Ground source heat pump systems

Benefits, drivers and barriers in residential developments

NHBC Foundation

Housing research & development in partnership with BRE Trust

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FOREWORD

Continuing our focus on issues related to the sustainability and zero carbon agenda, which remain at the fore of political focus in parliament, the NHBC Foundation has produced this review – *Ground source heat pump systems – Benefits, drivers and barriers in residential developments* – to look at issues surrounding the use of ground source heat pump systems.

Potentially offering a sustainable and zero carbon method of heating the home, ground source heat pump systems have been embraced by many European countries, chiefly Scandinavia, Sweden and the alpine countries. It must be remembered, however, that the technology is still in the early stages and that, without a renewable energy supply to meet its power demands, it can only reduce energy requirements in the home, not achieve the zero carbon target set by government.

This review has been produced at a time when the take-up of ground source heat pump systems is on the increase and is a valuable tool for specifiers, developers and builders looking to incorporate this new technology. With detailing on cost benefits, analysis on construction practices, reliability, maintenance and interfaces with other systems it makes important strides in addressing the use of ground source heat pump systems.

Setting out the practicalities and pitfalls associated with this new technology this review also calls for fresh research in key areas, including:

- The development of a design code for ground loop systems.
- Profiling of the seasonal performance of ground source heat pump systems as a whole.
- The development of product test standards for underfloor heating systems, with which ground source heat pump systems works best.
- Modelling and software development to calculate seasonal performance to establish suitability for specific projects.

Regulatory drivers are assessed in the review, chiefly Part L of The Building Regulations which is pushing forward thermal efficiency requirements and defines Target Emissions Rates. In addition, the requirements of the Code for Sustainable Homes continue to be fundamental in laying out the target for zero carbon homes.

I am confident this review provides a framework to help the industry get to grips with ground source heat pump systems in the short term, and develop research and processes in the long term, to ensure the technologies bring real benefits for the zero carbon homes of the future.

Imtiaz Farookhi

Chief Executive, NHBC

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1 Introduction

Ground source heat pump (GSHP) systems use low level heat energy created by solar gain in the near surface layers of the earth, to extract energy which can be used for space and water heating. This potentially limitless supply of energy appears to be a good route to a sustainable energy supply.

This review:

- summarises the background to GSHP systems used in residential developments
- assesses the state of the art
- provides brief guidance on specifying, checking the design and installation of these systems
- identifies the benefits, drivers and barriers in comparison with conventional heat sources
- proposes future research requirements.

The implications for the construction process, such as in-site investigation, external works, insulation levels, heating plant and timetabling are also discussed.

The benefits, drivers and barriers of GSHP systems are discussed in the following categories:

- Political (including planning, and English Partnership competitions)
- Regulatory (The Building Regulations 2000 Approved Document Part L1A. Conservation of fuel and power in new dwellings,[1] compliance with regulations set by local authorities, building control and standards set by the NHBC)
- Economics
- Construction practice
- Reliability, maintenance and availability

- Interface with other systems
- Provision of zero-carbon energy
- Full use of alternative heating systems.

Four areas of research are proposed to address the barriers to using this technology:

- Measurement of thermal conductivity of the ground to develop a simple design tool to ensure the ground loop system is correctly designed and installed.
- Research into heat delivery systems to develop product test standards for underfloor heating systems similar to those available for traditional radiators.
- Research into the seasonal performance of GSHP systems in direct comparison with condensing boilers.
- Development of application software to interpret prEN 15316-4-2: *Heat pumps. Heating systems in buildings – methodology for the calculation of system energy requirements and system efficiencies*,[2] and calculate seasonal performance. Although prEN 1536-4-2 is still in the drafting stage it is widely recognised in the GSHP industry as the 'standard'.

2 Background

2.1 What is a ground source heat pump system?

GSHP systems tap into the solar gain and thermal store properties of the ground as a source of large quantities of low temperature heat energy. This energy is converted into a high temperature for water heating and space heating in a dwelling using a heat pump (Figure 1). While this review concentrates on the use of the ground as a source of heat energy, other heat pump based systems use the air, free bodies of water (lakes) or ventilation heat recovery as their source of heat energy.

The ground gains most of its heat energy ultimately from the sun. Provided the GSHP system does not take out more energy than can be replaced by the sun over an annual cycle the system is sustainable.

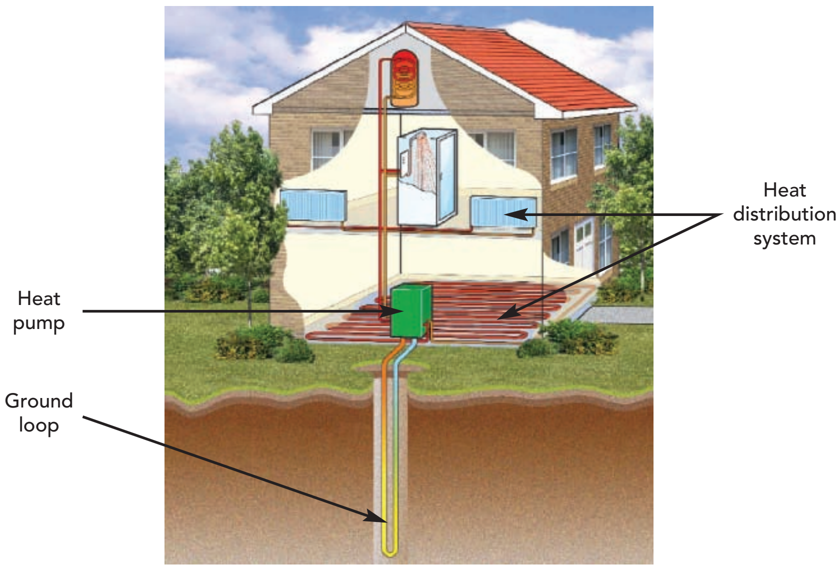

Figure 1 The ground source heat pump system.

2.2 How the system works

The heat pump uses refrigerant gases and a compressor to absorb heat from the ground which in turn delivers heat to the dwelling. The compressor is usually driven by an electric motor.

Typically the ground temperature is around 10°C to 12°C and the system circulates a fluid through pipes buried in the ground (called a ground loop), which takes the heat energy out of the fluid reducing its temperature to about 0°C; the energy is then sent back to be reheated by the ground. An alternative method, where there is free groundwater, is to use an open loop system. This system sucks groundwater from one area of the ground as the source of heat, extracts the heat in a heat pump and then releases the cooled water back into the ground at a different location. The open loop system is less popular in the UK because the Environment Agency is very protective of groundwater as it is a source of drinking water and is concerned about possible pollution from any plant and machinery.

A heat exchanger, called an evaporator, is used to interface between the fluid from the buried pipes and the heat pump. GSHP systems use the gained energy to heat another fluid, through a heat exchanger, called a condenser, (up to between 40°C in older systems to 65°C in the latest systems) that can be used to distribute heat in a building and return it to the heat pump at about 35°C.

The energy needed to run a heat pump is significantly less than the energy generated to heat a dwelling. While GSHP systems are not completely 'free' of outside energy supplies, if designed correctly, they have the potential to provide a sustainable energy source at a lower cost than traditional energy sources. If the energy required to power the GSHP system can be supplied from a sustainable source then a fully sustainable heating system is possible.

Typically for every kilowatt of power used to drive the GSHP system, 3 kW to 4 kW of heat can be delivered into the dwelling. The heat output varies over the year and the actual amount of heat delivered to a dwelling will depend on the available heat from the ground loop. The ratio of delivered heat energy to required energy to drive the system is known as the Seasonal Performance Factor. This should not be confused with the Coefficient of Performance which is the ratio of heat output of the GSHP system to the electrical input required to drive the compressors and pumps.

The other significant point is that the temperature of the fluid in the heat delivery system of a conventional central heating system leaves the boiler at about 80°C and returns at about 60°C. (BS EN 442 parts 1 and 2[3] set heat output ratings from radiators measured with a fluid flow temperature of 75°C and a return temperature of 65°C). The lower output temperature from the GSHP system means that heat delivery systems designed for conventional central heating systems are not suitable for use with GSHP systems.

GSHP systems are most efficient when the complete system – heat collection, heat pump and heat delivery – is designed to be compatible.

2.3 The heat pump market in the UK

The expectation is that between 500 and 700 GSHP systems will be installed in the UK annually. This is likely to increase with the accent on renewable energy sources and government grants easing the higher installation costs.

The GSHP industry is still being established compared with industries associated with gas/oil boilers and radiators or warm air heating systems. The industry has yet to establish guidelines for the design and installation of equipment so designers and installers have to devise their own criteria. Similarly it is difficult to check or assess the efficacy of equipment design. As with many systems with buried elements in the ground, ground loops are difficult to check after installation and maintenance.

Currently there are some companies offering package designs for developments of about six units or more of social housing. However, a high percentage of installations are aimed at smaller developments and refurbishments far from mains gas where the Standard Assessment Procedure (SAP) and EcoHomes rating of a new house can be improved by the inclusion of a GSHP system. This is a particular feature of developments for housing associations who can increase their funding if dwellings have an 'Excellent' EcoHomes rating rather than a 'Very Good' rating.

In general, the specifier of the GSHP system will rely on the industry for information and design criteria. However, the installation will be carried out by specialists who do not have to comply with industry codes and standards.

Post installation service agreements give the owner/operators peace of mind and security against maintenance and breakdown costs. Currently no independent warranty/insurance exists for GSHP systems after the installation warranties expire.

The GSHP industry is more developed in some European countries and in North America where industry-led codes are established. These codes can be very helpful but differences in climate, installation and ground conditions have to be taken into account. Such differences will significantly affect the efficiency of the system and the embedded length of the ground loops.

2.4 The heat pump market in Europe

In Europe GSHP systems have shown strong growth in installations in Scandinavia and alpine countries with generally colder winters, in locations remote from 'mains' gas supplies and often where the electricity supply has a low carbon content. In these locations the temperature differential between the ground and the environment is greater, so GSHP systems are more effective than air source systems. Table 1 shows the sales recorded by the European Heat Pump Association for space heating units, with Sweden leading the field followed by the alpine countries. These figures include all heat pumps, including air to air, but show the overall sales growth across Europe as just under 20% per year. There appears to be slow growth in mid-European countries, where statistics exist, thought to be a result of relatively cheap mains gas, except in the Czech Republic where there is high growth.

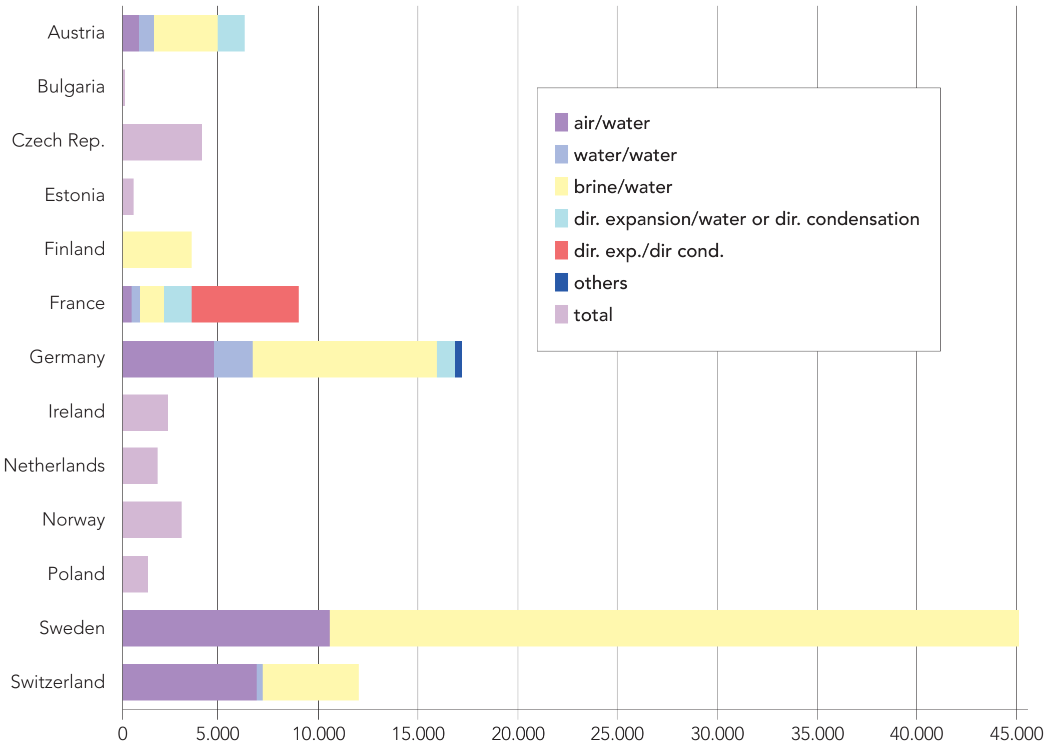

Figure 2 Heat pump sales figures for heating only (excluding heat recovery heat pumps), 2005. *Data from the European Heat Pump Association.*

These figures probably do not include air conditioning, which can also provide heating, except in Norway where dry winters have resulted in very high electricity prices, together with the preponderance of electric heating which provoked a somewhat uncontrolled market for anything that can be called a 'heat pump'.

In many European countries the market for GSHP systems is established and accepted as a practical alternative to other established systems. The lack of mains gas, irregular supply of oil (road transport in harsh winter conditions), together with increasing energy prices, are drivers for ground source heat energy.

TABLE 1

Sales figures for space heating units

Country	1992	2003	2004	2005
Austria	800	3780	5129	6700
Bulgaria	–	15	25	56
Czech Republic	20	1200	2400	4000
Estonia	–	510	750	1095
Finland	100	8540	12 648	22 300
France	4000	13 700	17 300	25 200
Germany	2000	15 838	20 636	26 037
Ireland	–	1300	1800	2300
The Netherlands	–	1557	1800	1900
Norway	1000	55 081	35 390	40 000
Slovenia	–	25	35	n/a
Sweden	15 000	68 100	100 215	101 360
Switzerland	2700	8695	9796	12 000
Portugal	–	–	–	46 200
Italy	–	–	–	13 000
UK	–	–	–	500
Poland	–	–	–	1465
Total	**25 620**	**178 341**	**207 924**	**304 113**

3 Specification and design

3.1 Specifying the system

GSHP systems are specified by their heat energy output rate and the temperature range of the input and output heat. The heat energy required for the dwelling will govern the output heat energy specification and the design of the ground loops will provide the input heat energy (see Figure 3). In general this part of the design is the simplest because the heat pump manufacturer will be able to supply a full specification of the equipment.

It is important to include all the heat requirements of the system and whether domestic hot water is included with space heating.

The specification of the heat pump needs to show that the heat gain from the ground can be converted into the heat demand of the delivery system.

3.2 System design

The design of GSHP systems is currently not regulated by standards – most designs rely on manufacturers' specifications. It is important to demonstrate that the overall capacity of the ground loops and the overall heating demand of the system over a whole year is less than the expected solar gain of the ground where the loops are installed.

3.2.1 Ground loop design

The ground loop system is where the low temperature heat is collected for delivery to the heat pump. This part of the design needs to demonstrate that the average annual solar gain exceeds the typical heat requirements of the ground loops. This is essential for a sustainable system.

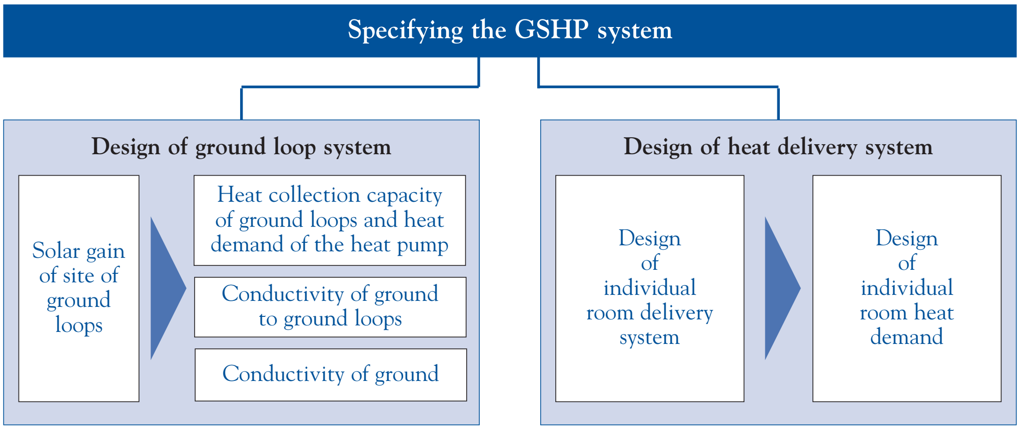

Figure 3 Specification and design of a ground source heat pump system.

The ground loops can be placed in the ground in one of four ways:

1. Excavating trenches and placing the pipes in the trench and backfilling.
2. Excavating boreholes in which to place the ground loops.
3. Jacking the ground loops vertically into the ground.
4. Including them in the foundations of the building.

In the first two methods the connection of the ground loops to the ground to ensure good conductivity is achieved during the backfilling. In the trenches this can be achieved using sand to surround the pipes, which protects the pipes from puncturing by stones in the backfill and usually gives good thermal conductivity. The jack-in system relies on the tight fit of the pipes in the ground for good thermal conductivity. The fourth option has been used in commercial buildings but is as yet less common in housing but where a dwelling requires piled foundations the loops can be cast into the piles. Clearly this requires rigorous quality control of the installation of the pipe work , the joints in the pipe work and the connections at the top of the pile; after casting they cannot be easily repaired.

The thermal conductivity of the ground per metre of ground loop will vary depending upon the soil type, the surface area of the pipe used in the loop and the depth below the ground surface of the loop. It is clear that conductivity per metre run of loop will be different for each installation method.

It is essential that the designer understands the solar gain of the site of the ground loops, the thermal conductivities of the ground and the ground/ground loop interface and justifies the source of the values used.

Figure 4 Borehole installation

Figure 5 Installing horizontal ground loops

3.2.2 The heat delivery system

Figure 6 GSHP for an average house

The heat delivery system works on the same principles as for a traditional central heating system except that the temperature of the fluid transferring the heat from the heat pump to the delivery system is lower than for, say a gas boiler. The size of radiators for normal gas central heating systems is calculated, according to BS EN 442, with a flow temperature of 75°C and a return temperature of 65°C. The heat output calculated on this temperature difference would be inappropriate for ground source heat systems as they typically have a flow temperature of 50°C and a return temperature of 35°C. Consequently a larger radiator area would be required. The design delivery system needs to demonstrate that the heat demand can be met by the delivery system. In many cases of new build underfloor heating will be specified as the most effective way to deliver low grade heat. The specification and installation needs to show that the insulation below the under floor heating and the conductivity of the materials above the underfloor heating will allow the system to operate efficiently with accountable losses included in the design.

It is essential that the designer shows that the delivery system can supply sufficient heat to meet demands and that all potential losses of heat are accounted for and can be demonstrated as such.

3.3 Design checklist

The following checklist will help builders and regulators when designing GSHP systems:

No	Item	Realistic values	Source of values verified
1	Annual solar gain of the site of the ground loops		
2	Conductivity of the ground at the depth of the loops		
3	Conductivity of the ground loops per metre		
4	Available heat from all the ground loops		
5	Output heat generated by the heat pump		
6	Heat demand for each room in the dwelling		
7	Heat delivery system design output (including losses)		
8	Total heat requirement (< than 5 above)		

4 Benefits, drivers and barriers

4.1 Benefits

- Uses a renewable energy source
- Reduces running costs
- Increases SAP ratings that improve EcoHomes ratings.

The direct benefits of GSHP systems are many but most significant are the reduced energy requirement and the use of a sustainable energy source.

The energy requirement of a GSHP system is restricted to that required to run the compressor in the heat pump and the fluid circulation pumps. In an efficient and well designed system the energy requirement can be as low as 20% to 30% compared with a conventional wet system. However, the system is powered by electricity so this saving may not be directly related to cost saving. The most up-to-date systems can produce water up to 65°C thereby reducing dependency on back up or supplemental systems and avoiding problems of legionella in hot water supply systems.

A further benefit is that if the system is designed appropriately, the mode of operation can be reversed to cool the dwelling and replace the energy previously taken from the ground. However, most GSHP systems can only have limited cooling capacity because the main heat delivery system includes the use of underfloor heating or radiator heating.

Indirect benefits of GSHP systems are:

- Low environmental impact with a significantly reduced carbon footprint.
- Improved SAP calculated ratings for assessing energy performance for dwellings issued in 2007.[4]
- Improved EcoHomes and Code for Sustainable Homes ratings for new build.
- Zero visual impact.

A GSHP system uses, if properly managed, a sustainable heat source. While not eliminating the need for energy from another source it will significantly reduce that demand so reducing the environmental impact. The lack of local emissions further reduces this impact.

Table 2 shows a comparison of heat supply from a condensing boiler (mains natural gas and oil/LPG) with automatic ignition with a GSHP system, both supplying underfloor heating.

TABLE 2

Comparison of SAP 2007 ratings with different primary space heating sources*

Item	Oil/LPG	Gas	GSHP system
Efficiency	83	83	320
Underfloor heating adjustment	+2	+3	x1
Total	85	86	320
Typical energy cost factor	1.2	1.2	0.31
Typical SAP rating	83	83	96

* Data taken from http://projects.bre.co.uk/sap2005.[4]

Table 2 gives 'typical' values of energy cost factor since in a real case many other performance indicators and heating requirements are needed to make an exact comparison. For the purposes of this exercise the heat requirement is the same and the calculation for energy cost factor involves the division of the efficiency of the heat supplier into the heat requirement. The typical SAP rating is then obtained by correlation with a published table. Table 2 shows that the inclusion of a GSHP system, assuming exactly the same design of dwelling, would give a significantly increased SAP value, enough to change the EcoHomes rating from one category to another (see Table 3). This can have a significant effect on, for example, housing associations whose funding can be increased if their housing has an 'Excellent' EcoHomes rating rather than a 'Very Good'.

TABLE 3

EcoHomes rating scores

Rating score	(%)
Pass	36
Good	48
Very Good	58
Excellent	70

GSHP systems currently available have zero visual impact since the ground loops are buried in the ground and the heat pump can be located in a suitable store cupboard or small purpose built unit attached to the outside of the building.

4.2 Drivers

- Environmentally friendly
- Reduces carbon footprint
- Supports the sustainability agenda.

There are political, environmental, regulatory and economic factors that drive the demand for GSHP systems.

4.2.1 Political

The sustainability agenda is a powerful reason for driving 'green' energy systems. A GSHP system uses an energy source – solar gain of the ground. If these energy sources are properly managed these systems can be sustainable. The systems have the potential to reduce mains energy use in a dwelling by about 75% compared with conventional systems – this could significantly reduce the building's carbon footprint. There are government sponsored grants available for the installation of GSHP systems that mitigate, to some extent, the extra costs of installation (see www.lowcarbon buildings.org.uk and www.est.org.uk).

4.2.2 Environmental

The effect on the environment of heating systems for housing can be judged by the emissions of CO_2 in the generation of the heat energy (see Table 4 which shows the emissions of CO_2 from various fuel types). GSHP systems generally use electricity to drive the compressors and circulation pumps. However, with condensing boiler efficiencies of 93% and GSHP system efficiencies of around 300% (using these figures to calculate the effective CO_2 emissions) it is clear that these systems produce less CO_2 in overall emissions than other sources of energy. As electricity becomes increasingly generated from renewable sources (wind power, hydro schemes, gas driven microsystems) the CO_2 emissions will be reduced which will further reduce the CO_2 emissions from GSHP systems.

TABLE 4

CO_2 emissions from various fuel types

Fuel type	CO_2 emissions kg/GJ delivered	Efficiency %	Effective CO_2 emissions
GSHP systems with electricity driven compressor and pumps	139	300	46
Electricity	139	100	139
Fuel oil	78	93	84
LPG	61	93	66
Natural gas	53	93	57

4.2.3 Regulatory

The regulatory drivers come from Part L of The Building Regulations 2000, Approved Document L1A: *Conservation of fuel and power (New dwellings)*.[1] This document was revised and effective from 6 April 2006 and now uses only the annual CO_2 emissions of the dwelling to judge energy efficiency (rather than using the SAP rating). Approved Document L1A outlines the way a Target Emissions Rate (TER) is calculated which will be the minimum energy performance required. The TER includes emissions from space heating, hot water provision and fixed internal lighting and is factored by a fuel factor (related to the CO_2 emissions in Table 4) and an improvement factor. The TER should be calculated for the best available energy source. In many cases this is likely to be a wet system using mains gas, but in some areas it could be oil, bottled gas or electricity if no mains gas is available.

The TER is used as a minimum level for the actual emissions rate, termed Dwelling Emissions Rate (DER). Appendix R of The government's Standard Assessment Procedure for energy rating of dwellings[4] is used together with fuel factors given in the Approved Document L1A[1] to calculate the DER.

As noted above in section 2.1 (Benefits) the EcoHomes rating of a new dwelling can be improved by specifying GSHP systems for space and domestic water heating.

4.2.4 Economical

Where no mains gas exists retrofitting a property with a GSHP system will be more expensive to fit but more economical to run than systems using only oil, bottled gas or electricity.

For new constructions, installation cost will be higher than for gas boiler based systems but running cost will be slightly lower at 2006 prices. As systems become more popular it is expected that the systems and their installation will reduce in price, making them comparable to traditional systems, but with reduced running and maintenance costs. Costs will be lower for multiple installations on the same site than for one-offs. Apart from better use of labour, there are usually one-off costs associated with system design and assessment of ground conditions.

4.2.5 Reliability, maintenance and availability

GSHP system technology is well proven and reliability of equipment is good in other countries around Europe where systems have been in use for many years (many compressors used in GSHP systems are manufactured in the UK). Many off-the-shelf systems are sourced from established markets. However, these markets are driven by different criteria, climatic conditions and ground conditions to the UK and varying access to mains energy supplies (see section 1.2 for further information).

Reliability must not be confused with one of the main problems experienced in the UK: poor performance from the system that in turn results in overworking the pumps and compressors. This is the result of poor system design or of application to insufficiently well insulated buildings.

4.2.6 Interface and other systems

Interface with other systems is straightforward since heat input and output from a GSHP can be in the form of cooled/heated water, ie the heat input is from the ground and output to heat the delivery system including provision of hot water. It is important that the heat delivery system is designed for the output temperature and flow rate from the GSHP system. In general the output temperatures are lower than conventional boiler heating systems and so larger radiators or properly designed underfloor heat delivery systems should be considered.

If a combined system were installed, a condensing boiler would be most efficient at temperatures slightly higher than those generated by a GSHP system. Using a heat store would allow a composite GSHP and condensing boiler system to be used. In reality the only likely combination would be a booster system to increase the heat output for domestic hot water supply. This could be achieved by using an electrical immersion heater run on an off-peak tariff.

4.2.7 Provision of zero carbon energy

A GSHP system can only provide carbon neutral energy if the source of energy for the compressor and pumps in the system comes from a renewable carbon neutral energy source. Major suppliers are charged with increasing the percentage of energy from renewable sources that could mitigate this situation or a local renewable energy source could create a carbon neutral system.

4.3 Barriers

- Installation cost
- Unfamiliarity by building designers
- Lack of guidance and standards
- Poor design which damages its reputation.

4.3.1 Political

There are no political barriers to the installation and use of GSHP systems.

4.3.2 Regulatory

There are no regulatory barriers to the installation and use of GSHP systems. However, there are regulatory barriers imposed by the Environment Agency particularly if open loop or direct exchange systems are used where the groundwater is used as part of the system and 'used' groundwater is returned to the ground. This could be a source of pollution of the groundwater which would need Environment Agency approval. The closed loop systems should not leak but for similar reasons the fluid used should be biodegradable with no likely pollutants.

4.3.3 Economical

Installation costs are perceived as being greater than conventional wet systems, ie condensing boilers with radiators. The actual cost/benefit of GSHP systems in meeting Part L of The Building Regulations 2000,[1] as compared to other systems, is significantly better than perceived. As systems become more popular the purchase price will reduce, and as designs become more proven the systems will become more efficient.

Currently some GSHP systems are over designed to compensate for lack of knowledge regarding the amount of renewable heat available over several seasons and years in UK soils. It is better to install more ground loops over a larger area to ensure capacity. The ground loop represents an important cost but adequate sizing is crucial for efficient operation, so careful design is necessary. This is one reason why the market may move towards air source heat pumps in the medium term.

If the GSHP system takes more heat than can be replaced by solar gain it becomes unsustainable reducing the available heat, making the system less able to meet demand. If this process persists then it could take several years of reduced heat extraction before the solar gain replaces the lost heat energy. The economical consequence of this is that the system has to work harder to satisfy the heat demand and so the system will become less efficient thereby increasing running costs. Maintenance of the system will not improve the situation, only the installation of additional ground loops.

Running costs currently only have a small advantage over traditional systems using mains gas as a primary energy source. There is a bigger advantage where the primary energy source is fuel oil, bottled gas or an all electric system.

4.3.4 Construction practice

Construction practice is centred on traditional trades providing electrical and plumbing skills. However, as GSHP systems are not yet so popular a specialist is required to deal with all of the problems of trades interfacing and planning activities during the construction phase. Furthermore there appears to be difficulties in getting suppliers to install complete systems including the design of heat collection, pump and delivery, although this is starting to change. The UK Ground Source Heat Pump Association, is bringing together these disparate skills. Also heat pump manufacturers are taking a keen interest in the capabilities of the installers that they will supply.

Design of heat delivery from GSHP systems needs careful consideration and needs to be matched both to the available heat and the required heat ie the heat loss of the building. The temperature of the heat supply fluid will be lower than traditional wet systems, therefore the heat delivery system needs a greater surface area to emit the heat. In many cases this is best achieved using underfloor systems although oversized radiators, if space permits, can be used. Underfloor systems need to be carefully designed for best heat delivery at the supply temperature. Special care is also needed for suspended floors where experience and special fittings to spread the heat and reflect the heat up to the underside of the floor are required. Traditional floor boarding is a good insulator and floor coverings such as carpet and underlay also act as good insulators.

It is clear that with the installation of buried slinky coils or jacked pipes, their links to the GSHP systems, the installation of these systems, and non-traditional heat delivery systems that the integration of GSHP systems in new build houses requires careful thought as to the scheduling of construction events and allowance for services access.

If the ground conditions do not allow slinky coils or jacked pipes then a borehole will have to be drilled at extra cost. The choice between slinky coils or borehole depends on a number of factors including availability of land and geology. Another option that is beginning to emerge is the incorporation of pipes in piled foundations. This has been successful in commercial properties where deep piles are required for supporting a multi-storey structure but scale effects may reduce the viability for low rise buildings. This needs careful detailed design as access to the pipes will be limited when in service and repair virtually prohibitive. (If the foundations are to be piled it is likely that there is soft ground that can take slinky coils or jacked pipes).

The solar gain of the ground is a renewable energy source but only on an annual basis. The ground, because of its mass, is an effective thermal store so that below about 2 m the ground temperature varies little over the seasons of the year. However, the solar gain has a limited rate of renewal and GSHP systems need to be designed so that energy taken from the ground is less than the annual solar gain. This could mean using a greater land area outside the footprint of the building, traditionally the space for stockpiling of building materials, access equipment and other plant movements with consequent risk of damage.

4.3.5 Reliability, maintenance and availability

Many GSHP installers use equipment imported from countries where the systems have been in use for some time. Scandinavian and North American suppliers have reputations for good quality and reliable equipment. However, a number of well known brand names (eg Worcester-Bosch, Baxi and Glen-Dimplex – see www.energysavingstrust.org.uk for a full list of certified products) are moving into the market. These manufacturers are cautious about poor installation of their equipment, so they insist on proper design and installation. Most of the smaller manufacturers are reputable, but do not have this incentive and may not be so financially sound. An understandable consumer worry is 'who puts it right if it goes wrong in five years' time?'

Equipment is readily available and can now be purchased directly from plumbers' merchants. This can present another problem as some installers may assume a GSHP systems is a direct substitute for a conventional boiler.

4.3.6 Interface and other systems

Older designs need back-up for supplementary water heating from about 55°C up to 65°C for hot water supply. Newer designs can produce hot water at 65°C. Perception is that a GSHP system needs some supplementary system as back-up or top-up. In the UK, this is a misconception for most well designed systems. Installation of a GSHP system to replace an existing wet central heating system requires a major redesign of the heat delivery system to work at the lower operating temperatures. If an older property has oversized radiators to cope with a poorly insulated dwelling, the redesign could include a significant upgrading of insulation. This upgrading would reduce the heat energy requirement to a level that could be supplied by a GSHP system using the existing radiators.

4.3.7 Provision of zero carbon energy

A GSHP system can only provide zero carbon energy if the electrical supply to drive system is from a renewable energy source.

5 Conclusion and future research requirements

5.1 Conclusion

GSHP systems are a relatively recent addition to the domestic heating market in the UK compared with gas and electricity fuelled systems. Elsewhere in the world, particularly where relatively inexpensive natural gas is not available, GSHP systems have been used more widely.

There is now more emphasis on using renewable energy sources. While GSHP systems cannot be fully independent from external power supplies (power is needed to drive the compressor and pumps) it can use a previously untapped renewable energy source and thereby significantly reduce demand from mains energy sources.

5.2 Future research requirements

GSHP systems operate in a different way to conventional central heating and domestic hot water systems that are familiar to designers, installers and consumers. There are gaps in general knowledge, and standards and regulations that allow systems to be designed and installed that will not meet the requirements of the end user.

5.3 Problems and proposed solutions

Poor design of the ground loop system: this problem can occur where heat demand is greater than can be provided, and/or continued use will deplete the available heat at a greater rate than can be replenished by solar gain. The problem will not be discovered for perhaps several years as the system gradually cools the ground so that the outflow and inflow temperature difference in the ground loop is reduced, making the system work harder to produce the required heat. This obviously reduces efficiency and pushes up running costs.

The imbalance between solar gain and heat demand can be compounded if the effects of a GSHP system in adjacent properties also reduce the available heat. There are well established processes for determining ground thermal properties onsite but unfortunately they are fairly time consuming. First estimates can be obtained from a service run by the British Geological Survey (www.bgs.ac.uk), but they are generally area based and linked to the underlying geology. The UK near-surface geology is complex and local variations could produce significantly different conditions even across a site.

Solution: research into site-specific measuring realistic values of thermal conductivity of the ground to identify its capacity to supply the required heat and thermal conductivity of the ground/ground loop interface. Research should assess the capacity of the system to transfer the heat energy from the ground to the GSHP system. Ground loops buried in trenches and loops set vertically in boreholes have different values. The research should produce a design tool that includes a rapid assessment test for site-specific calibration of the tool to ensure an adequate ground loop system is designed and correctly installed. The research should be supported by development of a method to assess solar gain of the ground, averaged over several years, and model the effect of heat take by an adjacent GSHP system.

Poor design of the heat delivery system for space heating in a dwelling: existing systems use radiators that are manufactured to BS EN 442-1 and BS EN 442-2[3] which set heat output ratings from radiators to be measured with a fluid flow temperature of 75°C and a return temperature of 65°C. This allows designers to readily select radiators to match heat requirements in a particular room. GSHP systems operate at lower temperatures (eg outflow at 50°C and return at 30°C) and radiator output cannot readily be calculated for resizing. Similarly there are, as yet, no standards or guidelines for the design of underfloor heating (probably the best way to use lower temperature heat supplies), particularly on floors above the ground floor level. It is essential to ensure that installers of underfloor heating understand how to design it for low-temperature operation.

Solution: research into the heat delivery systems to allow good designs when lower temperature heat is used. A ready calculation method is required to convert BS EN 442-1 and BS EN 442-2[3] values for lower heat level supply and a design code for underfloor heating that includes heat supply temperatures, floor construction and the effects of floor coverings on any storey of a construction.

Lack of robust data for UK conditions: although much is claimed about seasonal performance, most of it plausible, there is actually no robust data for UK conditions (ground-source or air-source).

Solution: install and monitor a GSHP system in a simulated occupancy dwelling over a year. The results would provide detailed information, if only for a single installation. These results could be compared with the procedures in prEN 15316-4-2 (this would also require some laboratory testing of the system before installation).[2]

For added relevance, the dwelling could be compared with a dwelling using a condensing boiler system. Ideally, this would be followed by a sizeable, well instrumented field trial. However, since the energy supply industries were privatised in the 1980s, no-one has been able to afford to do this type of trial (in the UK). The results of the single-installation tests mentioned above could be analysed to see whether meaningful results could be obtained from a reduced level of field instrumentation.

Complex draft European Standard: pr EN 15316-4-2, for testing heat pumps and calculating seasonal efficiency, is complex and difficult to interpret.[2]

Solution: develop and prove application software to interpret the draft Standard and calculate the seasonal efficiency (equivalent to the Seasonal Efficiency for Domestic Boilers for the UK [SEDBUK] developed under the Government's Energy Efficiency Best Practice Programme [5]).

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4 BRE, 2005. The government's Standard Assessment Procedure for energy rating of dwellings. Download from http://projects.bre.co.uk/sap2005. (This website also includes 2007 updates.).

5 Seasonal Efficiency for Domestic Boilers for the UK (SEDBUK). See www.sedbuk.com.

FURTHER READING

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NHBC Foundation publications

A guide to modern methods of construction

NF1, December 2006

Conserving energy and water, and minimising waste

A review of drivers and impacts on house building

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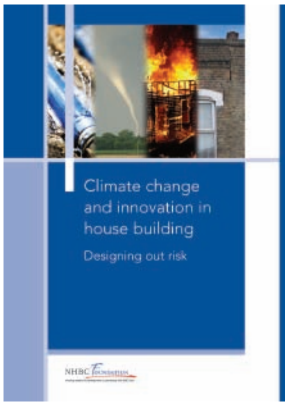


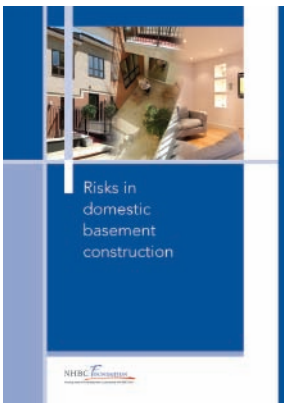
Designing out the risk

In the past 50 years, most dwellings in the UK have been built using brick and block or timber frame construction: lenders and insurers are familiar with them and can process applications for loans and insurance cover without undue concern. But recent years have seen the development of modern methods of construction, of which lenders and insurers have little or no experience, and they are uncertain about the level of risk that lending on or insuring such properties carries.

There is another area of dwelling performance – the consequences of climate change – that is not adequately covered by building regulations or design codes.

This review identifies the main areas of concern for lenders and insurers (fire, water leaks, storm, flood, ground movement, vandalism and theft), and focuses on how these concerns can be addressed at the design stage.

NF3, August 2007



Risks in domestic basement construction

Including basements in houses increases the floor area and living space, and the value to the owner. Basements can allow higher housing densities, which offers increased value to the developer. However, these increases in value may be accompanied by a need for greater site investigation and more detailed design to minimise the risks in construction and use.

This guide summarises current trends in basement provision, and the regulatory, performance, risks and planning issues that affect basements.

NF4, October 2007

NHBC Foundation publications in preparation

- Hydraulic lime mortars
- Microgeneration and renewable energy technologies
- Site waste management plans

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Ground source heat pump systems

Benefits, drivers and barriers in residential developments

Ground source heat pump systems use low level heat energy created by solar gain in the near surface layers of the earth which can be used for space and water heating. This potentially limitless supply of energy appears to be a good route to a sustainable energy supply.

This review has been produced at a time when the take-up of these systems is on the increase. It provides a valuable tool for specifiers, developers and builders looking to incorporate this new technology and reviews:

- the background to GSHP systems used in residential developments
- specification, design and installation
- the benefits, drivers and barriers in comparison with conventional heat sources
- future research requirements.

This review provides a framework to help the industry get to grips with ground source heat pump systems providing real benefits for the zero carbon homes of the future.

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The NHBC Foundation has been established by NHBC in partnership with the BRE Trust. It facilitates research and development, technology and knowledge sharing, and the capture of industry best practice. The NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the country's wider housing needs. The NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports house builders in developing strong relationships with their customers.

NF5
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