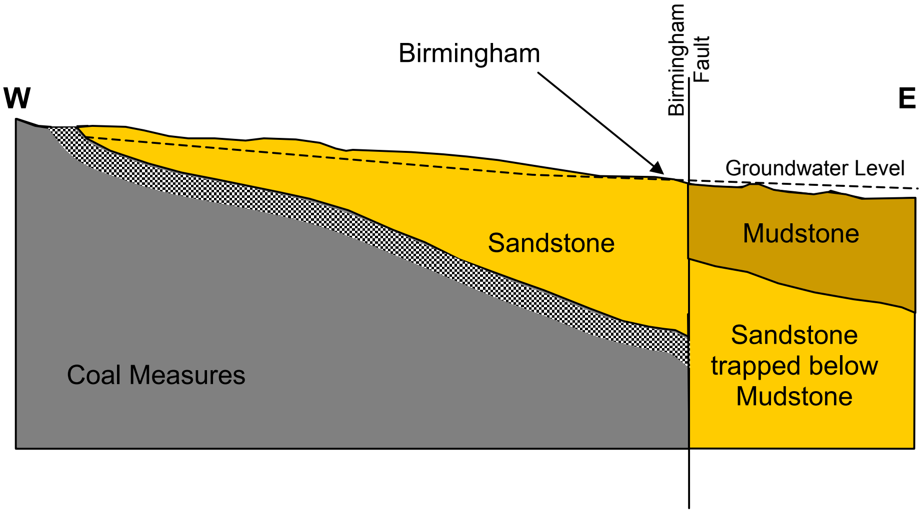
The Water Development Manager at British Waterways (Mr John Taylor) was contacted to find out whether they would be likely to support the use of canals both in general and with respect to the development at Typhoo Basin. British Waterways have stated that they would be willing for the canals to be used in this way (subject to gaining the necessary consents from the Environment Agency) and they are very keen for the wider use of the Birmingham canal network to be promoted. TNEI have also had discussions with British Waterways about also using the canal water for toilet flushing within the flats once heat has been extracted from it. They were interested in this concept and this may well justify further investigation in the future.

8. Case Studies

8.1 The Geology of the Central Birmingham area

The geology of the Central Birmingham area is detailed in Figure 12. The area is predominantly underlain by a rock formation of Triassic age which is split to the east of Birmingham by a roughly NE-SW trending fault (the Birmingham Fault). To the east of the fault sandstones underlie the surface drift deposits and to the West of the fault this sandstone aquifer is confined between mudstone formations. The Mudstones to the east of the fault are impermeable and the sequence is around 300m thick. The area is covered by superficial deposits of glacial/fluvioglacial sediments.

Figure 12 Simplified Geological Cross-section of Central Birmingham



8.2 The Hydrogeology of the Central Birmingham area

The sandstones which underlie much of Birmingham have supplied water to local industries over the past century. During the period 1860-1930 many wells were sunk to meet the needs of growing urbanisation. Abstraction from this formation was at a peak in the late 1940s/early1950s when around 75Ml/day (megaliters per day) was pumped and groundwater was drawndown by 25-30 metres below its original level. During the past 40 years the decline in industry and improved regulation of abstraction has resulted in a reduction in the amount of pumping carried out in the area and less than 15Ml/day is currently abstracted from this formation (CIRIA, 1993). Water levels in the Central Birmingham area have risen sharply due to reduction in abstraction and inputs to groundwater from recharge (from rainfall and surface runoff reaching groundwater) and from natural leakage (from canals leaking water to groundwater).

The areas where groundwater is particularly shallow include the lower reaches of the Rea Valley and the area surrounding Eastside. This rise in groundwater levels has affected some basements and industrial premises and some companies have initiated their own pumping measures to control locally elevated water levels. There is some concern that structures such as building foundations and sewers may be affected by rising water because these structures were created when water levels were much lower. There is also belief that the rising water levels may lead to reduced bearing capacity and instability of soils. The presence of shallow ground water in the

Eastside area may have implications for the construction of buildings at Eastside in the future.

The Birmingham Fault provides a barrier to the flow of groundwater where sandstone is in contact with mudstone and springs appear at this junction in some areas. However, at depth where the sandstones are in contact there is a limited groundwater flow across the fault.

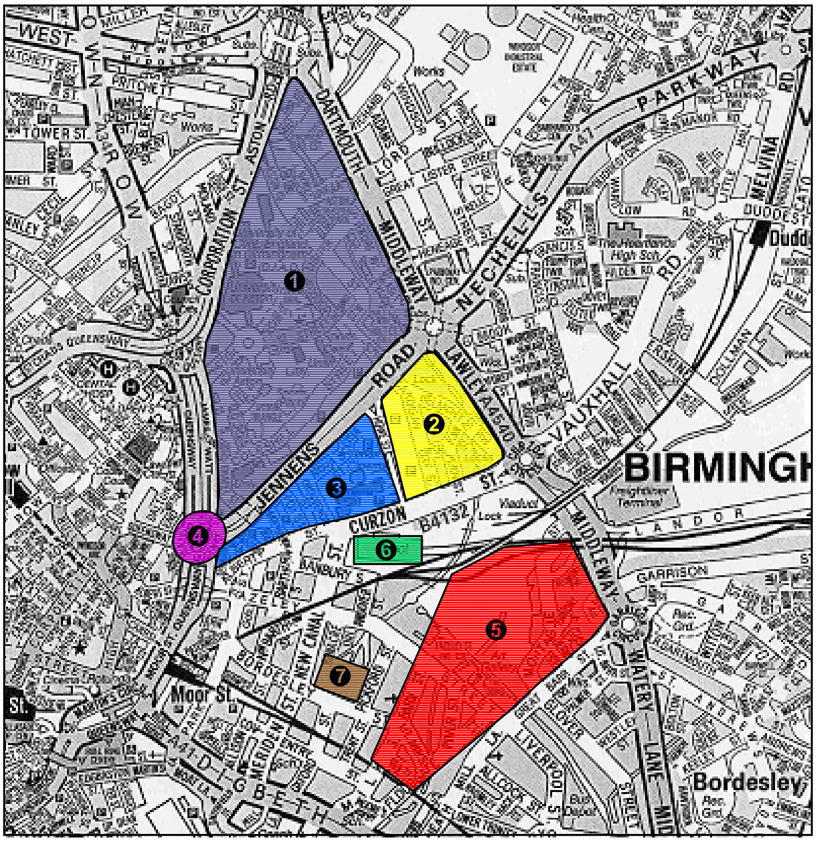
8.3 The Eastside Development at Birmingham

There is some uncertainty surrounding the exact nature and locations of buildings to be erected as part of the ongoing development of the Eastside area of Birmingham as many of the developments are still at a conceptual stage. Following discussions with a representative from Birmingham City Council, analyses have been carried out to provide information about the implications of using ground source heat for the types of development which might arise. Issues such as the use of canals or groundwater as a heat source and the contribution that ground source heat systems may make to addressing fuel poverty have been considered. The analyses comprise a detailed case study of one specific development and more general considerations of a range of other, possible Eastside developments.

8.4 General recommendations for developments planned for Eastside

As part of the planned development of Eastside, Birmingham City Council have suggested that the following developments are planned. (Refer to Figure 13 for location). Each development has been broadly assessed in terms of its potential for the incorporation of heat pump technology. The suitability of each development depends upon the geographical location of the site (i.e. whether it lies above potential reserves of groundwater, which in turn will depend on which side of the Birmingham Fault it is on or whether the site is proximal to canals). Suitability also depends upon the type of development proposed (i.e. whether the development one of the preferred applications for heat pumps as highlighted in Section 2).

Figure 13 Map of Developments Assessed at Eastside



- Aston Triangle ❶
- Technology Park ❷
- Learning and leisure quarter and City Park ❸
- Masshouse Plots ❹
- Housing at Rea Village ❺
- Curzon Street Station ❻
- Typhoo Basin ❼

The possible advantages of heat pump use were discussed more fully in Section 1 and are summarised in this section for the benefit of the Eastside study:

- Electrically driven heat pumps are very energy efficient devices because in most practical cases, the fuel used to generate the electricity required to drive a particular heat pump will be less than the fuel needed to supply the same amount of heat with a conventional boiler.
- This reduction in primary fuel consumption due to heat pump use means that heat pumps will invariably cause less environmental pollution than even the most efficient conventional heating system.
- The economic benefits are less clear cut because of the relatively high cost of electricity compared to gas and the capital cost of a heat pump compared to a boiler of the same output.

Table 6 is a more detailed version of Table 3 (Section 2) it has been included in this section so that planned developments for Eastside can be borne in mind whilst reading it. Table 6 indicates the important factors affecting economic acceptability which, in turn, allow the characteristics of potential applications to be identified. Note that the table refers only to commercial or residential space heating applications. The industrial use of heat pumps is not included.

8.4.1 Aston Triangle

This area comprises Aston University and Aston Science Park. At the University, a development of university facilities is planned which will include 600 residential units, teaching and sports facilities. The geographical location of the University would make it suitable for considering extracting heat from groundwater beneath the site. Buildings within this development that could benefit from this technology would be the residential units – which could be fitted with a communal type of scheme as has been proposed for Typhoo Basin. However, the leisure facilities are likely to be a more attractive application because they operate for long periods and may have cooling requirements. Swimming pools also create substantial low temperature heating demands because high levels of space heating are required. Therefore, the leisure facility would have both a high demand and high utilisation.

The development at Aston Science Park will include industrial and commercial premises and is planned to strengthen existing links between the University, the Science Park and the City Centre. Developments in this area would be accessible to groundwater at relatively shallow levels and there is also a canal running to the north of the site. This may be useful as a heat source provided that the canal is proximal to the planned development.

Table 6 Table highlighting the most favourable applications for heat pumps

Favourable Factors	Reason	Implications for Potential Application
High conventional heating fuel price compared to electricity price	Gives high operating cost savings	The most favourable applications do not have access to mains gas
High heat pump efficiency	Gives high operating cost savings	In general, this requires a low output temperature and a high heat source temperature. Therefore, good applications have low temperature heating systems, such as under floor heating. Water which has been subjected to some geothermal heating provides a good heat source. It should be noted that low temperature heating systems are planned at an early stage of a building development or refurbishment.
Relatively high heat demand	Gives high annual operating cost savings	Existing buildings which have limited scope to improve their thermal specification provide the best opportunities for heat pumps. New buildings can have very high thermal specifications. Consequently their energy demand for heating is low which results in a low potential for saving.
High utilisation	Improves the return on capital	In general, as more of a system's potential capacity is used, the greater the economic benefit. High space heating utilisation is achieved in buildings such as hospitals, hotels, leisure centres and residential homes. Heat pumps can be operated in reverse to provide a cooling stream for air conditioning. This provision can cause a significant increase in system utilisation.
Low parasitic costs	Parasitic costs reduce operating cost savings	Ground water heat sources can be effective with respect to heat pump efficiency. However, their use involves pumping which has an associated cost. Depending on the procedure used for transferring heat, pumping costs can be reduced if the source stream is close to or on the surface of the land where the heat pump is situated.
Reduced capital costs	Improves return on capital	Grants are available top offset the capital cost of heat pump installations but there are restrictions on the system specifications.

8.4.2 Technology Park

The Technology Park will involve the construction of new business incubation units which will straddle the Digbeth Canal. Proposed developments in this area would be able to access groundwater and also have access to water within the Digbeth Branch of the canal. As there is little information regarding the type of businesses which will occupy these units it is difficult to determine how appropriate heat pumps might be for this development. However, if the buildings have a requirement for heating and cooling and if some of the businesses have a demand for low temperature process heating then heat pump technology would be be worth considering. A similar type of facility is described in the Dunston Innovation Centre case study, this is heating using a closed loop vertical system which incorporates around 30 boreholes.

8.4.3 Learning and leisure quarter

The plans for this area include a new library and leisure facilities which will have a technology focus. The quarter will also contain the new City Park will mark the development of the first new park in Birmingham for 100 years. This area has suitable groundwater beneath it and in the eastern part of the area there is a Canal which may also provide a useful heat source. The planned library and leisure centre could be suitable heat pump applications for reasons stated earlier. Lack of information about other developments planned for this area prevent an assessment of their suitability

8.4.4 Masshouse Plots

The Masshouse Plots are situated in the Queensway area and are to be redeveloped to create a mixed use development comprising of offices, retail, residential and hotels. This area is underlain by shallow groundwater and TNEI have been involved in discussions with the hotel developers who are concerned about shallow groundwaters in the area. The hotels could provide good applications for heat pumps, again because of their demand and utilisation levels. This has been mentioned to the developers.

8.4.5 Housing at Rea Village

A Conceptual model has been developed for the creation of a village around the river Rea in the Digbeth area of Eastside. The area plots to the west of the Birmingham fault and lies on the confined aquifer. Therefore it is unlikely that groundwater systems could be used in any developments planned for this area. However the area is bisected by the Grand Union Canal, the Digbeth Branch and also the River Rea. Therefore, there is potential for heat extraction from any of these sources providing that any planned development is proximal to these heat sources.

8.4.6 Curzon Street Station

Curzon Street Station is a disused railway depot that has Grade I listed status. It is planned that this building will be refurbished to house the Royal College of Organists. The building overlies shallow groundwater reserves but the canal branches may be too distant for use as a heat pump source. The development is expected to include an air conditioned auditorium, recital rooms, catering areas and temperature controlled manuscript storage. The resulting heating and cooling demands should make this building a good candidate for heat pump use. There would be some challenges associated with installing any new heating system in a Grade I listed building. However, low temperature heating systems, such as underfloor heating, recommended for use with heat pumps are very non invasive. They have the potential to work well within the constraints of the existing building providing their use is planned at an early stage of refurbishment.

8.4.7 Typhoo Basin

The disused Typhoo Tea Factory at Typhoo Basin has been acquired by developers who plan to turn it into flats - this development has been discussed in more detail in the case study (see section 8.5).

8.5 Typhoo Basin Case Study

The Typhoo buildings in central Birmingham are no longer used commercially and have been purchased by a local developer. It is proposed to convert the existing buildings to residential accommodation. Available information suggests that the development will comprise about 350 separate residences distributed over seven floors. A further floor, the ground floor, will be used mainly as a car park. The accommodation varies from small, single-bedroom apartments to large 4-5 bedroom apartments.

8.5.1 Estimated heat loads for the development

The architect engaged by the developers has supplied plans and elevations of the proposed development and these have been used to calculate building demands (these data are included in Appendix B). From these data it has been calculated that the maximum demand for the whole complex will be 1000 GJ/annum which approximates to 278 000kWh. This estimate is based on an expectation of high insulation standards.

8.5.2 Available options for heating the development

The redevelopment of the Typhoo building will be a commercial venture therefore the proposed heating system should appeal to both the developer and the potential tenant/owner. Therefore, the direct use of renewable energy systems, such as wind, solar hot water or PV, either as main supply systems or to augment more conventional supplies, is unlikely to be favoured. However, developers are increasingly being encouraged to demonstrate some “green” aspects in their buildings and because heat pumps are a deliverable, energy efficient device they can help to improve the sustainability credentials of a development.

There are various options for heating the development and because the apartments are small and have very low heating demands, the most economic heating system for this application will tend to have low capital cost rather than low running costs. As the size of the accommodation unit rises, the heat demand rises and the supply costs become increasingly important. The options below detail the use of conventional systems within the Typhoo development:

- Condensing gas boilers are probably an acceptable choice for the larger units. They are relatively expensive but very efficient and, therefore, cheap to run.
- Resistive electric heating is likely to be a more economic choice for the small one bed roomed apartments. The relative running costs are higher, because of the high cost of electricity compared to gas, but the installation costs are low.

It is likely that there will be a preference for a single form of apartment heating. Since electric resistance heating is the common choice for small units and, often, an acceptable choice for larger, well-insulated dwellings, there is a strong argument for using it as the base case for comparison with the ground source heat system. In addition to offering a reasonably cost effective system, there are other, less tangible benefits from an electric heating system. Under-floor or wall panel heat emitters can be used which do not take up valuable wall space and there is no space taken up by heating plant. Furthermore, there is no local pollution.

8.5.3 Capability of the Canal to meet heating demand

If low temperature heating systems were used throughout the development then a heat pump coefficient of performance of around 4 could be expected. The analysis of the heat demand (Appendix B) indicates that the maximum design point heat load would be about 1.8MW and, on this basis, 1.35MW of heat would need to be supplied from the low temperature source. If canal water were to be used, it would be unrealistic to allow the heat extraction to cause more than a 5°C temperature drop to try and ensure that the return canal water was above freezing in winter. To supply 1.35MW of heat with a 5°C temperature drop requires a flow rate of about 64kg/sec. This is very high for the relatively small volume of canal water in the immediate vicinity of the Typhoo building although British Waterways have suggested that this amount may be available from the Canal.

TNEI recommend that a further investigation is undertaken to ascertain whether the canals could supply the entire development heat load on a sustainable basis. Information is required on the bulk mean canal water temperature in winter and on the flow, if any, through the local canal system. Also, the design point heat load of the building needs to be confirmed. Unfortunately, the initial evidence is not promising and effective heat pump use may involve only a contribution to the total heating load. However, this situation should not be assumed until the required investigations have take place.

8.5.4 Potential for using Heat Pumps in the Typhoo Building

Heat pumps would offer the normal benefits of low running costs and the absence of local pollution. The adjacent canal enhances the prospects of low operating costs since it could provide a convenient low temperature source with minimal pumping costs. The prospects of using heat pumps in the building are enhanced by the absence of any committed development activity. This allows the design to incorporate heating systems which would be highly compatible with heat pump requirements. In particular, it would be very advantageous to install low temperature, under floor heating, radiant panels or wall grids within the apartments.

As with conventional boilers, the small apartments may present a serious difficulty if each residential unit was to have its own heat pump. It is likely that the design point loads of these units will be 1 to 2 kW (this assessment requires further analysis when more details of the building become available) and it might be difficult to obtain systems with such a low capacity. Also the price per unit output would be high as this increases dramatically as the rated output falls. For example, based on a particular manufacturer, the capital cost per unit output of a 15kW device is approximately £172 but £292 for a 7.5kW device. This difficulty could be overcome if heat pumps were used to supply a district heating network. However, before this is considered in more detail some general implications of heat pump use need to be reviewed.

8.5.5 Comparison with alternative arrangements

Two scenarios for heat pump use were considered for the development and these were compared with conventional gas-fired boilers and electric night storage heating. The results are summarised below:

- Heating the entire building (See Table 7)

The analysis suggests that savings of approximately £7600 per annum would be possible if the accommodation units and stair wells were heated by heat pumps rather than night storage heaters and about £1000 compared to boilers. Thus, very large savings are possible if heat pumps were used rather than the most likely preferred choice of conventional systems, night storage heaters.

Table 7 Cost of heating the entire building using various arrangements

Type of heating	Annual Operating Cost
Electric Night Storage	£12700
Mains Gas	£6130
Heat Pump	£5090

However, high capital expenditure is required to achieve these savings. The cost of installing night storage heaters in a small flat is only a few hundred pounds but the total cost of a heat pump installation, i.e. the heat pump, heating and source heat circuits would be several thousand pounds. The number of flats involved means that the total additional capital expenditure could well exceed £150 000 which puts the big saving in perspective. The capital cost difference between boilers and heat pumps is considerably less. For a small flat, £300 to £500 would be a reasonable estimate. This suggests that the extra capital cost would be £15 000 to £20 000, which is still high compared to the savings. More accurate estimates of installation costs would require a much more detailed survey of requirements and installation possibilities.

- Heating the communal areas (Table 8)

Table 8 Cost of heating the stairwells using various arrangements

Type of heating	Annual Operating Cost
Electric Night Storage	£3000
Mains Gas	£1430
Heat Pump	£1190

This analysis suggests that savings of approximately £1800 per annum would be possible if the accommodation units and stair wells were heated by heat pumps rather than night storage heaters and about £250 compared to boilers. Heating in the communal areas would tend to be operational for a much longer period than individual apartments and, therefore, the utilisation of the heat pump would be relatively high. This is an important factor in the economics of heat pump operation (as described in Section 2).

It is important to note that a heat pump capacity of 300kW could be required to achieve the full potential savings in the entire building. However, if the stair wells alone are considered then the stair well savings could be made with an output capacity of only 20kW. This is a much more favourable situation from an economic standpoint due to the much higher utilisation of the equipment. Further details about the intended operation of the building are required to confirm this conclusion.

9 Conclusions and Recommendations

- Heat pumps were developed in the early 1970s in response to the oil crisis and are a proven energy efficient technology which have the potential to provide heating in cooling in a range of domestic and commercial settings.
- Heat pump systems are best suited to low temperature heating systems such as underfloor heating or radiant panels.
- Several factors affect the economic potential of a heat pump installation, these include developments having high hours of usage and those which have a demand for heating and cooling.
- Some areas within the West Midlands (approximately one quarter of the region) are underlain by suitable groundwater reserves to consider using groundwater sourced heat pumps.
- The Unitary Authorities of Warwick Worcestershire, Staffordshire, Shropshire, Telford and Wrekin have areas which have potential for the development of heat pump systems. Sustainability staff and energy managers within these Authorities should be made aware that this potential exists within certain parts of their areas.
- Architects and Developers who are active within the West Midlands Region need to be made aware of the requirements for a technically and economically feasible heat pump installation (as outlined in this report) so that the moist suitable types of development can be targeted for this technology.
- TNEI would recommend that new developments planned within the region are compared to the maps produced in Section 6 to determine whether they may suit a groundwater sourced heating system.
- TNEI would also recommend that the Government Office for the West Midlands promote this technology and encourage its use in suitable developments throughout the region. These developments can then be used to provide a working demonstration of what this technology has to offer.
- Heat pumps also have the opportunity to complement community heating networks (i.e. district heating) and developers need to be encourage to consider this option when creating new housing developments

9.2 Eastside Case Studies

- Much of the Eastside area is underlain by a sandstone aquifer which is capable of supplying significant quantities of groundwater
- Changes in industrial practices has caused a reduction in the amount of water being abstracted from the aquifer beneath the Eastside area consequently groundwater levels in this area are very shallow.
- The combination of canals, the River Rea and the presence of shallow groundwater at Eastside mean that there is the potential for heat pump systems to exploit all of these heat source for use within developments planned for Eastside.
- British Waterways are prepared to support the use of canals for heating and cooling buildings.
- The type of developments planned for Eastside (hotels, leisure facilities and mixed use developments) may well suit heat pump heating and cooling systems.
- The fact that many of these developments are still at a conceptual stage means that there is time to think about the incorporation of heat pumps to meet the heating and cooling needs of some of these buildings (i.e. features such as low temperature heating systems can be planned).
- TNEI would recommend that when Birmingham City Council receive proposals for developments at Eastside, they categorise the building in terms of the

descriptions provided in Table 6 (i.e. hours of usage, and cooling requirements) to determine whether the building may be suitable for heat pump technology before bringing this to the attention of developers.

- Of the developments planned for Eastside, the most suitable for the application of heat pump technology would be the hotels and mixed use developments planned for the Masshouse area, leisure facilities and accommodation planned for Aston University, the library in the learning and leisure quarter, Curzon Street Station and Typhoo Basin.
- At the Typhoo Basin development, the analysis undertaken has shown that heating the communal areas of the development using heat pumps which will extract heat from the adjacent canal, may offer the most practical and economic application for heat pumps within this development.
- There may also be some potential in creating a demonstration community heating project in some of the housing planned at Rea Village which would use the canals or the River Rea as a heat source
- For any Council or Community projects, Clear Skies funding could be accessed to cover the capital costs of a proposed installation.

10 References

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Appendix A

Glossary of Terms Used in Section 5

- ***Groundwater*** - Water which is naturally occurring beneath the surface of the ground. Groundwater resides in pores and fractures in consolidated rocks and in unconsolidated sediments.
- ***Surface water*** - Water that is found above ground level e.g. rivers, streams and lakes.
- ***Aquifer*** - Rocks or sediments beneath the ground which are is capable of storing and transmitting water, and have a sufficient supply of water to enable economic abstraction.
- ***Confined Aquifer*** – When an aquifer is between formations of lower permeability and groundwater becomes trapped and is under pressure
- ***Abstraction*** - This is the removal of groundwater from an aquifer
- ***Water table*** – This is the level which water sits in an unconfined aquifer
- ***Drawdown*** - This is the lowering of the groundwater level due to abstraction of groundwater.
- ***Recharge*** - This is the replenishment of an aquifer by an inflow of water from any source e.g. rainfall, rivers, discharges.
- ***Recovery*** - This is when the water level in an aquifer returns to the level it was prior to any abstraction.

Appendix B

Typhoo Basin Development
Heat Demand Calculations

The heat demand for the entire development has been assessed by extrapolation from an estimate for buildings C-1, C-2 and C-3.

Building design and dimensions

The “C” buildings would comprise essentially of two sets of two blocks of flats/apartments separated by three stair wells. Each block type will be designated type A and type B respectively in this analysis. Floors 1 to 6, inclusive, would contain the flats/apartments; the ground floor would be used for parking. In total, the blocks would contain:

- 32 one bedroomed apartments
- 4 one bedroomed flats
- 16 two bedroomed flats

The building is narrow and each flat/apartment and the stair wells would span the width. Adjacent blocks would abut the end walls over most of their area and it is assumed that both sides of the building would be mainly glazed (available drawings show only one side).

Estimates of the basic dimensions of the type A and B blocks are given in Table 1

Type	Length m^2	Width m^2	Height m^2	Volume m^3
A	10.5	11.5	19.6	2400
B	19.5	11.5	19.6	4400

Table 1
Basic Building Dimensions

The heat transfer areas through which heat would be lost for all the flats/apartments in the “C” building are shown in Table 2.

Location	Glazed external walls m^2	Floor over parking area m^2	Roof m^2	Walls adjoining stair wells m^2	Walls adjoining adjacent properties m^2	Non-glazed external walls m^2
Type A (total)	822	242	242	450	342	108
Type B (total)	1528	448	448	900	-	-
Overall total	2350	690	690	1350	342	108

Table 2
Heat Transfer Areas

Total floor area of accommodation: 4 100 m^2

It is important to note that the various dimensions, areas, etc are only approximate.

Thermal Properties

It has been assumed that the building will have a high standard of thermal insulation. Table 3 shows the base case “U” values for all the relevant heat transfer surfaces.

Surface	“U” Value (W/m^{2}K)
Glazing	2.1
Floor over parking, roof and external walls	0.2
Walls to stair wells and adjoining properties	1.0

Table 3
“U” Values

Air changes would be expected to be in the range 0.5 to 1 change per hour.

Higher performance double glazing systems are available. For example, the use of low emissivity glass would reduce the glazing “U” value to less than 1.8 W/m^{2}K. This has been regarded as an optional choice because of high cost.

Design Point Conditions

The design point temperatures are shown in Table 4

Situation	Temperature (°C)
Internal	21
External	-1
Inside stair wells	18
In car parking area	-1

Table 4
Design Point Temperatures

It has been assumed that, because the accommodation units are relatively small, the internal temperature would be uniform.

The number of degree days has been assumed to be 2500 (base 15.5°C)

Internal and solar gains

The internal gains are estimated as 24 hour averages. They are based on the following assumptions:

i. Total occupancy: 70 persons
ii. Electric cooking
iii. Each flat contains the following appliances:

- Refrigerator
- Freezer
- Cold fill washing machine
- Dishwasher
- Kettle
- Television

It is further assumed that the internal gain from lighting would be 13W per unit and solar gain would be 23W/m^2 of glazed area.

On this basis, the internal solar gains are indicated in Table 5

Source	Estimate (W)	Total gain for all accommodation units (W)
Metabolic	62.N	4300
Water heating	16.N + 25 .A	2400
Cooking	108.A	5600
Refrigerator	30.A	1600
Freezer	77.A	4000
Washing Machine	18.A	1000
Dishwasher	31.A	1600
Lighting	13.A	700
Miscellaneous	14.A	700
Solar Gain	23.2350	54000
TOTAL		77 000

Table 5
Internal and Solar Gains

Design Point Heat Loss

The heat loss through the various surfaces based on their surface areas, “U” values and design point conditions as shown in Tables 2,3 and 4 respectively is given in Table 6.

Surface	Heat Loss (kW)
Glazing	109
Floor over parking area	3
Roof	3
Walls adjoining stair wells	4
TOTAL	129

Table 6
Heat losses through building surfaces

There is no heat loss to adjoining apartments because they are at the same temperature. However, in addition to the surface losses, there is a ventilation loss depending on the number of air changes per hour.

0.5 changes per hour: ventilation loss = 50kW
1.0 changes per hour: ventilation loss = 100kW

Thus, the total design point heat loss is estimated to be in the approximate range 180 – 280 kW. This is equivalent to approximately 3.5kW to 5.4kW per accommodation unit, which is broadly in line with the much cruder estimate given in the previous analysis. However, as will be indicated later, because of relatively high internal/solar gains, the heating plant would not normally be required to operate with this level of output.

The Stair Well Heat Losses

The stair wells complicate the analysis of the total heat requirements of the "C" buildings because it is not clear whether these would be directly heated and, if so, over what period the heating would be operational.

To a first approximation, it is reasonable to assume that the dominating heat loss would be ventilation losses. The volume of the stair wells is about 3200 m^3 and 1 to 2 air changes per hour could be expected. On this basis, the design point heat loss would be 20 to 40 kW. Note that some of this requirement would be satisfied by heat losses from the adjoining apartments. Based on areas and "U" values given earlier, this would be about 4kW, ie, a relatively small amount of the total requirement. It is also a relatively small component of the heat loss from the accommodation units and could be ignored at a first approximation.

Annual Energy Demands

A procedure known as BREDEM 3, devised by the Building Research Association has been used to assess the annual energy demands. Full details of the analysis are not given because it relies on numerical data which is part of the procedure. However, in broad terms, it involves estimating the contribution to the total demands made by the heating system and internal/solar gains and the concept of the degree day which is a measure of the length of time and the extent to which the external ambient temperature falls below some specified value. In this case, the specified value is the required internal temperature. Estimates must also be made of the mean internal temperature over time for a given requirement. This feature of the procedure is necessary because British practice is not to have heating systems operating continuously.

For the purpose of this analysis, it has been assumed that each apartment is heated throughout twice per day. The Bredem procedure indicates that for these conditions the 24 hour mean internal temperature would be 18.8°C. Also, in effect, the heating system would need to raise the temperature to only 10.8°C since the internal/solar gains would produce the rest of the heating requirement. The number of degree days in Birmingham to a base of 10.8°C is 1198.

This results in an annual heat demand of 1000 GJ/annum or, approximately,
278 000 kWh/annum.

Annual Stair Well Heat Demands

Clearly, the annual demand depends on the length of time the heating system operates. Assuming one air change per hour and operation of the heating system each time the temperature falls below 18°C then the annual heat demand for the three stair wells would be, in total, approximately 300Gj/annum or 85 000kWh.

Comparison of Gas Boiler, Electric Heating and Heat Pump

Accommodation Units

Night time storage would allow the full heating demand to be satisfied with an electrical supply at the economy tariff. Assume that this costs 3.5p/unit. On this basis, *the annual cost of operating the night storage heaters would be approximately £9700*

Assume a gas boiler with an efficiency of 80% then 278 000 kWh of heat output would require 347 500kWh of gas. Assume a gas price of 1.35p/unit, then

Annual operating cost of boilers = £4700 (approximately)

Assume a heat pump has a COP of 4 then 278 000 kWh of heat output would require approximately 70 000 units of electrical input. Assume an electricity price of 5.6p/kWh, then:
Annual operating cost of heat pumps = £3900 approximately

Therefore, the annual saving in heating costs provided by the use of heat pumps would be about £5800 compared to electric night storage heating and £800 compared to gas. The equivalent percentage reductions are about 60% and 17% respectively

Stair wells

Using the same procedure as for the accommodation units

Annual operating costs of night storage heaters = £3000
Annual operating cost of boilers = £1430 (approximately)
Annual operating cost of heat pumps = £1190

Therefore annual saving due to heat pump use is:
£1800 compared to electric night storage
£240 compared to gas

Implications for "C" buildings

The analysis suggests that savings of approximately £7600 per annum would be possible if the accommodation units and stair wells were heated by heat pumps rather than night storage heaters and about £1000 compared to boilers. Thus, very large savings are possible if heat pumps were used rather than the most likely preferred choice of conventional systems, night storage heaters. However, high capital expenditure is required to achieve these savings. The cost of installing night storage heaters in a small flat is only a few hundred pounds but the total cost of a heat pump installation, i.e. the heat pump, heating and source heat circuits would be several thousand pounds.

Given that there are over 50 flats in "C" building, the total additional capital expenditure could well exceed £150 000 which puts the big saving in perspective. The capital cost difference between boilers and heat pumps is considerably less. For a small flat, £300 to £500 would be a reasonable estimate. This suggests that for the whole of the "C" building, the extra capital cost would be £15 000 to £20 000, which is still high compared to the savings. More accurate estimates of installation costs would require a much more detailed survey of requirements and installation possibilities.

It is important to note that a heat pump capacity of 300kW could be required to achieve the full potential savings in "C" building. However, if the stair wells alone are considered then the stair well savings could be made with an output capacity of only

20kW. This is a much more favourable situation from an economic standpoint due to the much higher utilisation of the equipment. Further details about the intended operation of the building are required to confirm this conclusion.

Implications for the whole site

Within the accuracy of this analysis, the “C” buildings constitute about one seventh of the total development. Therefore the use of heat pumps could save, potentially, around £53 000 compared to night storage heaters and £7000 per annum compared to the use of gas boilers. However, these savings require high additional capital expenditure and a more economically effective system might involve only public areas as this gives a higher utilisation.