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GROUND SOURCE HEAT PUMPS - A TECHNOLOGY REVIEW

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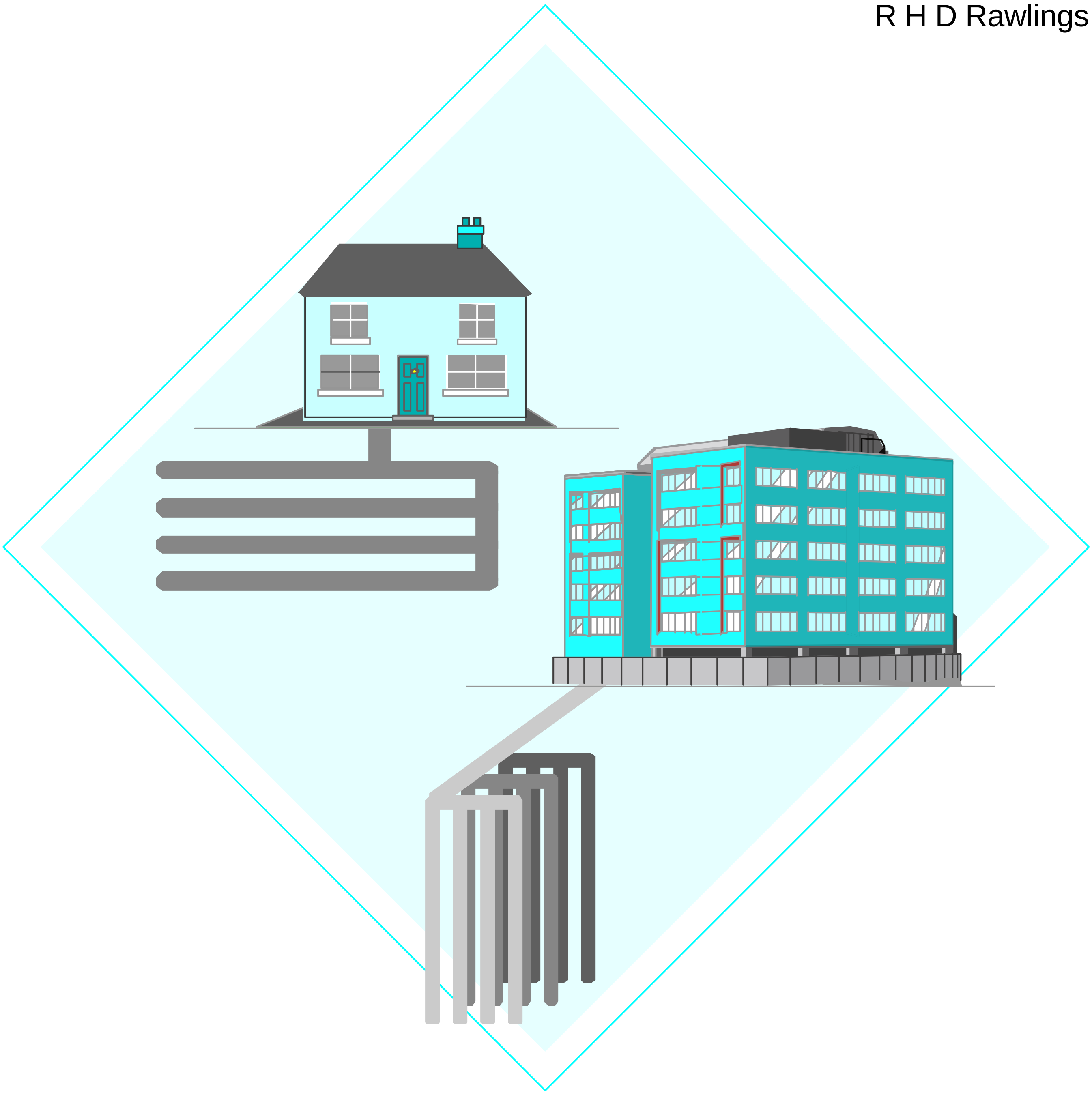

Scottish and Southern Energy plc

BSRIA

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EXECUTIVE SUMMARY

Ground source heat pumps are receiving increasing interest in North America and Europe because of their potential to reduce primary energy consumption and thus reduce the emission of greenhouse gases and other pollutants. This technical note provides a detailed, literature-based review of ground source heat pump (GSHP) technology then looks more briefly at applications of the technology, applicable standards and regulations, financial and other benefits and the current market status.

Heat pumps are widely used in buildings for space heating and cooling and for water heating. The majority of heat pumps currently in operation use air as the heat source, however, interest in using the ground as a source has been growing. Relatively stable ground temperatures, approximately equal to the average air temperature, mean that heat pumps which use the ground as a source are inherently more efficient than those using ambient air. Interest is focused on closed loop systems which consist of a sealed loop of polyethylene or polybutylene pipe buried in the ground either in a shallow trench or vertically in a borehole and connected to the heat pump. Either refrigerant (direct system) or a water/antifreeze mixture (indirect system) is circulated through the ground coil. Direct circulation systems are more efficient than indirect systems but the design is more complex and there is the risk of refrigerant leaks. The majority of systems are indirect. The components of the system, the energy source, the ground collector and the heat pump and how these affect the system performance are discussed in detail.

Efficiencies of heat pumps used to supply low temperature water-based heating systems (eg underfloor heating) are high. Coefficients of performance of between 3 and 4 are common for indirect systems and, for direct systems, are higher (3.5 to 5.0). The reliability of heat pump components is good, with expected lifetimes of 10 to 15 years. The expected lifetime for polyethylene or polybutylene ground coils is much longer, with warranties being offered for up to 50 years.

A typical seasonal performance factor for a ground source heat pump system with an electrically driven vapour compression cycle heat pump is 3.0 and high efficiency, heating only heat pumps can give seasonal performance factors of 3.8. The highest seasonal performance factors are for systems with horizontal collectors with direct circulation supplying low temperature heating systems, for which seasonal performance factors often exceed 4.0 and are expected to reach 5.0 in the near future.

Capital cost are higher than for alternative systems, mainly because of the costs associated with the ground coil, but costs are being reduced. For commercial applications where heating and cooling are provided, the additional cost of the ground coil can be substantially offset by the elimination of other plant and a reduction in the space needed for plantroom. Capital costs appear to vary considerably between countries and direct comparisons are difficult. For residential systems, costs appear to be lowest in North America and Sweden, which may be partly due to economies of scale. In Britain there are currently too few installations to permit accurate cost assessment.

Average energy savings of over 50% compared with direct electric heating and 33% compared with air source heat pump systems have been found for residential systems in the US, implying a simple payback of between 3 and 7 years with respect to direct electric systems. Domestic systems in Scandinavia providing heating only, have similar payback periods. In Switzerland, although capital costs are much higher than in the US, they are only about 25% higher than the alternative oil fired system and running costs are about 25% lower. Payback periods are longer at between 10 and 12 years, but still well within the lifetime of the system. For commercial systems, studies in the US and Canada suggest a simple payback period of under 3 years when compared with a water loop heat pump system and that maintenance costs will be reduced. Other benefits include low noise, good aesthetics and good security.

The use of ground source heat pumps also has wider benefits. Utilities are promoting the technology as it can help to reduce their internal costs through the ability to reduce both peak and average load demands. There will also be benefits to the community as the consumption of fossil fuels reduces and emissions of greenhouse gases and other pollutants also reduce and become more centralised. Detailed studies in the US, Switzerland and the Netherlands have all concluded that ground source heat pumps already have an advantage environmentally over gas or oil heating.

A market study estimated the total worldwide stock of ground source heat pumps to be approximately 400,000 in 1996 with total annual sales of about 45,000 units. The market has been mainly new housing but the number of commercial installations is growing fast. Systems operating in parallel with conventional heating systems are also beginning to be installed in existing houses which theoretically form the largest potential market.

Between 1996 and 1998 the rate of installation in Europe more than doubled but generally the market growth has been slow. In Britain the technology is still at a demonstration stage with approximately 50 installations. Barriers to the wider uptake of the technology appear to be:

- lack of awareness of the technology and its benefits
- capital cost
- low energy prices
- lack of manufacturers, suppliers and installers.

In most of the countries which have a significant market, initiatives to overcome these barriers and encourage the use of ground source heat pumps have been taken. Usually the government has played an active part, with initiatives forming part of a national energy policy. An increasingly important factor is concern for the environment not only at government level but also, particularly in Switzerland, it appears to influence the choice of heating system for individual house owners. In North America electric utilities have been very instrumental in the promotion of ground source heat pumps, and utilities in Europe have also taken an active interest. Direct financial incentives have been used and can have a big impact but their use in future by the utilities is less likely in an increasingly competitive market. Future activities are likely to focus on education, marketing, technical advice and favourable tariffs or innovative forms of financing (leasing etc).

The prospect for ground source heat pumps looks attractive. In Europe and the UK the demand for space cooling is growing, especially in commercial buildings. This trend could favour the use of ground source heat pumps which can provide low operating costs for heating and the extra comfort of cooling in summer. There is considerable potential for both heat pump efficiencies and electricity generation efficiency to improve. A heat pump coefficient of performance of 4.0 combined with a generation efficiency of 55% (gas combined cycle plant) would result in an energy efficiency factor of 2.2. Ground source heat pumps thus have a large potential to reduce both primary energy consumption and CO_2 emissions. As the proportion of renewable sources used for electricity generation increases CO_2 emissions will be further reduced and the introduction of replacement refrigerants will also reduce the global warming effect.

For the market for ground source heat pumps to become established in countries such as the UK, governments and utilities need to work together to promote this technology which effectively provides a continuous, high performance source of solar energy.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

AREP	Alternative refrigerants evaluation program
ARI	Air Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
CFC	Chlorofluorocarbon
CMC	Critical moisture content
COP	Coefficient of performance
CSA	Canadian Standards Association
DTH	Down the hole hammer
DX	Direct expansion
EPRI	Electric Power Research Institute
GCHP	Ground coupled heat pump
GSHP	Ground source heat pump
GWHP	Ground water heat pump
GWP	Global warming potential
HCFC	Hydrochlorofluorocarbon
HHV	Higher heating value
IGSHPA	International Ground Source Heat Pump Association
NECRA	National Rural Electric Co-operative Association
ODP	Ozone depletion potential
OSU	Oklahoma State University
PE	Polyethylene
PER	Primary energy ratio
PFC	Perfluorocarbon
PMV	Predicted mean vote
PPD	Predicted percentage of dissatisfied
PVC	Polyvinyl chloride
SPF	Seasonal performance factor
SWHP	Surface water heat pump
TEWI	Total equivalent warming impact

1 INTRODUCTION

The first documented suggestion of using the ground as a heat source appears to be in 1912 in Switzerland in a patent filed by H. Zölly (Wirth, 1955) but at that time the efficiency of heat pumps was poor and energy prices were low so the idea was not followed up. In the forties investigation into ground-source heat pumps started up again both in the US and the UK.

In the UK the ground as a source for a heat pump was first used by Sumner for space heating in a single storey house in the mid 1940s (Sumner, 1976). A horizontal collector at a depth of about 1 m was used to supply heat via copper pipes buried in a concrete floor. A coefficient of performance (COP) of 2.8 was achieved. In 1948 he installed 12 prototype heat pump systems using ground collectors each with a 9 kW output. The average COP of these installations was 3. However this study was stopped after two years.

The first ground source heat pump in North America was installed in a house in Indianapolis in October 1945 (Crandall, 1946). This consisted of copper tubes buried at a depth of about 1.5 m in the ground with the refrigerant circulating directly through them. In the next few years virtually all the methods of exploiting the ground as a heat source/sink which are used today were investigated in the US (Kemler, 1947) and a study in 1953 listed 28 experimental installations. Studies were also carried out in Canada, where the emphasis was on understanding the theoretical basis of using heat from the ground (Ingersoll et al 1951). The first Canadian system was in an experimental house at Toronto University (Hooper, 1952).

Commercial use of the ground as a heat source/sink did not begin until after the first oil shock in 1973 but was well established by the end of the seventies by which time there were over 1000 ground source heat pumps installed in Sweden (Granryd, 1979). The vertical earth heat exchanger was introduced into Europe in the late 70s (Rosenblad, 1979; Drafz, 1982) and from that time on has been used in various types mainly in Sweden, Germany, Switzerland and Austria (Sanner et al 1996).

Since 1980 there have not been any major technological advances in the heat pump itself except for improved reliability. However, considerable progress has been made in other areas such as system integration, reducing costs for the ground heat exchanger, improving collector configuration and control systems and strategies.

Today ground source heat pumps are an established technology with over 400,000 units installed world wide (around 62% of which are in the US) and about 45,000 new units installed annually. They are receiving increasing interest in North America and Europe because of their potential to reduce primary energy consumption and thus reduce the emission of greenhouse gases and other pollutants. Studies carried out for the Department of Energy in the US (L'Ecuyer, 1993) identified ground source heat pumps as the technology for space heating and cooling which had the highest potential energy efficiency. The Geothermal Heat Pump Consortium was thus set up in 1994 with the aim of stimulating uptake of the technology and increasing the number of installations from approximately 40,000 units/year to 400,000 units/year by the year 2000. It was estimated that this could save over 300×10^9 MJ/year and reduce greenhouse gas emissions by 1.5 M metric tons/year of carbon equivalent. Although this target was very ambitious, and will not be met, there has been sustained interest in the technology.

Overall efficiencies for ground source heat pumps are high because the ground maintains a relatively stable source/sink temperature, allowing the heat pump to operate close to its optimal design point. Efficiencies are inherently higher than for air source heat pumps because the air temperature varies both daily and seasonally and air temperatures are lowest at times of peak heating demand and highest at times of peak cooling demand.

This report provides a detailed literature based review of ground source heat pump (GSHP) technology and looks more briefly at applications of the technology, applicable standards and regulations, financial and other benefits and the current market status.