POTENTIAL USE OF GROUND ENERGY IN THE EXTRACTIVE INDUSTRY

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Abstract

There are significant economic and environmental drivers for the reduction of industrial energy usage, and there is a corresponding interest in renewable and alternative sources of energy. Ground energy systems are an established low and zero carbon (LZC) technology widely used in the UK, outside the minerals industry, to reduce energy consumption and carbon emissions associated with the heating and cooling of buildings

To date very few ground energy applications have been implemented on extractive industry sites in the UK. This may be a missed opportunity because many quarry sites already have features, such as flowing groundwater from dewatering systems, or extensive borehole networks, which can be used as part of the ground collector elements of these systems.

The current paper identifies the potential for technology transfer from other industries to allow exploitation of the potential ground energy heat sources on quarry sites, including natural ground, static water bodies in flooded or restored quarries, backfilled workings, and water from dewatering systems. If these heat sources can be matched to on-site or off-site heat demands (such as heating of residential properties, or agricultural greenhouses), there are considerable opportunities to reduce energy costs, improve environmental performance and provide additional revenue streams to quarry operators.

Preene, M. and Digges La Touche, G. 2010. Potential use of ground energy in the extractive industry.
Pp. 106-114 in Hunger, E. and Walton, G. (Eds.)
Proceedings of the 16th Extractive Industry Geology Conference, EIG Conferences Ltd, 194pp.

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Introduction

Ground energy systems are an established form of Low and Zero Carbon (LZC) system which can be used to provide heat energy as an alternative to conventional fossil fuel based systems. Over the last decade in the UK these systems have been widely applied to provide heating and cooling to commercial, industrial and residential buildings, typically using natural ground as the heat source. Significant growth in the application of such systems is predicted by the Environment Agency (2009), in response to economic, environmental and regulatory drivers. Interestingly, to date, there have been only a very small number of applications of ground energy systems on minerals industry sites.

The minerals industry is subject to similar pressures to reduce energy usage and, in particular to reduce reliance on energy derived from fossil fuels. It is likely that the easiest and most sustainable gains in energy performance and emissions will be gained not from radical innovations but from incremental improvements in efficiencies and by transfer of established technologies from other industries. Therefore, the current paper is intended to promote technology transfer from other industries, and presents the background to the established ground energy technique and discusses the range of potential applications on mineral industry sites.

Energy issues in the Extractive Industry

The minerals and extractive industry is under pressure to reduce energy usage and the corresponding carbon emissions. Some of the drivers to reduce energy use and carbon emissions come from the industry's desire to be more sustainable and to meet their own internal targets, and some from Government and regulatory pressure.

Depending on the scale of the operations, UK quarry operators may be subject to the requirements of Climate Change Agreements or the Carbon Reduction Commitment (CRC) Energy Efficiency Scheme (Statutory Instrument No. 786). The practical upshot of these Government Schemes is that energy use and carbon emissions must be quantified, and reduced on an ongoing basis.

At the time of writing this paper, the UK Government is proposing (DECC, 2010a) a new subsidy scheme for England, Wales and Scotland called the Renewable Heat Incentive (RHI). This will provide a long term (up to 20 years) subsidy to the users of heat energy from renewable sources. The apparent intention is to make renewable heat sources (including ground energy systems) financially attractive compared to traditional fossil fuel derived heat sources.

There are two principal ways that fossil fuel use and the corresponding carbon emissions can be reduced:

i. by reducing energy usage; for example by applying energy efficiency measures; and

ii. by displacing fossil fuels with lower carbon alternatives such as renewable energy sources or LZC technologies which produce energy much more efficiently, from moderate inputs of traditional energy sources.

Ground energy systems are one type of LZC technology. This paper reviews the background to ground energy systems and will identify potential ground energy applications for quarry sites, exploiting a range of thermal sources. The potential benefits and constraints of ground energy applications on quarry sites will be discussed.

Ground Energy Systems

Ground energy systems (sometimes known as ground source heat pumps (GSHPs) or geothermal systems) are an established LZC technology which can produce heat energy very efficiently by exchanging heat energy with the ground. These systems are increasingly being considered as part of space heating and cooling systems for residential and commercial buildings in the UK, from single dwellings up to major commercial developments.

Although ground energy technology has been widely applied on a commercial basis in the United States and Scandinavia since the 1970s, until very recently there were relatively few applications in the UK with only an estimated 3500 systems installed by 2008 (Environment Agency, 2009). It is widely predicted that there will be very significant growth in the number of ground energy installations in the UK, driven by two key factors. Firstly, the rise in price of conventional fuels (principally natural gas), making ground energy more attractive financially. Secondly, changes in regulation: in the UK, local planning regulations and the Building Regulations explicitly require that building services engineers consider the heating and cooling efficiencies and carbon emissions of buildings.

Quarry and mineral sites often have features such water filled restored workings or groundwater pumped from dewatering systems which have the potential to be used as part of ground energy systems. To date there has been little application of ground energy systems on quarry sites although a recent MIST/MIRO report (Ellis *et al*, 2008) identified the potential. In reality, there are various potential barriers to the successful and economic implementation of ground energy systems on quarry sites, not least the need to match the availability of energy sources with nearby energy demands.

Principle of operation

In concept, ground energy systems are very simple. They exploit subterranean thermal sources, most commonly natural features such as the ground, groundwater, or bodies of water (e.g. lakes or ponds). An artificial system known as a ground collector (typically a sub-surface array of boreholes or pipework loops or other structures) is used to extract heat energy from, or inject heat energy into, the source. The ground collector is linked to a heat transfer system (typically using heat pumps) which passes heat energy from the source to the thermal load, most commonly derived from the space heating and cooling demand for a building.

Ground energy systems are categorised into two principal types based on the nature of their ground collectors: open loop and closed loop. Open-loop systems abstract water from ground collectors connected to a water source (an aquifer or a shallow pond), and pump it to the surface (Figure 1a). The water is then passed through a heat transfer system, before being disposed of (at a different temperature than before) either to waste or by re-injection back into the original source. In contrast, closed loop systems do not abstract water, but instead circulate a fluid through a ground collector comprising a loop of pipes (the ground loop) buried in the ground (Figure 1b). The circulating fluid passes through a heat transfer system at the surface, and is then recirculated back through the buried ground collector, to exchange heat with the surrounding soil or rock. Characteristics of open loop and closed loop systems are summarised in Table 1.

The ground and groundwater beneath a site can, in principle, be used as a heat sink or source. This is because, in the absence of external influences, and below the relatively shallow zone of annual temperature variation, the ground acts as a large, thermally stable mass, where the temperature varies little during the year. Ground temperatures within 100m of the surface typically reflect the mean annual air temperature at a site (in the UK, 10 to 14°C). In the summer months the ground will be cooler than the surface air temperature, so heat can be readily rejected to the ground in order to cool a building. Conversely, in winter the ground will be warmer than surface air temperature, and can readily be used as a heat source (Figure 2).

Heat pumps

A ground energy system cannot function without a heat transfer system to pass the thermal loads from the load side (e.g. a building) to the source side (e.g. the ground collector and the surrounding ground). The most common form of heat transfer system is one or more heat pumps. A heat pump is simply a mechanical device which (in its most common form) uses an electrically driven refrigerant vapour compression cycle to upgrade heat from one reservoir to another. The configuration of the heat pump most commonly used in ground energy systems is the water-water type, where heat is transferred into and out of the heat pump using water-based fluids. For example, a heat pump can use the ground beneath a site (at say 12°C) to produce warm water at say 35–45°C to heat a building. Obtaining heat in this way does sound a little illogical, but heat pump technology

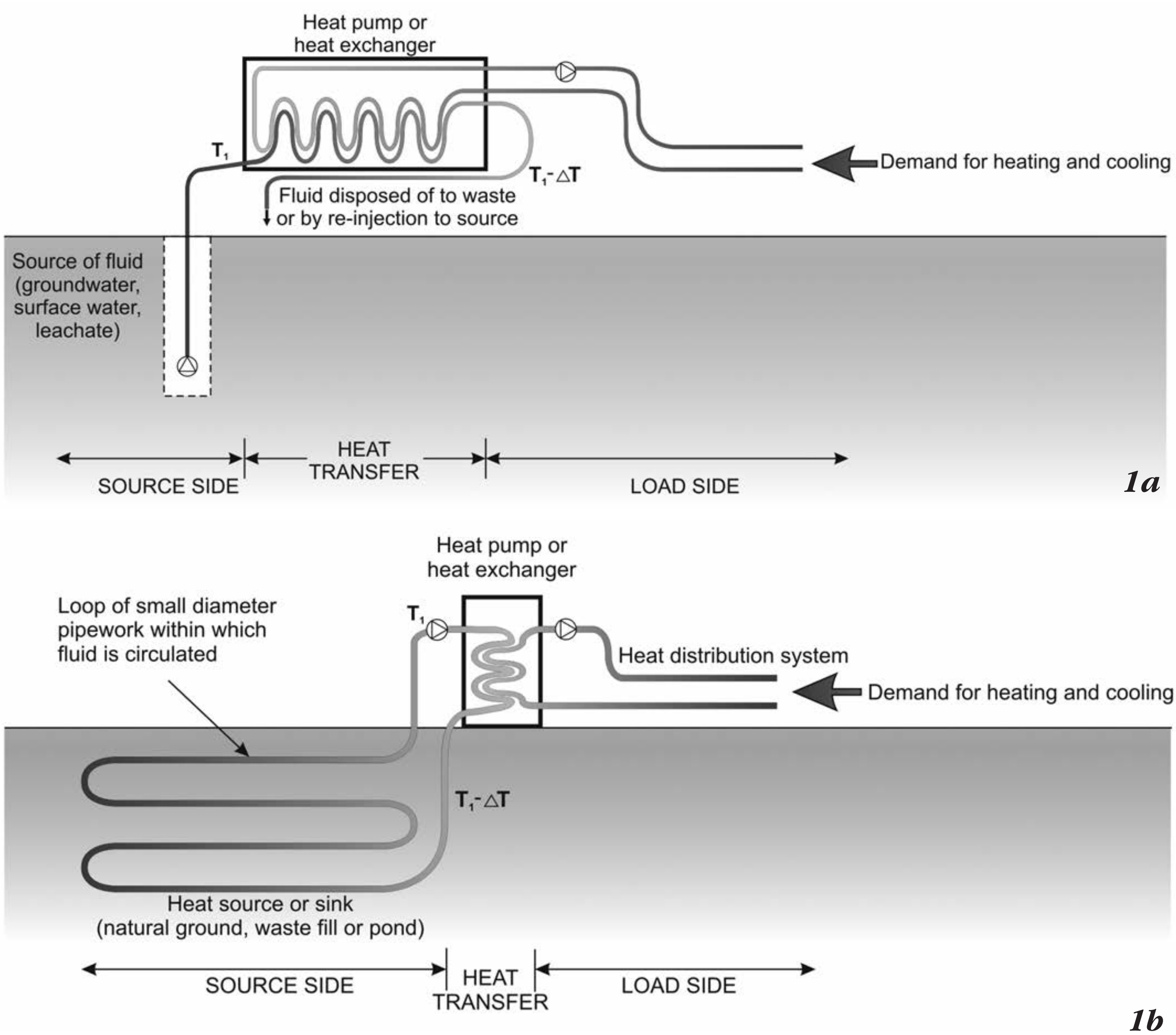


Figure 1. *Principles of open loop (**1a**) and closed loop (**1b**) ground energy systems.*

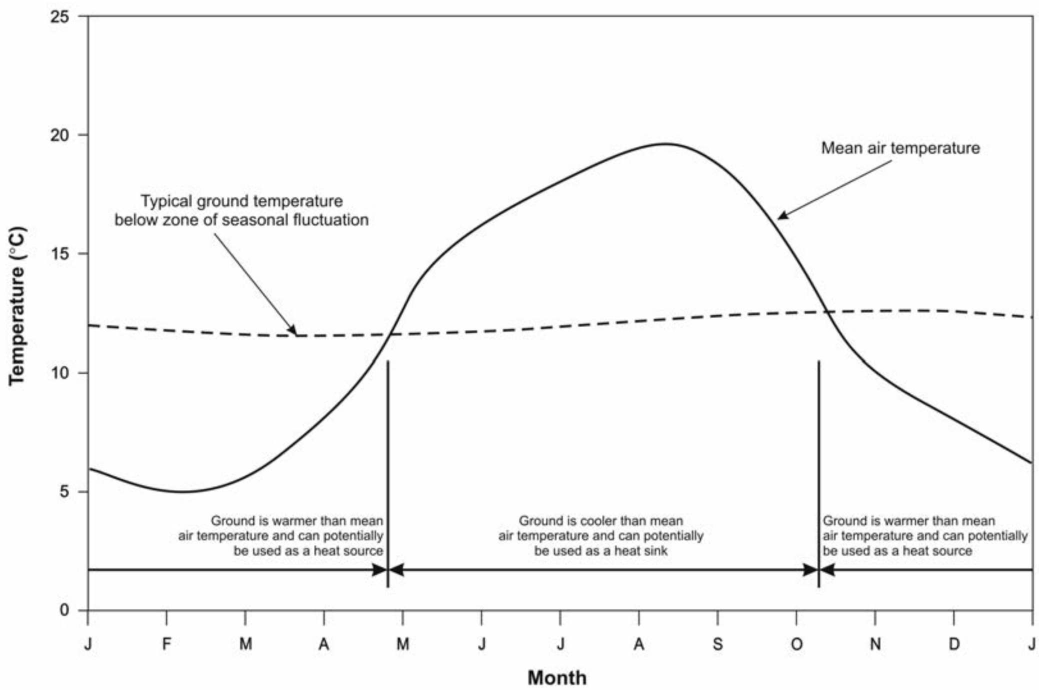


Figure 2. *Typical relationship between surface air temperature and ground temperature.*

Characteristic	Open Loop	Closed Loop
Abstraction of fluid (groundwater or water from lake/pond)	Required in all cases (although net abstraction may be zero if all of the water is re-injected into the source).	Not required.
Disposal of warmer or colder water	The water pumped by the system must be disposed of without causing unacceptable impacts. Typical disposal routes include to sewer, to surface water or by re-injection back into the original source at a point distant from the location of abstraction.	Not required.
Regulatory constraints	Typically subject to the requirements of groundwater abstraction licensing. Water disposal may also require regulatory consent.	Because no water is extracted, these systems are typically not subject to direct regulation. However, regulatory bodies may insist that any boreholes or ground loops are constructed in such a manner that they do not form a pathway for seepage.
Dependence on favourable hydrogeological conditions	Open loop systems based on groundwater are only practicable when significant water-bearing strata (which collectively form an 'aquifer') are present beneath a site. Open loop systems can also be used where lakes/ponds exist.	Closed loop systems do not require the presence of an aquifer or surface water body, and can be practicable in a wide range of geological settings.
Potential for off-site impacts	May be significant under certain hydrogeological conditions (e.g. permeable aquifers with significant hydraulic gradients), or where the water temperature of a lake/pond is significantly changed.	Limited - heat migration from the boreholes or ground loops is primarily by conduction and this is a relatively slow process.
Typical scale of source infrastructure	Under favourable hydrogeological conditions, where borehole yields are significant, relatively small numbers of abstraction boreholes can supply large peak thermal demands. Where water is abstracted from a lake/pond infrastructure requirements are relatively modest.	The peak thermal capacity of a closed loop borehole is typically much less than that of an open loop borehole. Closed loop systems typically require much greater number of boreholes (or great lengths of ground loop) compared to open loop systems.
Long term operational issues	Clogging and encrustation (e.g. due to ochre or scale deposits) can occur in groundwater abstractions. Surface water (pond/lake) intakes may be affected by the build up of sediment or vegetation. Periodic inspection and maintenance of groundwater abstraction points and surface water intakes is advisable.	Long term maintenance requirements of closed loop ground collectors are relatively modest.

Table 1. *Typical characteristics of open loop and closed loop ground energy systems.*

is more than 100 years old and is part of everyday domestic life in developed countries. The humble kitchen refrigerator is essentially a heat pump. Heat is extracted from the interior of the refrigerator and is rejected to the kitchen via the coils located commonly at the back of the unit.

Heat pumps based on the vapour compression cycle use electricity to operate a compressor (which is the part of a kitchen refrigerator that makes a noise when it is operating); therefore they do use some external energy, but they use this very efficiently. One approximate measure of the efficiency of a ground energy system is the coefficient of performance (COP). This describes the ratio of the total heat output to the quantity of electrical energy used to drive the heat pump.

The external energy E used to drive a heat pump to produce heat energy H is related to COP by:

$$COP = H/E \qquad (1)$$

Actual COPs in practice are strongly influenced by the source temperature and the output temperature of the heat pump, but COPs of 3 to 5 are not unusual for well-designed systems. This means that for every kW of electrical energy used, 3 to 5 kW of heat energy can be obtained. As a result the energy usage (and hence the energy bill at the end of the year) will be typically 20 to 30% of the total for a conventional fossil fuel system. Table 2 presents unit heat energy costs (pence per kWh heating) based on data from DECC (2010b). This shows that at COPs of 3 to 5, ground energy systems can produce heat at unit costs per kWh comparable to cost of natural gas from grid supplies. For sites not connected to the gas grid, ground energy systems can provide heat at significantly lower cost than heat from conventional electrical or oil-fired heating systems.

Fuel used for heating	Cost per kWh (p) Min	Cost per kWh (p) Max
Gas[1]	1.78	2.47
Electricity[1]	6.34	8.18
Oil[1]	5.68	5.69
Heat pump[2] (COP = 3)	2.11	2.73
Heat Pump[2] (COP = 5)	1.27	1.64

1 Costs based on DECC Quarterly Energy Prices Report, June 2010. Data for medium and large manufacturing energy users (DECC, 2010b).

2 Calculated from equation (1) and COP, assuming electrically driven heat pump.

Table 2. *Estimated unit costs of heating.*

The proposed introduction of the Renewable Heat Incentive (RHI) scheme in England, Wales and Scotland (DECC, 2010a) will provide a subsidy for every kWh of heat produced by ground energy systems (and other LZC technologies). The RHI has the potential to make the unit energy costs from ground energy systems much less than from traditional fossil fuel sources. This will help offset the additional capital costs associated with the installation of LZC technologies.

It is sometimes possible to operate ground energy systems without a heat pump. If the difference between the source temperature and the required output temperature is relatively small, it may be possible to use a simple heat exchanger in place of a heat pump. This approach is known as 'direct heating' or 'direct cooling' since there is no requirement to use electricity to drive a heat pump (there will however be a small power requirement for a circulation pump). Such 'direct' GSHP systems are highly energy efficient and may have COPs in excess of 20; unit heating and cooling costs are correspondingly low.

Identifying potential sources of Ground Energy on Quarry sites

Quarry sites may contain various possible sources of ground energy on a given site. Each type of source will have different positive and negative features. Understanding the characteristics of the source is vital if ground energy systems are to be successfully implemented. The principal ground energy sources relevant to quarry sites are briefly summarized below and in Figure 3.

Natural ground

Natural ground is a potential energy source on quarry sites, just as it is on any site; this is the most common source of energy exploited for conventional ground energy systems used to heat and cool buildings. Where an aquifer or other water bearing strata are present, open loop systems can be used. Closed loop systems can be used in a wider range of ground conditions, whether water bearing or not.

Static water bodies

Where quarries are restored as water bodies, there are opportunities to exploit ground energy by both open loop and closed loop systems. Open loop systems involve pumping (or allowing gravity flow) of water from the water body, and passing the water through a heat pump or a heat exchanger. Closed loop systems involve placing a heat exchanger system (either a proprietary unit or one fashioned from coils of pipe) within the water body. The heat exchanger can be placed in the base of the quarry prior to flooding, or can be floated out and sunk after the works are flooded.

Backfilled workings

Another potential source of ground energy on quarry sites is backfilled workings. In low permeability materials it may be appropriate to install a closed loop ground collector during the backfilling of the works. Where quarries were dewatered in operation, it may be possible to install wells or sumps during backfilling, to allow water to be abstracted and used in an open loop system once quarry backfilling is complete.

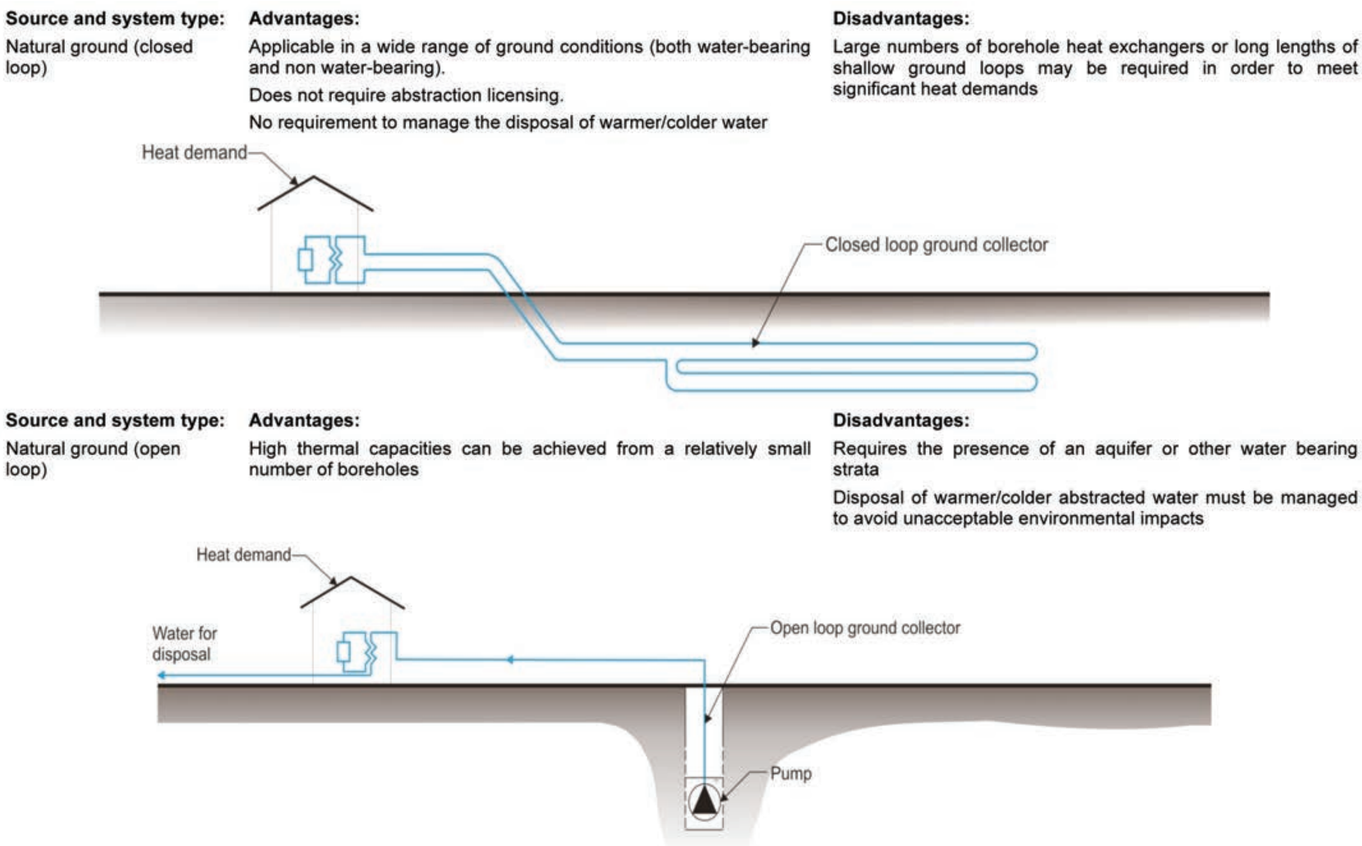
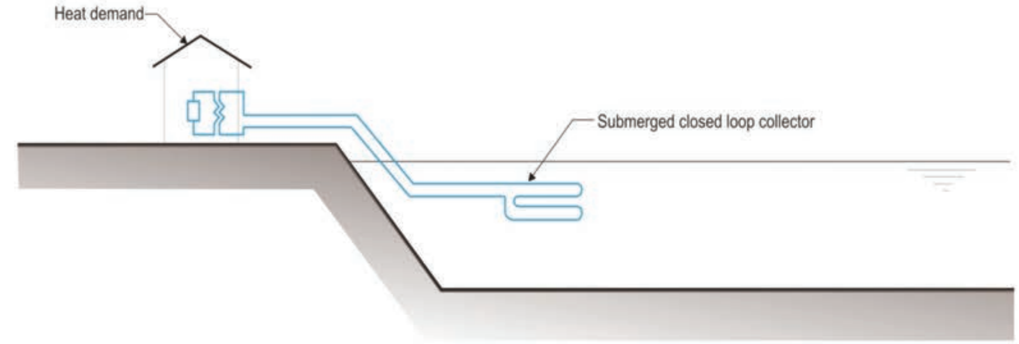
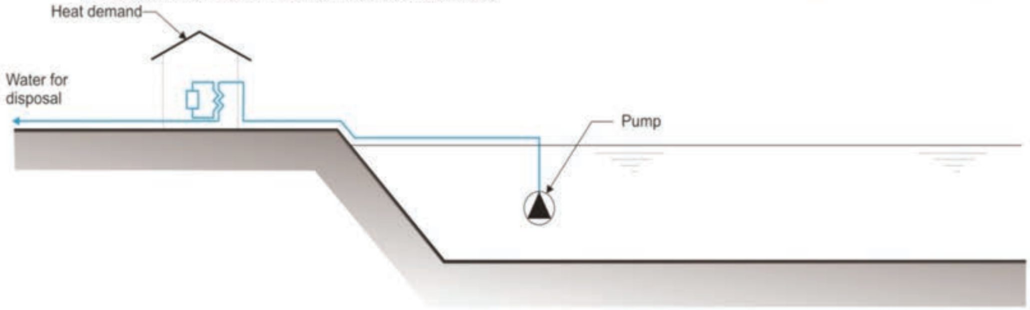


Figure 3. *Potential sources of ground energy on quarry sites.*

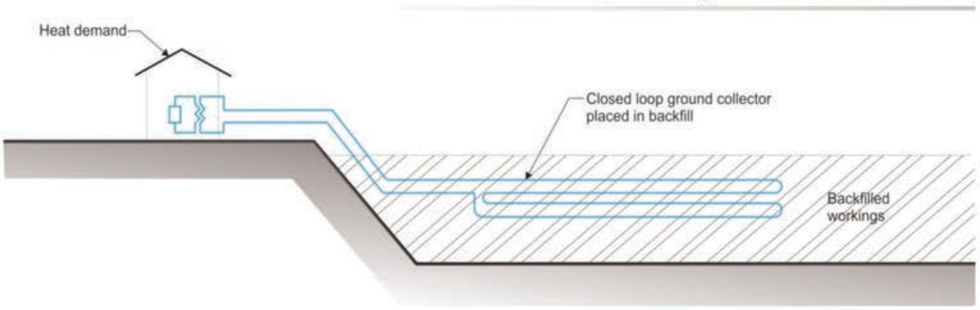
Source and system type:	Advantages:	Disadvantages:
Static water bodies (closed loop)	Ground collector arrangements are straightforward and can be retrofitted into existing water bodies Does not require abstraction licensing No requirement to manage the disposal of warmer/colder water	Exchanging of heat with the water body may result in temperature changes which could affect ecological conditions



Source and system type:	Advantages:	Disadvantages:
Static water bodies (open loop)	Only relatively straightforward pumping infrastructure is required Existing gravity water flows can also be harnessed	Disposal of warmer/colder abstracted water must be managed to avoid unacceptable environmental impacts



Source and system type:	Advantages:	Disadvantages:
Backfilled workings (closed loop)	Does not require abstraction licensing No requirement to manage the disposal of warmer/colder water	Placement of buried ground collectors may require changes to the methods and sequencing of backfilling Long lengths of buried ground loops may be required in order to meet significant heat demands



Source and system type:	Advantages:	Disadvantages:
Backfilled workings (open loop)	High thermal capacities can be achieved from a relatively small number of abstraction points	Requires both geological strata and backfill to be highly permeable Placement of abstraction points may require changes to the methods and sequencing of backfilling Disposal of warmer/colder abstracted water must be managed to avoid unacceptable environmental impacts

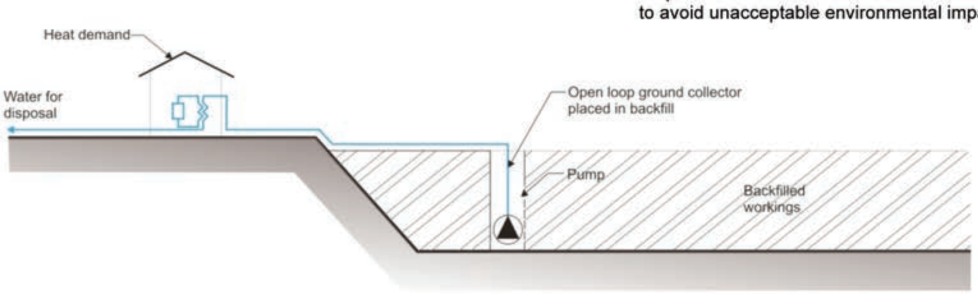


Figure 3 continued

Source and system type:	Advantages:	Disadvantages:
Dewatered quarries (open loop)	Heat energy can be extracted from water that is already being pumped, minimizing additional capital and operating costs	Disposal of warmer/colder abstracted water must be managed to avoid unacceptable environmental impacts May restrict options to develop micro-hydropower schemes using dewatering flows

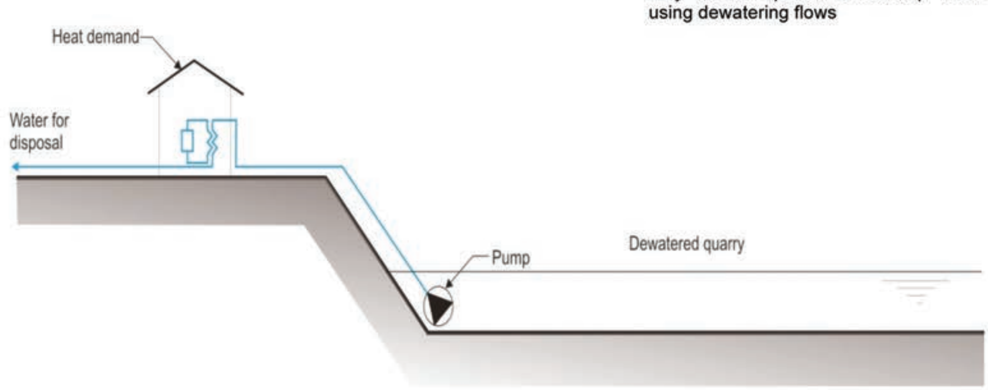


Figure 3 continued

Dewatered quarries

Probably the most obvious source of ground energy on quarry sites is the water pumped from dewatering systems. The quarry operator is already pumping this water, which contains a lot of heat energy. It makes sense to try and exploit this energy. This can be done by diverting some or all of the water flow though a heat pump or a heat exchanger, to allow heat to be extracted for use via open loop systems.

Regulation of Ground Energy Systems

There are specific environmental regulation issues that relate to closed loop or open loop systems. Open loop systems involve the pumping of groundwater and, in general, will require an abstraction licence from the relevant UK regulators (Environment Agency (EA), Scottish Environment Protection Agency (SEPA), Northern Ireland Environment Agency (NIEA)). In contrast, closed loop systems are not currently regulated under the abstraction licensing system. The environmental regulation of ground energy systems is rapidly evolving at present, and reference should be made to current publications by the regulators (for example EA, 2007a, 2007b; SEPA, 2010), which include guidance on environmental issues of both closed loop and open loop systems.

Potential heat demands associated with Quarry sites

The potential demand for the heat energy available from quarry sites can be divided into two categories: on-site demand and off-site demand. Heat demand can include the requirement for cooling systems for office buildings or for industrial processes.

The most obvious use for the energy from quarry sites is on the site itself. This is because the on-site heat demand will be nearby, and will typically be under the control of the quarry operator. As a result the practicalities and commercial relationships will be straightforward. Many quarry sites will contain site offices and workshops which may require heating (and occasionally cooling). Ground energy systems can be used to replace electric or gas heaters in these applications. Some quarry sites will also have process (concrete batching or asphalt coating) plants on site. Asphalt plants in particular are significant users of heat energy, but the temperatures involved are typically much higher than can be generated from ground energy systems. In general there appears to be little potential to use ground energy systems to provide energy to process plants, apart from some opportunities for temperature moderation of water and aggregates in ready mix concrete batching plants.

The potential for off-site heat demand will vary significantly from site to site. It is relatively unusual in the UK for quarry sites to be located in densely populated areas; more commonly they are in rural areas or on urban fringes. However, it is likely that, as a result of housebuilding programmes, in the coming years an increasing number of operational and restored quarries will be near significant development areas. They may be corresponding opportunities to provide heat to residential and commercial properties in the surrounding area. One way that heat can be supplied to multiple properties is via district heating systems. These allow a relatively small number of heat sources (ground energy or conventional heat sources) to feed into a heat network (typically comprising buried pipes used to circulate warm water) which supplies heat to multiple properties. District heating systems are currently relatively rare in the UK, but can be a very efficient way to utilize power from conventional and renewable sources. It is probable that district heating systems (perhaps rebranded as community heating networks) will increasingly be considered as an option when new developments are proposed.

In addition to heating and cooling of buildings, there are potential heat demands associated with agricultural land uses. Examples include glasshouse heating, drying of produce, fish farm heating and other large scale uses of low temperature heat. For quarries located in rural areas the exportation of heat for agricultural use could be an area with significant potential.

How can ground energy be used on Quarry sites?

It is clear that quarry sites contain several potential sources of ground energy. However, this energy is not exploitable unless three conditions are met:

i. There is a demand for the heat energy;

ii. The temperatures of the heat demand are compatible with ground energy systems; and

iii. The heat demand is located close to the source.

These factors are explored in more detail below:

Demand for the heat

Without a demand and viable end use, the heat energy is of no value. The first stage in developing a ground energy scheme will probably be the identification of end uses (and hence potential consumers) for the heat that can be harvested from a quarry site. Potential heat uses are identified in the previous section and in Table 3.

Temperatures of heat demand

Unfortunately, ground energy systems cannot generate heat at very high temperatures. These systems operate most efficiently when providing warm water up to around 35ºC, and can provide maximum temperatures of up to 60ºC, albeit at lower efficiencies. Ground energy systems are likely to be viable only when matched with heat demands in these temperature ranges. Where higher temperatures are required it may be possible to use ground energy systems to provide a pre-heating input, with heating to final, higher temperatures achieved by traditional heating systems. Such a 'hybrid' arrangement could significantly reduce fossil fuel use in a heating system.

Location of heat demand

Ground energy systems typically produce heat in the form of warm water, which must be transmitted through insulated pipes from the source to the point of demand. Such transmission is relatively inefficient, and successful ground energy examples are rare where the source of

Heat Demand	Suitability for supply from ground energy system	Comments
On site demands		
Space heating of site offices and workshops	May be suitable	Ground energy systems will operate most efficiently where low temperature heat distribution systems (e.g. underfloor heating) are used. This may require retrofitting into existing buildings. Could be configured to provide cooling in summer months
Ready mix batching plants (Temperature control of aggregates and batch water)	May be suitable	Ground energy systems could be used to maintain water and aggregates at moderate temperatures to prevent process interruptions or problems due to excessively high or low temperature of materials
Asphalt coating plants (Drying of aggregates and heating of bitumen)	Not suitable	Temperatures required in coating plants are significantly higher than can be delivered by ground energy systems
Ancillary uses (Pre-heating of fuels and frost protection of water systems)	May be suitable	Ground energy systems could be used to pre-heat fuel oils to 45-60ºC or to provide energy to frost protection systems
Off site demands		
Space heating of individual residential properties	May be suitable	Most likely to be suitable for new-build developments with modern standards of insulation and low temperature heat distribution systems. Can be used on older properties but additional retrofitting of energy efficiency measures may be required. Could be configured to provide cooling in summer months
Space heating of larger commercial or community properties	May be suitable	Most likely to be suitable for new-build developments with modern standards of insulation and low temperature heat distribution systems. Can be used on older properties but additional retrofitting of energy efficiency measures may be required. Could be configured to provide cooling in summer months
District heating of community systems	May be suitable	Design of district heating systems needs to be carefully matched to the temperatures available from heat pumps. Could be configured to provide cooling in summer months
Agricultural uses	May be suitable	Possible uses include glasshouse heating, drying of produce, fish farm heating. Heat use must be at a sufficiently low temperature to match the output of the heat pump

Table 3. *Potential applications for ground energy from quarry sites.*

ground energy and the location of heat demand are separated by more than a few hundred metres.

Sustainability of ground energy use

It is important to recognise that the ground is not an infinite heat source. Previous studies have shown that shallow ground energy systems tap into heat energy stored in the ground that is predominantly solar in origin, rather than from geothermal heat flux from depth. The earth's surface acts as a large solar collector, and the heat energy stored in the ground is continually replenished, primarily from solar radiation.

Energy input to the ground from solar flux is finite. The reason that ground and groundwater temperatures are relatively stable during an annual cycle is that natural heat inputs and outputs are approximately in balance. The introduction of a ground energy system extracting heat (or rejecting it in the case of cooling systems) will change that balance.

In order to be considered sustainable, the rate of extraction of heat by ground energy systems should be limited to rates that do not result in large temperature changes in the heat source (i.e. the ground, groundwater or surface water). In the example of systems used for heating, excessive rates of heat extraction will result in the temperature of the source (ground or water) reducing with time. Over several years of year-on-year reduction in source temperature it is possible that the ground or water around the ground collector will freeze. This will cause significant practical difficulties and will reduce the efficiency of the ground energy system, as well as having detrimental environmental impacts.

A key stage in the design of ground energy systems is to assess the sustainable rate of heat extraction, considering the characteristics of the source and the proposed ground collector.

Commercial aspects

Where quarry operators plan to use heat from ground energy systems to meet on-site demand, the commercial situation is straightforward. The heat energy from the ground energy system will simply replace heat from conventional sources (e.g. gas, oil, electrical heating) so the operator will use less and pay less to their energy supplier.

However, where the quarry operator intends to harness heat energy on their site and export it to supply off-site demand the commercial situation may be more complex. The quarry operator would effectively become a heat supplier to off-site third parties. The benefits are that the sale of heat would be a new income stream for the operator, but the downside is that there would be a need for commercial arrangements with those buying the heat, and systems for metering and billing are likely to be necessary. In practice, it may be appropriate for the quarry operator to become part of, or develop a relationship with, an 'energy supply company' (termed an EsCo) who will manage the sales and distribution of the heat energy. Where heat is supplied to residential developments, it is possible that community groups may wish to form or collaborate with EsCos.

Conclusion

Ground energy systems are a proven and reliable low and zero carbon (LZC) technology, increasingly being applied in the UK, outside the minerals industry, to provide heating and cooling to buildings. Current and future regulatory and economic drivers to reduce energy costs and carbon emissions are likely to make ground energy systems increasing attractive in the future. The current paper identifies that there is considerable potential to apply ground energy systems on quarry sites.

Quarry sites may contain several potential ground energy heat sources, including natural ground, static water bodies in flooded or restored quarries, backfilled workings, and water from dewatering systems. These heat sources provide opportunities to reduce energy costs, improve environmental performance and provide additional revenue streams to quarry operators if they can be matched to on-site or off-site heat demands (such as heating of residential properties, or agricultural greenhouses).

Acknowledgement

The authors are grateful to Mr Paul Newbury of Hanson UK for providing generic information regarding on-site heat demands on typical UK quarry sites.

References

DECC. 2010a. Renewable Heat Incentive Consultation on the Proposed RHI Financial Support Support Scheme. Department of Energy and Climate Change. February 2010.

DECC. 2010b. Quarterly Energy Prices, June 2010. Department of Energy and Climate Change.

Ellis, P., Healy, N., Leake, C., Smithyman, R., Ward, A., Moore, S. & Mann, D. 2008. Water-based quarry restoration: opportunities for sustainable rural regeneration and nature conservation. Report MA/6/2/013, Minerals Industry Sustainable Technology Programme, Minerals Industry Research Organisation.

Environment Agency. 2007a. Groundwater Protection Policy and Practice, Part 2 – Technical Framework. Environment Agency, Bristol.

Environment Agency. 2007b. Groundwater Protection Policy and Practice, Part 4 – Legislation and Policies. Environment Agency, Bristol.

Environment Agency. 2009. Ground Source Heating and Cooling Pumps – State of Play and Future Trends. Environment Agency, Bristol.

SEPA. 2010. Supporting Guidance (WAT-SG-62) Groundwater Abstractions – Geothermal Energy. Scottish Environmental Protection Agency. February 2010.

Statutory Instrument No. 786. The CRC Energy Efficiency Scheme Order 2010, 17 March 2010