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Investigation on the application of heat pump systems in residential buildings in the UK

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Investigation on the Application of Heat pump systems in Residential Buildings in the UK

By

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Abstract

Heat pump systems are receiving increasing interest in the recent decades as an alternative energy source for space heating & cooling in both residential and commercial buildings. Due to its potential to reduce energy consumption and thus reduce emissions of greenhouse gases, this technology has been well established in many countries in the world. It is still at a development stage in the United Kingdom (UK), but the UK market is growing rapidly with an ever increasing number of installations each year. It is also considered that the heat pump technology can make important contributions to the UK's CO_2 target, which is cutting CO_2 emissions by 34% of 1990 levels by 2020 and 80% by 2050.

This thesis mainly discusses the application of heat pump systems in residential buildings. It introduces how the system works, heat pump systems' types, the current and potential deployment of the system and its cost, design and installation. Although heat pump systems are being increasingly installed around the world, there are only a few current studies on their actual performance. Therefore, this study analyzes the effectiveness of heat pump systems by providing reasonable comfort at an affordable cost in comparison to conventional heating systems through a field study. It indicates that the GSHP system provides the highest comfortable level of heat, with relatively low energy consumption (cost affordability) and CO_2 emission. The only negative aspect is the higher installation cost when compared to conventional heating systems.

To find whether the GSHP users are satisfied with the system performance and how their operations would impact the system efficiency, a survey was carried out among 162 GSHP users. It is found that GSHP can meet the heating and DHW demand of residential buildings with a relatively low cost. But a sizable amount of users experienced various problems with GSHP, including intrusive noise, slow warm up and so on. Customer service after the installation of GSHP needs to be improved to make GSHP widely accept, especially for technical support and maintenance issues.

Keywords: Renewable energy, Heat pump system, GSHP, Domestic heating

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List of Abbreviations:

GSHP	Ground Source Heat Pump
ASHP	Air Source Heat Pump
HP	Heat Pump
EU	European Union
GHG	Greenhouse Gas
DECC	Department of Energy & Climate Change
DBERR	Department for Business Enterprise and Regulatory Reform
NEF	The National Energy Foundation
EHPA	European Heat Pump Association
RHI	Renewable Heat Incentive
EST	The Energy Saving Trust
LCBP	The Low Carbon Buildings Programme
CERT	The Carbon Emissions Reduction Target
COP	Coefficient of Performance
BHEx	Vertical Borehole Heat Exchanger
TRV	Thermostatic Radiator Valves
DHW	Domestic Hot Water

1 Introduction

1.1 Background to the Project

With energy demand rising and fossil fuels depleting at an alarming rate, heat pump systems (including ground source heat pump and air source heat pump) have received considerable attentions in the recent decades (Sung 2010). They can make use of the geothermal energy or air source energy to provide an efficient and sustainable way of space heating/cooling and domestic hot water for various building categories.

The concept of heat pump has been recognized since the 1800s (Stuart 2010). These systems have been recognized to provide viable, environment-friendly alternatives to conventional unitary systems. They can make significant contributions to reductions in electrical energy usage and CO2 emissions.

Ground source heat pump (GSHP) is one of the fastest growing applications of renewable energy in the world, with annual increases of 10% in about 30 countries over the past 10 years (Lund *et al.* 2004). Most of these growths have occurred in the United States and Europe, though interest is developing in other countries such as Japan, Turkey and China. Generally, the efficiency of GSHP is higher than air source heat pump (ASHP), since the ground temperature is higher than the ambient air in winter, while lower than that in summer, and also appears more constant. However, the capital cost of GSHP is 30–50% more expensive than ASHP, which is the main hurdle of the application despite its several advantages (Lohani, Schmidt 2010).

The current UK market for ground source heating and cooling is still small, but growing rapidly. The technology contained within GSHP has the potential to increase energy efficiency whilst simultaneously reducing CO_2 emissions, reduce demand on the utility's services networks and assisting to meet the UK government targets. ASHP can be more feasibly installed in areas of high-density housing such as flats and terraced dwellings, where the installation of

GSHPs would be more difficult due to limited space for ground loops. High-density housing comprises approximately 40% of the UK housing stock (Kelly, Cockroft 2010).

So far, there have been a large number of studies on the designing, installing and energy analysis about the heat pump systems (Ma 2003, Ge 2011, Nagano 2006, Nam 2008, and Stafford 2012). However, there is little data collected to describe the system performance in the real life, where actual performance can be affected by user operation and site and local climate conditions. So customers have to rely on the performance claims from the manufactures, and these claims are based on testing which is carried out in a 'laboratory' environment.

1.2 Aims and Objectives of this Thesis

Research Aims

The aims of this research are to determine the effectiveness and efficiency of GSHP in the real life, how users' operations impact the performance of GSHP and help users get the highest system efficiency.

Research Objectives

The following objectives need to be achieved:

- Provide GSHP users (building owners and occupants) with general knowledge on heat pump systems, such as the heat pump system work principle, heat pump types, design and installation process;

- Introduce the current status of the UK heat pump market and barriers of the market development;

- Analyze the performance and the actual energy consumption of heat pump and conventional heating systems respectively;

- Determine whether GSHP users are satisfied with the GSHP performance or not and how their operations affect the system efficiency, as well as how to improve the customer service to meet users’ requirements on GSHP by a survey.

1.3 Research Methodology

1.3.1 Phases of the Research

The research was conducted in three phases and an initial one, as summarized in Figure 1.1. The preparatory work decides the aims and framework of the thesis. Phase 1 reviews the general information on GSHP, provides GSHP users the knowledge of the technology i.e. the work principle, GSHP deployment, UK market barriers, cost and efficiency. Phase 2 describes the actual performance and cost of GSHP through a case study. Phase 3 carried out a survey, post 162 questionnaires to GSHP users to research how users' operation impact the GSHP performance. These 3 Phases together would help GSHP technology more widely accepted and help users maximizing the system efficiency.

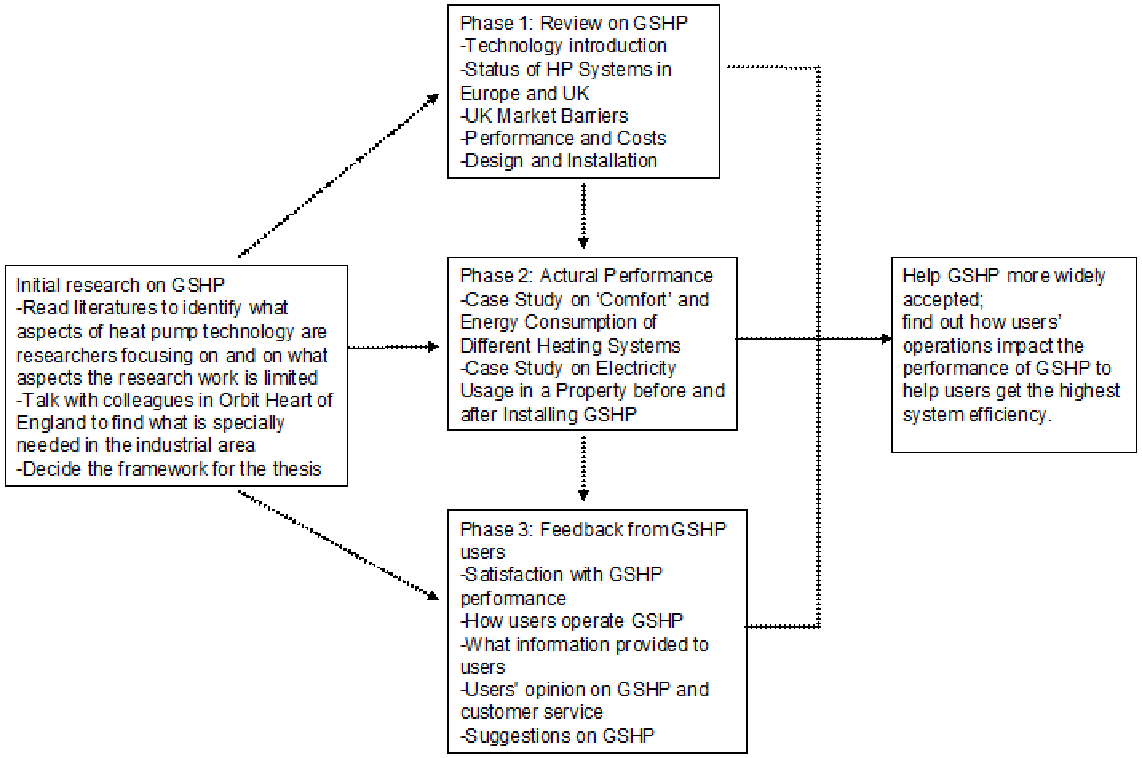

Fig.1. 1 Phases of the Research

1.3.2 Data Collection

There are two main techniques of data collection were used in this thesis: document review and questionnaires. The study of documents was an integral part of Phase 1 and Phase 2 of the research. Phase 3 mainly used the methodology of questionnaire. The questionnaires then were converted into electronic form and were analyzed. Some data measured by other members within Orbit Heart of England was also used in this thesis.

Document Review

The study relies on extensive review of documents i.e. various publications, policy documents, standards and studies from heat pump areas. To systematize and summarize the information in these documents, a summary of the main details important for the research was made for each of them.

Questionnaires

Aimed at identifying the reasons that some GSHP systems performed badly and finding methods to improve the GSHP performance and customer satisfaction, a questionnaire was designed. There were totally 162 questionnaires were post to the tenants lived in Orbit's properties where installed GSHP systems. Of which, 62 responses were received. This gives a feedback rate of 38.3% which is a considerable response rate according to an experienced building surveyor from Orbit Heart of England. The questionnaire planning and design will be introduced in Chapter 8.

A letter was put in the envelope together with the questionnaire, describing the purpose of the questionnaire to the tenants. An empty envelope with stamp on was also included in the envelope. These avoided tenants paying the postal fees and encouraged them to response and post the questionnaire back. The questionnaires were posted on 19th June 2012, and were filled and posted back between 25th June and 20th July 2012. They were then electronic recorded and the files were kept for further analysis.

2 Heat Pump Technology

This Chapter describes the working principle and types of heat pump systems, helping heat pump users to decide which type of systems is most suitable to their properties.

2.1 How Do Heat Pumps Work

The ground, a body of water and the air warmed by the solar energy could be used as the renewable energy reservoir of heat pump systems. A heat pump (HP) system consists of three main components: the heat source system, the heat pump itself, and a heat distribution and storage. Auxiliary energy – usually electricity or gas – is needed to run the compressor and the pumps. In heating mode, ambient energy (such as the ground, water, environment air) is the heat reservoir and the building is the heat sink. In cooling mode, the heat sink and heat source are swapped (see Fig. 2-1) (Borre 2011).

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Fig. 2- 1 A typical heat pump system (Borre 2011: 39)

Heat pumps for heating operate as follows:

1. The low grade heat is extracted from the heat source by a collector loop and transported to the evaporator.

2. Within the closed circuit of the heat pump, the refrigerant which is responsible for transferring and transporting the heat enters the evaporator in a liquid state, evaporate to a low pressure vapour, thus storing the generated energy.

3. The low pressure vapour passes through an electrically-driven compressor, where the pressure is increased significantly, resulting in a high pressure and temperature vapour.

4. High temperature vapour enters the condenser and releases (transfers) the heat to the heating system for the building, yielding a high pressure, moderate temperature liquid after being cooled and condensed.

5. The moderate temperature liquid which comes from the condenser passes through an expansion valve which causes a reduction in its pressure and temperature. And then the liquid refrigerant enters the evaporator to begin another cycle (Stuart *et al.* 2012).

Advantages of heat pump systems:

The running cost of heat pumps are cheaper than other traditional heating systems such like oil/gas boilers, direct electric heating systems and so on; Can lower CO_2 emissions; Have no fuel storage requirements, Saving space; Safe in operation, have no 'combustion' involved and no emission of potentially dangerous gases; Require less maintenance; Can provide both heating and cooling (ICAX INTERSEASONAL HEAT TRANSFER 2007).

2.2 Types of Heat Pump Systems

Ground Source Heat Pumps (GSHP) and Air Source Heat Pumps (ASHP) are the mainly two types of HP applied in domestic buildings.

2.2.1 Types of Ground Source Heat Pumps

Fig. 2-2 shows the basic operation principle of a ground source heat pump (GSHP) system. It is most efficient when being used to supply low temperature distribution systems such as underfloor heating. But it can also be used with a wet radiator system if the radiators are correctly designed and the building has a steady and generally low heat demand.

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Fig. 2- 2 The operation principle of GSHP systems (German Renewable Energies Agency Information Platform n. d.)

GSHP systems can be generally classified as open or closed systems. For closed-loop GSHP system, heat carrier medium is circulated within the ground loops, making it a ‘‘closed’’ system. For the open systems, groundwater is used as the heat carrier, and is brought directly to the heat pump (Omer 2008). There are four basic types of ground loop systems, which are horizontal loop, vertical loop, pond/lake loop and open loop system respectively (U.S. DEPARTMENT OF ENERGY 2012)

1) Horizontal-loop Systems (Closed Systems)

For the horizontal-loop systems, the pipes are buried horizontally in trenches. This can reduce the installation cost of the ground heat exchanger, since trenching cost is generally lower than drilling. But they require more landing and piping, because the temperature of the ground near surface is subject to large temperature swings associated with the weather. The trenching depth is generally 1.5-2m (GEOTHERMAL HEAT PUMP CONSORTIUM 2004).

Horizontal heat exchangers can be divided into three subgroups: single-pipe (Fig. 2-3, Fig. 2-4), multiple-pipe and spiral.

Fig. 2- 3 Horizontal ground loops (European style) (Omer 2008: 357)

Fig. 2- 4 Horizontal ground loops (North European) (Omer 2008: 357)

In order to save surface area with ground loops and reduce the trenching cost, some special ground heat exchangers (Fig. 2-5) have been developed (GEOTHERMAL HEAT PUMP CONSORTIUM 2004).

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Fig. 2- 5 Multiple-pipes system (Omer 2008: 358)

The spiral (slinky) loop is a variation on the multiple pipe configurations (Fig. 2-6). It requires more piping but less total trenching than the multiple pipes (Omer 2008).

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Fig. 2- 6 Slinky loops (HomemicroTechnology Resource 2009)

The advantages of horizontal-loop systems include: relatively easy to install and have high flexibility of design; the trenching costs are typically lower than borehole/well drilling; greater control over entering fluid temperature.

Disadvantages include: require large ground area and longer pipe lengths; performance will be affected by seasonal variation; antifreeze solution viscosity will increase the pumping energy; pipe system could be damaged during the backfill process.

2) Vertical Loops (Closed Systems)

The vertical borehole is the most expensive but the most efficient configuration, because the under-earth level of heat increases and stabilizes with depth. The vertical closed-loop ground heat exchangers consist of a borehole of diameter 75-150mm into which are inserted two plastic pipes (polyethylene or polypropylene) that are connected at the bottom with a U-bend to form a loop (Fig. 2-7).

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Fig. 2- 7 Borehole heat exchangers (double-U-pipe) (Omer 2008)

Vertical loops are installed by drilling vertical boreholes typically 150 ft to 450 ft (45.7 to 137.2 m) down into the ground (the depth of 70-120m are more typical). The size and number of loops needed are mainly determined by the heating load needed, as well as static water level and the type of soil it will be drilled through (Omer 2008).

Advantages of vertical closed-loops: require less total pipe length and less ground area than other closed loop systems; seasonal soil temperature swings are not a concern; require the least pumping energy and have high efficiency.

Disadvantages: the installation costs are usually higher than horizontal-loop systems because of requiring drilling equipment; there are potential environmental damages to aquifers if not installed properly; if the soil temperatures change due to incorrect design, potential long term damage would happen.

3) Submerged Loops (Closed Systems)

If there is an adequate water body at the installation site, the closed-loop piping system can be submerged. A submerged closed loop (Fig. 2-8) is not common, since an open loop system is generally preferable if a water body is available. It may be advantageous where the system heat load is small or the water quality is poor which may hamper an open loop (ENERGY.GOV 2012).

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Fig. 2- 8 Submerged loops system (Wikipedia 2009)

4) Open-loop Systems

Open-loop systems tend to be used for larger installations. The most powerful GSHP system worldwide uses groundwater wells to supply 10MW of heating and cooling to a hotel and offices. They use local groundwater or surface water (i.e., lakes) as the heat exchange fluid that circulates directly through the geothermal heat pump system. The water flows “one-way” through the heat pump units and then is discharged (ENERGY.GOV 2012).

Advantages of open loop systems include: the design is simpler and the installed cost is lower; have no need to use a chemical fluid for the heat transfer medium and have greater efficiency by avoiding thermal degradation associated with ground closed-loops; can be combined with potable water supply well.

Disadvantages include: subject to various local, state, and federal clean water and surface water codes and regulations; large water flow requirements may exceed local water availability; heat pump heat exchanger subject to suspended matter, corrosive agents, scaling, and bacterial contents; circulating pumps typically require highest pumping power; the system performance can be affected by the water temperature fluctuations; heat rejected to the water source can have a biological effect on the local ecosystem.

2.2.2 Types of Air Source Heat Pumps

Air source heat pump (ASHP) systems (Fig. 2-9.) use raw ambient air to generate heat. The system passes air through an evaporator so heating the refrigerant with heat from the air. The refrigerant is then compressed and expands in the condenser giving up its heat. The heat can then be used to heat radiators, underfloor heating systems, or warm air convectors and hot water in the home (Energy Saving Trust 2012).

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Fig. 2- 9 Air source heat pump system (BUILDING AND ENGINEERING SERVICES ASSOCIATION n. d.)

There are two main types of air source heat pump system: **Air-to-water system** is similar with a conventional central heating system. It uses the energy available in the outside air with a refrigerant circuit which increases the temperature to a useful level. **Air-to-air system** produces warm air which is circulated by fans to heat the building directly. But it is unlikely to provide hot water.

Although the ASHP is cheaper and quicker to install comparing to GSHP, it still has the disadvantages: have lower COP than GSHPs and the efficiency is dependent upon local climatic conditions; will make noise because of a fan system; need a defrost cycle to prevent ice forming on its heat exchangers in cold conditions (ICaX INTERSEASONAL HEAT TRANSFER 2007).

3 Status of Heat Pump Systems in Europe and UK

3.1 Current Status of HPs in Europe

BSRIA, a research organization of built environment in the UK, has produced a global Heat Pump study on the analysis of global heat pumps market. The research suggests that the worldwide market for heat pumps is growing fast (BSRIA 2008). In Europe, the significant market for residential heat pumps exists only in Sweden, Switzerland and parts of Austria. The market share of heat pumps remains small in other countries (Fawcett 2011). In 2008, a lot of decisions on renewable source were made in Europe, including the launch of energy packages, consequently heat pumps became an established heating technology in the major European Countries. Fig. 3-1 shows the heat pump sales in 20 European countries. The 20 countries covered are presented in Appendix I. The total sales in these countries reached 752,106 units in 2010. It indicates that heat pumps sales vary hugely between different countries, from a very high uptake in Sweden and Italy, to very low in the Lithuania (European heat pump association 2010).

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Fig. 3- 1 Heat pump sales in 2010 per country (European heat pump association 2010: 30)

There are three major factors that influence the European heat pump market, which are:

1) The energy-price ratio of different energy sources and technologies. The energy prices for 2011 in different European countries can be found in 'Europe's Energy Portal' (EUROPE’S ENERGY PORTAL 2011).
2) The tendency towards an energy supply independent of non-renewable source (European heat pump association 2009).
3) A policy framework consisting of institutional and financial subsidy schemes on a European and on a national level favoring renewable energy sources.

3.2 Energy Saving Target in Europe and UK

In 2005, European Union (EU) had an 8.5 percent share of energy from renewable source. This needs to be increased by 11.5 percentages in order to meet its 20 percent target for 2020. The European Commission has proposed individual 2020 targets for each member state ranging from 10 percent to 49 percent of total final energy consumption (European Solar Thermal Industry Federation n. d.). These 2020 targets are compared with the actual percentage shares in 2005 as shown in Appendix II and Fig. 3-2.

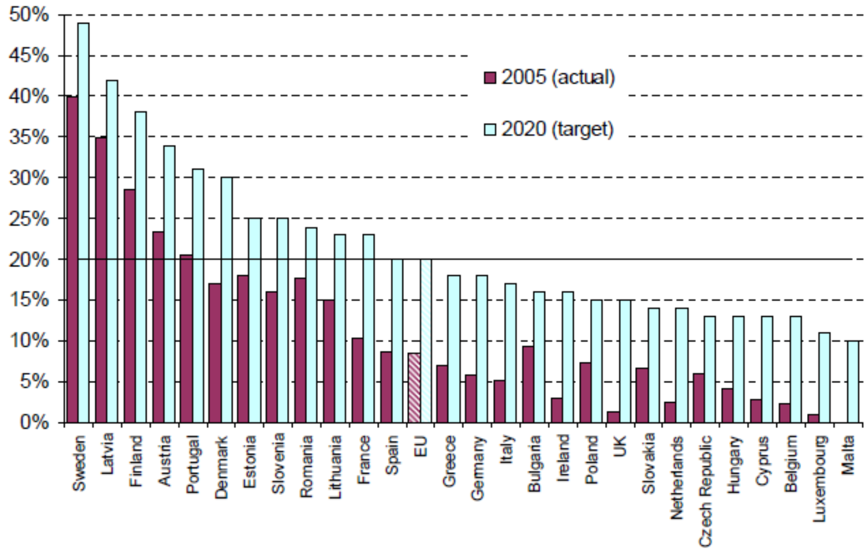

Fig. 3- 2 Share of total final energy consumption of energy from renewable sources, 2005 and 2020, after normalisation of hydro (European Solar Thermal Industry Federation n.

d.).

As it can be seen, the UK faces the largest proposed increase in renewable sources share of total energy consumption, requiring an additional 13.7 percentage point increase on the level in 2005. 'This would increase the UK's position in the EU from third lowest in terms of renewable source share in 2005 to tenth lowest in 2020' (Department for Business Enterprise & Regulatory Reform 2008). In 2006, the domestic sector accounted for over 30% of the overall UK energy consumption. The heating (combined space and water heating) consumes approximately 83% of the total domestic energy consumption (see Fig. 3-3).

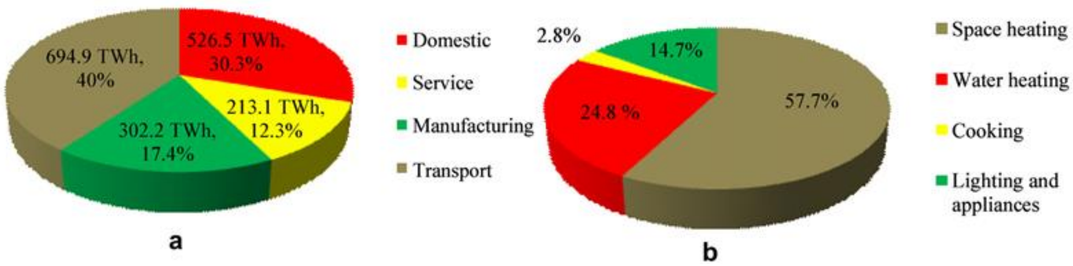

Fig. 3- 3 UK energy consumption for 2006 (Singh, Muetze, and Eames 2010: 874) (a) sector-wise; (b) sources of energy consumption in the domestic sector

It is clear that reducing the high share of energy for heating in the total energy demand in the domestic sector requires introduction of more efficient heating systems such as the heat pumps. In addition, to meet the UK government's ambitious goal for 2050 of reducing greenhouse gas (GHG) emissions by 80% of that in 1990, new technology is essential as well (Singh, Muetze, and Eames 2010).

3.3 Current and Potential Deployment of GSHPs in the UK

3.3.1 Current Deployment of GSHPs in the UK

The market for heat pumps in the UK is still in its infancy. It is estimated that, in 2005/06, there were only around 1000 GSHP installations in UK, with 3,000 units sales are reported in 2007 (Fawcett 2011). But the UK GSHP market is expending rapidly. The Environment Agency estimated that there were 8,000

GSHP units installed in UK at the start of 2009, half of which were installed in 2008 (GREEN WORKS n. d.)

Department of Energy & Climate Change (DECC) suggests that there were around 37,000 heat pump units (including GSHPs and ASHPs) across the UK in 2011. 28,000 of those units are in the domestic sector and 8,500 in the non-domestic sector (DECC 2011).

The UK Department for Business Enterprise and Regulatory Reform (DBERR, 2007) estimated that the number of GSHP installations could increase to 35,000 units by 2015 and 55,000 by 2020 (Busby *et al.* 2009).

The National Energy Foundation (NEF) and European Heat Pump Association (EHPA) estimated the annual growth rates of GSHP market in the UK from 2000 to 2011, as shown in Table 3-1 (Environment Agency 2009). It shows that there were sporadic high annual growth rates of GSHPs in the UK market in 2001/2002 and between 2004 and 2006. This reflects the low number of installations in initial market and often is seen in immature markets.

Table 3- 1 Estimated annual UK market growth rates of GSHP systems (Environment Agency 2009: 10)

Year	Estimated Annual Growth rate
2000 - 2001	50%
2001 - 2002	233%
2002 - 2003	40%
2003 - 2004	96%
2004 - 2005	82%
2005 - 2006	160%
2006 - 2007	112%
2007 - 2008	27%
2008 - 2009	83%

2009 - 2010	50%
2010 - 2011	51%

3.3.2 Potential Market of GSHPs in the UK

The Environment Agency Reported the growth scenario and high-growth scenario of the GSHP installed numbers to predict the future GSHP market trends in UK. Both of the two scenarios begin with a growth rate of 4000 units in 2008, but differ from there on (Environment Agency 2009).

Growth Scenario

The growth scenario assumes that 50% annual growth can be achieved in the early stages of the GSHP market. However, the market barriers to be described in Chapter 4 will impact the GSHP installations growth as the annual installed numbers increase (Environment Agency 2009).

As illustrated in Fig. 3-4, the installation rate starts to level off at approximately 40,000 units per annum from 2017 onwards, resulting in a total of around 320,000 units by 2020 (Environment Agency 2009).

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Fig. 3- 4 The annual installation rate and total installed systems in the UK under the growth scenario (Environment Agency 2009: 41)

High Growth Scenario

It is assumed by the high growth scenario that all market barriers could be overcome and 50% annual market growth is maintained until 2020. The Renewable Heat Incentive (RHI) being introduced by UK Government is assumed to be an efficient market enabler but the initial capital cost of installation will be a key factor in decisions to select GSHP as a suitable choice of renewable technology. As it can be seen in Fig. 3-5, the GSHP installation rate reaches around 400,000 units per year by 2019; the total units installed by 2020 are around 1.2 million. It is suggested by the stakeholders that these are achievable, although the figures are very high (Environment Agency 2009).

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Fig. 3- 5 The annual installation rate and total installed systems under the high growth scenario (Environment Agency 2009: 42)

3.4 Conclusions

This Chapter analyzed the status of heat pump systems. It indicates that the number of actual installations in UK is far smaller than some other European countries, but, it has a significant opportunity for expansion.

4 UK Market Barriers and Potential Solutions of GSHP Systems

This charter presents the reasons that make UK GSHP market smaller than other EU countries.

4.1 UK Electricity Supply

Unlike other European domestic properties which are supplied with three phase power, the majority of UK homes are supplied with a single phase electricity supply, which can only support a maximum 12 kW heat pump unit. Installing larger systems will cause voltage surges or spikes resulting in issues such as flickering lights (Feuvre 2007). Supplying 3-phase power to domestic housing is not a feasible option and will require high investment. Fitting ‘smart’ start systems to heat pumps can remediate the effect of inductive start up currents.

4.2 Competition with the Gas Distribution Network

The UK has a long history of being self-sufficient in fossil fuels with around 75 % of UK homes are served by gas distribution grid. It is expected that gas will remain as the ‘preferred’ source of fuel for the next 25 years due to current infrastructure and supply market ‘financial’ support. A high efficiency gas fired boiler is currently the cheapest heating fuel in the UK and consequently provides a cost-effective and dominant heating option, making GSHP less competitive. Besides, the natural gas boiler is also small and easy to install and less noisy compare with GSHP system with a comprehensive supply chain supporting both installation and future maintenance. Consequently GSHP has been mainly applied in areas ‘off’ mains gas grid in UK. However, the heat pump techniques will become more attractive with the UK gas diminishing and prices increasing (Simon, n. d.).

4.3 Housing Related Issues

Compare to other European countries, the majority of UK properties are built with very low level of insulation, resulting a higher and more variable heat demand. But GSHP systems will work best with a steady and generally low heat demand. Although the UK Building Regulations have raised energy efficiency standards of new and refurbished homes in recent years, the poor thermal performance of UK homes generally cannot be fixed overnight. Since new buildings which are built to higher thermal performance requirements only account for a small percentage of the total housing stock. In face, '86% of the 1996 housing stock will still be standing in 2050, around two-thirds of homes built before 2005 will be standing in 2050' (Feuvre 2007).

4.4 High Initial Costs

The capital cost of GSHP systems are generally higher than conventional heating systems, requiring a longer pay back period on operating costs saving. This is a major barrier for GSHP technology being adopted widely. 'The introduction of the Renewable Heat Incentive (RHI) coupled with capital grant and soft loan schemes will increase running cost savings and speed up payback' (Environment Agency 2009).

4.5 UK Geology and Climate

There is an extensive range of geology in UK, which will raise the need for thermal conductivity testing to determine the size of heat pump and drilling methods of boreholes. With the development of the Geology Survey, the price of testing ground thermal conductivity is expected to be lower. The UK is subject to a more moderate 'maritime' climate, which reduces the need for cooling system. The heat pump systems will be more prevalent if the cooling requirement in the UK is as high as say Japan, USA etc (Feuvre 2007).

4.6 Insufficient Installer Network

A shortage of designers and installers with relevant skills and knowledge represents an important barrier to the market penetration as the GSHP market grows in UK. This can be mitigated through training programmes (such as BPEC and NVQ) of designers and installers for GSHP systems and a greater understanding by consumers of the benefits of heat pumps resulting in increased 'market' demand of this type of system. Besides, the lack of design guide, standard or guidance in the design of GSHP in UK currently will also hinder the expansion of heat pump market. Schemes such as the MCS were identified as solutions (Simon, n. d.)

4.7 Awareness & Acceptance

The GSHP system is already a mature technology, but there is a 'lack of understanding and confidence on their use amongst both potential users and investors' (Dept. of Trade and Industry, 2005). Therefore, industry associations and the government need to launch initiatives to increase awareness and promotion of GSHP systems.

4.8 Environmental Impacts

The Energy Saving Trust (EST) stated that the use of refrigerants in GSHPs may lead to environmental risk. If toxic chemicals leak from the pipes, they definitely will contaminate the groundwater. But it also noted that new types and blends of refrigerants are being developed which would minimize these negative aspects (GREEN WORKS. n. d.)

4.9 Utility Involvement

According to the case studies of Germany, Austria and Switzerland, utilities have played key role in developing the heat pump market through promotion, active marketing, forming networks with installers and offering financial incentives. There also are some involvements from utilities with heat pumps in the UK, but it has been on a far smaller scale with very little publicity and active marketing to end users (Feuvre 2007). The backing of a technology, product or company by a large utility will reduce the uncertainty about performance and perceived risk of GSHP systems and can take a number of forms (Energy & Environment 2012). Some examples that describe the Utility roles are shown in Appendix III.

4.10 Role of Government

To boost the heat pump market, the Sweden regulations state that the distribution temperature for wet heating systems should be not over 55 °C; Switzerland introduced a carbon tax in 2008. These options are obviously good approaches to stimulate HP market but have not appeared in UK's strategies. Some countries such as Germany, Austria, Switzerland and Sweden have begun to stimulate the heat pump market through generous subsidies since the late 1970's. The UK government did not follow this path due to its abundant domestic fossil fuel reserves.

Currently, the number of renewable energy based targets in UK is growing. Heat pumps are eligible for funding under several schemes, which include: 'The Low Carbon Buildings Programme (LCBP); Energy Saving Scotland’s home renewables grant; the Carbon Emissions Reduction Target (CERT); and the Renewable Heat Incentive (RHI)' (Feuvre 2007). Relevant information is available at： http://www.greenworks.co.uk/funding-and-grants.php (GREEM WPRLS. n. d.) But these schemes support a wide range of technologies and none of them is dedicated heat pump programmes. For example, to improve the insulation levels of UK properties, the UK government has taken some actions such as introducing tighter building regulations, zero carbon homes programme and energy efficiency programmes.

Therefore, the GSHP market should be further accelerated by the co-operation between various parties which include local authorities, research bodies, installers, manufacturers and drilling contractors (Feuvre 2007).

4.11 Conclusions

This Chapter states the main barriers for the heat pump market expansion, including the high initial cost, low insulation level of UK housing, competition of gas distribution network and so on. Overcoming these barriers needs the joint efforts of manufacturers, utilities and the government.

5 Performance and Costs of HPs and Traditional Heating Systems

The efficiency of a 'heat pump' is measured by its Coefficient of Performance (COP), which is the ratio of the heat output of the system and the total amount of electricity needed to run the heat pump. The system efficiency of 'the whole system' represents the ratio of the heat output of the system and the amount of electricity needed to run the entire heating system (including domestic hot water; supplementary heating; and pumps). Compared with conventional heating or cooling systems that use fossil fuels, geothermal heating and cooling systems can only use up to 75% less electricity and reduce greenhouse gas (GHG) emissions by 66% or more (Omer 2008).

5.1 COP and CO_2 Emissions of Different Heating Systems

5.1.1 Efficiency of HP Systems and Conventional Heating Systems

The Energy Saving Trust (EST) took the year-long field trial on the technical performances of the heat pumps at 83 sites (including 29 ASHPs and 54 GSHPs) across the United Kingdom. Their monitored data showed that the well-designed and installed heat pump could be operated well in the UK and can reduce carbon emissions compare to electric or gas heating (Roy 2010). Fig.5-1 and Fig. 5-2 show the distribution of measured systems efficiencies of GSHP system and ASHP system respectively.

Fig. 5- 1 **Distribution of measured system efficiencies (GSHP) (Roy 2010: 15)**

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Fig. 5- 2 Measured system efficiencies (ASHP) (Roy 2010: 15)

Table 5- 1 The range of COP and system efficiency of heat pump systems (Roy 2010: 16)

	Heat pump COP		System efficiency	
	ASHP	GSHP	ASHP	GSHP
Range	1.2-3.3	1.3-3.6	1.2-3.2	1.3-3.3

It can be seen from Fig. 5-1, Fig. 5-2 and Table 5-1 that the system efficiencies of the 'mid-range' GSHPs were about 2.3 to 2.5, and the highest figure was above 3.0; the ‘mid-range’ of measured ASHP system efficiencies was near 2.2, and the highest figures of that were also over 3.0; heat pump performance can vary considerably from one installation to another, making the range of heat pump COP and system efficiency are wide, which indicates that the heat pump is sensitive to the designing, installing and commissioning, as well as the customers' behavior.

Appendix IV provides average efficiencies for common heating appliances (U.S. DEPARTMENT OF ENERGY 2012).

5.1.2 Environment Effect and CO_2 Emissions of HP Systems

The United Kingdom has adopted the most ambitious target in Europe of reducing carbon emissions. Compared with the greenhouse gas emission (GHS) levels in 1990, the UK intends to decrease GHS by 34% before year 2020. The CO_2 emissions come from the energy we use in our homes which accounts for 27% of the total carbon dioxide emissions in the UK, so around a quarter of this 34% saving must also come from our home consumption (Roy 2010).

As there is no combustion equipment operated in heat pump system, it will significantly reduce the CO_2, NO_x, and SO_2 emissions, apart from what is produced at source of electrical generation. Appendix IV shows the amount of CO_2 emissions per kWh heat produced by GSHP and other heating systems. It can be seen that the CO_2 emissions of GSHP powered by conventional electricity is lower than that of oil/gas fired boiler and electrical heating, a little higher than that of condensing gas boiler with 100% primary energy efficiency. The GSHP with ‘green’ electricity is considered to have no CO_2 emissions.

Eric P. Johnson researched the carbon footprints of ASHP system for 18 UK property types. The results indicate that: At UK efficiencies, the carbon footprint of ASHP is comparable or higher than that of gaseous fuels, lower than that of heating oil and far lower than that of solid fuels used in heating (Johnson 2011).

5.2 The Costs of Different Heating Systems

The EST estimates that the initial capital cost of a typical ASHP system for residential buildings is in range of £6,000 to £10000. This is around 30-50% less than that of a GSHP system. However, the annual running cost of GSHP is normally less than that of ASHP, leading to a net saving (Hepbasli 2003 and

Enviko n. d.) As discussed above, the ‘mid-range’ GSHP system efficiencies were between 2.3 and 2.5, while that for ASHP was only near 2.2, according to the study from EST.

According to 'The Greener Homes Price Guide', the initial capital costs of HP system with a 180 Litres hot water tank are listed below (The Building Cost Information Service 2009).

Table 5- 2 Initial cost of heat pump systems (The Building Cost Information Service 2009: 36)

	House Type		
	Terraced house (42 m^2)	semi-detached house (84 m^2)	detached house (250 m^2)
GSHP-Horizotal system	£ 8000-10000	£ 9000-11000	£ 9500-11500
GSHP-Vertical system	11500-13500	14500-16500	17000-19000
ASHP	£ 7500-9500	£ 7750-9750	£ 8000-10000

A report from manufacturer Dimplex analyzed annual running costs of heat pump systems and other conventional heating systems (see Fig. 5-3.), and the installation cost of Dimplex GSHP and ASHP (see Appendix V), as well as the payback years of the GSHP system and the condensing gas boiler systems for a 4 bed detached, 180m^2, new residential building (see Appendix V). The space heating and water heating load in this building is 16200 kWh/year (Davis 2010).

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Fig. 5- 3 Annual running costs of different heating systems for heating and hot water (Davis 2010: 38)

5.3 Conclusions

This Chapter reviews the system efficiencies, costs and CO_2 emissions of different heating systems. Heat pump manufacturers claim that their products have very high COP, which can be up to 5. But only little data is available to describe the 'actual' performance of heat pump systems in the real life operation. The field test from EST showed that the system efficiencies varied significantly among different properties and were lower than the European figures. But the average efficiency of heat pump systems in the UK is still higher than conventional heating. Heat pump systems will play an important role in meeting UK's CO_2 target. The initial costs of GSHP systems are normally higher than other heating systems, but, will save money for users in long term.

6 Design and Installation of GSHP for Residential Buildings

The design parameters for ground heat exchanger include the climate, ground properties, and the building's characteristics. Generally, ground properties affecting the design parameters of GSHP systems can be divided into two types: thermal properties of the soil and the hydraulic properties of groundwater (Pertzborn 2010 and Hwang 2010).

6.1 Factors Impacting on the Ground Component of a GSHP System

Geological factors affect the efficiency of a GSHP system significantly. For instance, GSHP systems would work better in areas of silt or clay than sand; rocks strength should be taken as an important factor when drilling a vertical loop (Gale 2005). The main factors impacting ground properties were introduced below.

6.1.1 Thermal Properties

The two rock/soil properties which most affect the design of a GSHP system are the thermal conductivity (λ) and the thermal capacity (C_p). Thermal diffusivity ($\alpha = \frac{\lambda}{C_p \rho}$) is related to the thermal conductivity (λ), thermal capacity (C_p) and density (ρ) describes the rate at which heat is conducted through a medium (Busby et al. 2009).

Rollin (ROLLIN 1987) and Bloomer (BLOOMER 1981) published the typical values of thermal conductivities for UK rocks. Appendix VI gives the expected thermal properties of superficial deposits and values of thermal diffusivity and thermal conductivity for various rock types (ROLLIN 2002*).*

6.1.2 Temperature

The temperature of the ground determines the temperature gradient within the collector loops of the ground source heat pump (LINACRE and GEERTS 1997). Soil temperatures vary both with daily and seasonal cycles down to a depth of approximately 15m. Below the depth of 15 m however the temperature is fairly constant and will roughly equal to the mean annual air temperature of the region (RYBACH and SANNER 2000).

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Fig. 6- 1 Estimated temperature at 100 m depth (Busby et al. 2009)

The estimated temperature at 100 m depth for Great Britain is shown in Fig. 6-1. The values are ranged from 4 °C to 17 °C with the lowest values corresponding with the highest topography. Temperatures at 100 m depth vary between 10 °C and 17 °C within the Southwest of England.

6.1.3 Groundwater

Groundwater is present nearly everywhere, but it is only available in usable quantities in aquifers (either confined or unconfined). The surface of an unconfined aquifer is at atmospheric pressure. In contrast, a confined aquifer is locally isolated from the atmosphere by one or more impermeable layers. If the recharge area (unconfined) is at high enough elevation and the permeability is high, the water pressure in the confined portion of the aquifer will be higher than atmospheric, and the water column in a borehole will rise above the base of the impermeable confining layer. In extreme case, the water in the confined aquifer will be under enough pressure to rise to the surface as a flowing artesian well. This can complicate the construction and completion of the borehole (Busby et al. 2009).

6.1.4 Ground Conditions and Geotechnical Properties

To make sure the appropriate GSHP system is designed, the correct method of installation is selected (trenching or drilling), it is vital to consider a number of preliminary ground engineering aspects, in particular: the thickness and the nature of any superficial deposits; the depth of any weathered bedrock geology; the strength of the bedrock geology and any hazardous ground conditions. To get more accurate information on the ground properties, extensive research efforts, including theoretical analysis and field tests, have been applied to estimate ground properties (Wang 2008, Roth 2004). However, field tests such as the Thermal Response Test (Esen 2009, Li 2012) and the Pumping Test (Vinsot, Delay 2011) are both expensive and time-consuming. On the other hand, theoretical analyses are rarely conducted in hard rock to several 100 m depth.

It is possible to obtain customized GSHP GeoReports from the British Geological Survey on a site specific basis, but this does incur a fee. Alternatively individual GSHP installers may apply their own experience to create the optimum design, which can be an issue to barrier a higher efficiency.

6.2 Vertical Closed-loop GSHP System Design

6.2.1 Heat Pump Sizing

As described in Microgeneration Installation Standard: MIS 3005, the following procedure should be followed to size and select a heat pump correctly

(Department of Energy and Climate Change 2008).

i) 'A heat loss calculation should be performed on the building using a method that complies with BS EN 12831'.
ii) The heat loss calculation shall be taken based on the internal and external temperatures specified in BS EN 12831.
iii) The selected heat pump should provide at least 100% of the calculated design space heating power requirement.

6.2.2 Ground Loop Sizing

Sizing the ground heat exchanger is one of the most important tasks in designing GSHP systems. To achieve good performance of the GSHP, it is critical to calculate the ground loop size accurately.

Under-sizing the ground loop will result in: a. the comfort level of buildings will be decreased; b. the annual energy extracted from the ground would be decreased over time as the reduced ground temperature might unable to recover; c. householders might use auxiliary heating, and the antifreeze will become more viscous because of the drops of ground temperature, increasing the pumping requirement, which both will reduce the system efficiency. While the oversizing will shorten the system lifespan, increase the installation cost and reduce the performance efficiency.

There are various design methods to determine the ground loop length of GSHP system, such as using computer softwares, manual methods (ERDOGAN 2010), and the use of rules of thumb. However, using rules of thumb to design the ground loop length often leads to oversized, expensive systems or undersized failures (Geothermal Heat Pump Installation 2009).

The loop lengths should be determined by means of manual methods or computer Software (such as EED, GLHEPRO, and GLD) that accounts for the following design parameters: building loads, ground thermal characteristics, heat pump characteristics, loop operating temperature range, field geometry, pipe characteristics, grout or backfill thermal characteristics, local drilling practices and restrictions, and local ground water conditions (McCray n. d.).

6.3 Installation of Vertical Closed-loop GSHP System

The borehole drilling or ground loop emplacement represents a significant proportion of the installation cost, so it is important that these are not unnecessarily over engineered.

6.3.1 Drilling Methods

'Fig. 6-2 is a schematic representation of a typical rig used to drill holes for borehole heat exchangers, install the heat exchanger, and backfill the hole with materials that ensure both good heat transfer and groundwater protection' (Culver n. d.). This section introduces the most common drilling methods.

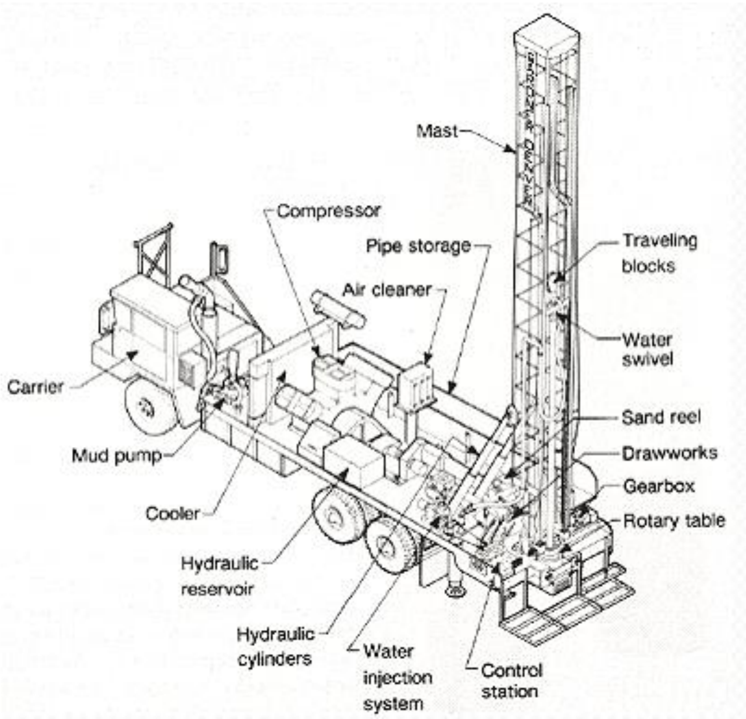

Fig. 6- 2 Direct rotary rig Error! Bookmark not defined.

1) Rotary Drilling

Rotary drilling is the most common drilling method in both water and geothermal well drilling. There are several rotary equipment types: Mud-rotary is used commonly in areas with less hard sand-stones and shales; in areas where the rocks are very competent (resistant to mechanical stresses) and the water table is low, the air-rotary is more common; Percussion equipment is rather widely applied in competent rocks for 15 cm diameter holes.

'Borehole advancement by mud rotary drilling is achieved by rapid rotation of a drill bit which is mounted at the end of drill pipe. The drill bit 'cut' the formation into small pieces (cuttings) which are removed by pumping drilling fluid (mud) through the drill pipe, out the drill bit and up the annulus between the borehole and drill pipe. The drilling fluid is also used to cool the drill bit and stabilize the borehole wall, prevent fluid loss into the formation and to reduce cross contamination between aquifers' (AQUIFER DRILLING & Testing Inc 2010).

Opposed to a water-based fluid such as in mud rotary drilling, air-rotary drilling which uses air with a foaming agent as the circulating fluid works less well with formation that yield large amounts of water.

2) Reversed Rotary Drilling

Reversed circulation is a variant of the rotary drilling. In reverse circulation, drilling fluid (usually water or very thin mud) flows down the borehole annulus and up the center of the drill rods. Reverse air drilling is most successful when drilling in soft sedimentary rock and unconsolidated sand and gravel (Culver n. d.).

3) Percussion Action

The Percussion Action method, also called the down-the-hole (air) hammer, is not a true rotary method, but a percussion method adapted to a rotary rig.

The down-the-hole hammer acts similarly with a large jackhammer. It is less efficient than hydraulic systems and cannot be used more than about 50 ft to 100 ft (15m to 30m) below the top of the groundwater column (Culver n. d.).

4) Alternatives You May Encounter

Other drilling methods you may encounter include ‘Drill Through Casing Driver’, which is typically used for installation of larger water wells (Robertson GeoConsultants Inc n. d.); ‘Core drilling’ that widely used in mineral exploration, civil works foundation investigation, and wells for scientific investigation; and **‘**Auger drilling’, which is restricted to generally soft unconsolidated material or weak weathered rock.

Appendix VII compares the advantages and disadvantages as well as productivities of several drilling methods which likely to be encountered in Borehole Heat Exchanger installation (Soulsby 2010, Kavanaugh 1997)

6.3.2 Grouting to Vertical Closed-Loops

To make the ground loops as cost-effectively as possible, GSHP designers and ground loop installers strive to obtain the following two goals: (1) protecting groundwater from contamination which may be resulted from surface waters or from flow between aquifers; (2) achieving the best possible thermal contact between the country rock and the heat exchanger loops.

To achieve these two goals, the keys are to chose proper grout or backfill materials and install vertical borehole heat exchanger (BHEx) properly following the local regulations. Improper backfilling has very often been the cause of the BHEx failures, much more frequent than loop failure.

Appendix VIII should be used to select an appropriate grouting material, based on the geological conditions expected to be encountered during the vertical closed-loops installation (Michigan Department of Natural Resources & Environment 2010).

The grouting process can be found in 'Best Practices for Geothermal Vertical Closed-Loop Installations'.

6.3.3 Case Study of Drilling

The borehole drilling is a complicated process. Unexpected situation would happen, making the whole project delayed. The project conducted in Bariles, UK by Orbit is a very typical example. If this has been explained to customers, they would not have complained about this project so much as mentioned in section 8.5.2.

Nearly all drilling for geothermal heat pump installation in UK is by rotary drilling method. There are two type of rotary drilling method based on flush – water or air. The choice is generally determined by the strata to be drilled through. Hard strata, granite etc., requires the use of air with a down the hole hammer; there is a choice for sandstone and mudstone of either air or water; and for softer formation water is used with a polymer to stabilize the hole during drilling.

Air rotary is an aggressive form of drilling, and not suitable for drilling adjacent to residential properties in softer formations. A GSHP installation project was carried out by Orbit Heart of England in Brailes, Warwickshire, UK. The strata at Brailes are predominantly mudstone with limestone bands and therefore water flush is the natural choice. However, when the second borehole at Brailes was being drilled, the drillers encountered artesian water at 3m and again at 14m under ground. The ground water within discrete strata bands was under pressure, when the strata were drilled into, the groundwater came up the hole to above ground level. This was an unexpected situation, and also one of the reasons that the whole project was consequently delayed whilst the site conditions were resolved.

To control the groundwater, the drillers installed a steel casing into the borehole and also applied water flush drilling technique (i.e. water is circulated down the drill rods at pressure to bring cutting from the cutting head of the drill string back to ground level). They installed the ground loops and grouted using a heavy barite bentonite mud to seal the inflow of water and then pulled back the casing. Using this method the water inflow at the deeper depth was sealed successfully.

In some instance the water from the upper water strike formed a pathway to the surface after grouting, washing away some of the grout required drillers to return and seal the boreholes using a heavier grout mix.

A mixture of enhanced bentonite with sand was chosen as the grout in the drilling process. In this case, to make the grout heavier to control the artesian water, Barite was introduced. The cement was then added to the grout when drillers returned to seal the water.

The presence of artesian water in Brailes caused drillers significant problems over and above those generally associated with drilling and maintaining a clean environment around residential properties and required additional time and management to control and resolve. The drilling delay in Brailes indicates that it is essential to identify the geological conditions at the drilling site before starting works.

6.4 Conclusions

This Chapter introduces the design and installation of closed-loop vertical GSHP systems, giving GSHP users a general view on the design process and drilling methods. Thereby, the rotary drilling is the most common drilling method used in GSHP industry. However, which method to chose is depending on the geology conditions of the work site. Unclear geological information may raise unexpected problems during the drilling, which is proved in a GSHP installation project carried out in Brailes, Warwickshire, UK.

7 Case Study on ‘Comfort’ Levels and Cost of GSHP System

7.1 Case Study on ‘Comfort’ and Energy Consumption of Different Heating Systems

Orbit Heart of England carried out a field test on the temperature, humidity, CO_2 emissions and energy consumptions of 5 properties with different heating systems (GSHP; storage heaters and electric radiator; storage heaters, oil heater and electric fire; gas source radiator; ASHP) in 2010. Appendix IX gives the general information of the properties and the definition of temperature and humidity range for different comfortableness levels (Goldsmith 2010:1).

Table 7-1 shows the mean temperature, humidity and CO_2 indoor and outdoor of the 5 properties. It is an accepted UK standard that properly ventilated buildings should have CO_2 levels between 600ppm and 1,000ppm (Illinois Department of Public Health 2011) and the average indoor CO_2 levels should not exceed 700 ppm above the outdoor ambient levels [(Persily 1997).

Table 7- 1 The mean temperature, humidity and CO_2 over the deployment period (Goldsmith 2010: 2)

Address	Indoors			Outdoors		
	AVG. Temperature (℃)	AVG. Relative Humidity	AVG. CO_2 (ppm)	AVG. Temperature (℃)	AVG. Relative Humidity (%)	AVG. CO_2 (ppm)
2 Leam Road	19.61	54.60	1066.50	N/A	N/A	N/A
11 Elm Close	19.37	48.89	949.64	2.97	88.95	N/A
22 Town Ground	17.64	59.89	1535.20	5.49	75.02	743.79
30 Elliott Drive	18.35	51.02	1116.83	2.58	86.24	627.65
32 The Green	17.97	57.49	1149.53	8.13	85.13	788.96

It can be seen in Table 7-3 that, except 11 Elm Close, the other properties tested all had a CO_2 level over 1,000 ppm (parts per million). But the CO_2 level in 2 Leam Road was just a little more than 1000 ppm. While the CO_2 level in 22 Town Ground reached 1535.20 ppm, and it is also the only property where the CO_2 exceed the difference limit (700 ppm) between outdoor CO_2 level and indoor CO_2 level among the homes where outdoor CO_2 measurements are available.

2 Leam Road had the highest figure (19.61℃) of indoor average temperature, followed by 11 Elm Close (19.37℃) and 30 Elliott Drive (18.35℃), 32 The Green and 22 Town Ground had relatively lower temperature, which were 17.97 ℃ and 17.64 ℃ respectively.

Note: CO_2 data is reported as a dry air mole fraction (the number if molecules of carbon dioxide divided by the number of all molecules in air).

Monitoring data for 2 Leam Road

Fig. 7-1～Fig. 7-3 show the temperature exposure, humidity exposure and temperature frequency for 2 Leam Road during the deployment period.

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Fig. 7- 1 Temperature exposure in each room for 2 Leam Road (Goldsmith 2010:5)

As can be seen in Fig.1, 2 Leam Road was in comfortable conditions in the majority of the time. There were a few instances where levels fell below the comfort zone occurred in all rooms other than the kitchen (99% of its time in comfortable or warm conditions). Most occurrences of these cold spots were in the upstairs landing and downstairs landing. In bedroom A, 3.5% of its time being in the region of health risk, this is a concern as occupants spend long period of time in this room.

Fig. 7- 2 Humidity exposure in each room for 2 Leam Road (Goldsmith 2010:6)

The humidity levels throughout 2 Leam Road were at a comfortable level, with only the two landing areas showing some signs of dampness.

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Fig. 7- 3 Temperature frequency for 2 Leam Road during deployment period (Goldsmith 2010:7)

Monitoring data for 11 Elm Close

Temperature exposure, humidity exposure and temperature frequency for 11 Elm Close during deployment period are given in Fig. 7-4～Fig. 7-6.

Fig. 7- 4 Temperature exposure in each room for 11 Elm Close (Goldsmith 2010:9)

In 11 Elm Close, Bedroom A and bathroom caused concern as they respectively spend 41% and 83% of the time in conditions which are detrimental to occupants' health. The kitchen and living room were the most comfortable rooms in the home.

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Fig. 7- 5 Humidity exposure in each room for 11 Elm Close (Goldsmith 2010:10)

Humidity was at a comfortable level in 11 Elm Close in most of the time, but in bedroom A, bedroom B, Cupboard A and hallway, it experienced dry conditions during a noticeable period time, with bedroom B showing the longest periods of time with dry air.

Fig. 7- 6 Temperature frequency for 11 Elm Close during deployment period (Goldsmith 2010:11)

Monitoring data for 22 Town Ground

Temperature exposure, humidity exposure and temperature frequency for 22 Town Ground during deployment period are given in Fig. 7-7～Fig. 7-9.

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Fig. 7- 7 Temperature exposure in each room for 22 Town Ground (Goldsmith 2010:13)

The majority of the house at 22 Town Ground was cold and under conditions that present potential health risks. The occupants complained that the bathroom was very cold nearly all the time, and Bedroom B was also in cold conditions in majority of time. Bedroom A and living room were in slightly better conditions as they were occupied most frequently and doors were closed at all times to allow heat to build in the room.

Fig. 7- 8 Humidity exposure in each room for 22 Town Ground (Goldsmith 2010:14)

The majority of the home at 22 Town Ground was in comfortable humidity conditions except of the bathroom and kitchen, which showed high levels of damp. Both of these two areas had been known for mould growth.

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Fig. 7- 9 Temperature frequency for 22 Town Ground during deployment period (Goldsmith 2010:15)

Monitoring data for 30 Elliott Drive

Temperature exposure, humidity exposure and temperature frequency for 30 Elliott Drive during deployment period are given in Fig. 7-10～Fig. 7-12.

Fig. 7- 10 Temperature exposure in each room for 30 Elliott Drive (Goldsmith 2010:17)

The main living areas at 30 Elliott Drive were mostly in comfortable conditions, with only bedroom B showing some signs of coldness. The downstairs landing and upstairs landing were in the zone of potential health risks, and they were also known for damp and humidity issues. The bathroom was in cold conditions in over 99% of the time and in a state that potential health risks could occur in around half of the total deployment time.

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Fig. 7- 11 Humidity exposure in each room for 30 Elliott Drive (Goldsmith 2010:18)

The main problem areas at 30 Elliott Drive were the landing areas which showed long exposure to dampness in the home. This damp could be seen on the external wall on the stairs, which had led to peeling wallpaper and signs of mould.

Fig. 7- 12 Temperature frequency for 30 Elliott Drive during deployment period (Goldsmith 2010:19)

Monitoring data for 32 The Green

Temperature exposure, humidity exposure and temperature frequency for 32 The Green during deployment period is given in Fig. 7-13～Fig. 7-15.

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Fig. 7- 13 Temperature exposure in each room for 32 The Green (Goldsmith 2010:21)

At 32 The Green, the living areas were mainly cold, with the living room being under potential health issues conditions 32% of the time. The occupant mentioned that he did feel cold most of the time. These conditions could have detrimental effects on the occupants' health as they already had existing health problems. The boiler room and the hallway were in comfortable conditions, but the boiler room was a utility room. The hallway was deployed opposite the boiler room, thus higher temperature was recorded.

Fig. 7- 14 Humidity exposure in each room for 32 The Green (Goldsmith 2010:22)

At 32 The Green, most rooms showed comfortable humidity levels, with only slight dampness in the living room. But the occupant did dry clothes in this room, making an increase in the humidity.

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Fig. 7- 15 Temperature frequency for 32 The Green during deployment period (Goldsmith 2010:23)

Table 7-2 and Fig 7-16 show the energy consumption of different heating systems in the 5 properties. As can be seen, the energy consumption per day per m2 at 30 Elliott Drive (1.4 kWh/day/m2) was the most, much more than that at 2 Leam Road (0.9 kWh/day/m2). 22 Town Ground consumed 0.85 kWh/day/m2, followed by 11 Elm Close (0.71 kWh/day/m2). The energy used by 32 The Green (ASHP installed) was the least.

Although the energy consumed by GSHP system at 2 Leam Road was not as less as expected, it provided the most comfortable indoor warmth among all the heating systems tested. Tenants lived in 32 The Green felt cold at half of time tested in living areas, but they used the least energy. Although the higher outdoor temperature (8.13 ℃) outside of 32 The Green may be one of the causes for low energy consumption. 22 Town Ground and 11 Elm Close used the similar heating systems. But the indoor comfortableness at 22 Town Ground was a little worse than that at 11 Elm Close, while its energy consumption was more than 11 Elm Close. This may due to its poorer insulation conditions.

Table 7- 2 Energy consumption

Address	Type of heating	Electricity used over entire deployment period (kWh)	Average energy usage per day per m^2 using both daily electricity and gas figures ($kWh/day/m^2$)
2 Leam Road	GSHP	915.5	0.9
11 Elm Close	Storage heaters and portable electric radiator	589.1	0.71
22 Town Ground	Storage heaters, a small oil heater and an electric fire	857	0.85
30 Elliott Drive	Gas source radiator	1568	1.4
32 The Green	ASHP	441.4	0.43

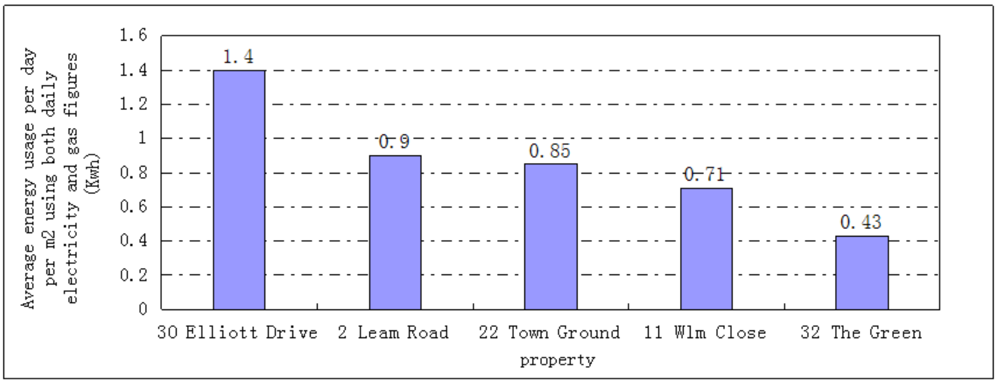

Fig. 7- 16 Average energy consumption per day per m2 in the 6 properties.

7.2 Case Study on Electricity Usage in a Property before and after Installing GSHP

In order to check whether there is a reduction of electricity usage after the installation of GSHP in Orbit's properties, the old electricity bill (before the GSHP was fitted) and the new electricity bill (after the GSHP was fitted) at 9 Elm Close, where installed GSHP in March 2010. The general information of this property is given in Appendix IX.

The electricity consumption and cost is shown in Appendix X. As it can be seen, at 9 Elm Close, where the amount of energy consumed was 10331 kWh during Apr 2009 – Apr 2010, with 2293 kWh in day time, and 8036 kWh at night; and 4094 kWh during Jan 2011 to Jan 2012, with 3877 kWh in day time, and 1027 kWh at night. The total electricity consumption with GSHP was reduced by 60.4% compare to night storage system.

However, the electricity cost was increased by 16.17%, with £784.78 (night storage) and £911.65 (GSHP) respectively. This is because the electricity price increased from 2009 to 2012 as shown in Table 7-3. If the electricity price keeps constant during the test period, the electricity cost of this property will be during £694.47 Jan 2011 to Jan 2012, with 11.51% reduction compare to year 2009.

7.3 Conclusions

This Chapter summarized some new findings from a field test report made by Orbit Heart of England. According to the monitoring data on the temperature, humidity, CO_2 emissions and energy consumptions of different heating systems, the GSHP system provided the most comfortable level among all the heating systems tested, with a average indoor temperature of 19.61 ℃ and a second lest CO_2 emission amount (1066.50 ppm). The energy consumption (0.9kWh/day/m2) of GSHP was not the least, but much less than that of Gas source radiator (1.4 kWh/day/m2).

According to the data collected from a property of Orbit Heart of England, the electricity consumption of GSHP was reduced by 60.4% compared with the night storage, and the electricity cost would be decreased by 11.51% if the electricity price keeps the same with that in 2009.

8 Feedback from GSHP Users

GSHP systems are being increasingly installed around the world, and are fast establishing themselves as a safe, reliable technology. But, so far, there have only been a few studies carried out on how well GSHP users can control the system and whether they are satisfied with the performance in meeting their respective needs and operational cost. How the system is used has an important effect on the performance of GSHP. Therefore, a survey was carried out among some householders who have installed GSHP systems. The purposes of this survey include: Research on how residents' operation on GSHP impacts the energy consumption in the house; Find whether users are satisfied with the GSHP performance and customer service; Check if they have any difficulties to control the system; determine how to improve the customer service.

A total of 161 questionnaires were posted to tenants of Orbit Heart of England in June 2012, of which 62 were completed. The feedback rate is around 38.5%, which is considered a considerable response rate according to an experienced building surveyor from Orbit Heart of England who had carried out quite a lot of surveys among customers. It indicates that the tenants are interested in and are concerned in the performance of their heating systems.
Appendix XI shows the general information of the properties investigated and one of the filled questionnaires.

Questionnaire Planning and Design

The questionnaire was designed in consultation with an experienced building surveyor and discussion with some colleagues from the Sustainable Investment Group in Orbit Heart of England. A number of questionnaires and literatures on GSHP were also reviewed before designing questions. There four purposes of the survey as mentioned above:

1. How users’ operation impact the energy consumption

The study of EST (Energy Saving Trust 2012) suggests that users' operation will impact the GSHP performance significantly and GSHP may need to be on constantly to povide heat efficiently. So questions, including 'do you start the system with higher temperature than needed?', 'Do you heat the whole property or just heat occupied rooms?', ‘Do you run the system constantly/short period during the day/ night?’ and ‘Do you change the heating times depend on season/whether?’ were asked.

The study of Paul J. (Paul, Tonva, and Robert 1995) suggests that the COP of heat pump is a function of the entering water temperature which is influenced by the setting temperature of the system. So, ‘What temperature do you set for your GSHP?’ is an essential question.

According to the communication with colleagues and some tenants from Orbit Heart of England, some tenants may use extra heating devices supplementing the GSHP. Using extra device will definitely increase the electricity consumption, since they are not as efficiency as GSHP. Therefore, questions ‘Do you use separate heating device in any room in addition to GSHP?’ and ‘How regularly do you use an immersion heater for your hot water?’ were added to the questionnaire.

2. Whether users are satisfied with the GSHP performance and customer service.
International Ground Source Heat Pump Association (International Ground Source Heat Pump Association 2012) gives some 'Frequently Asked Questions' on GSHP, in which, questions such as 'How noisy is the GSHP unit?', 'What about comfort that GSHP provide? ', 'Whether additional heat sources are necessary in extremely cold climates with GSHP?', and 'How and how much will I save money with a GSHP?' were included. This means that these questions are what GSHP users most concern. So, similar questions were putted into the

questionnaire.

3. If users have any difficulties to control the system

Making users fully understand how to control the GSHP is very essential to getting the highest efficiency of GSHP. Therefore, the following questions were designed for the questionnaire: ‘How easy do you find it to control the GSHP?’, ‘How well do you understand how to control the GSHP system?’, ‘What information were you provided with about how to use your GSHP?’ and ‘Were you satisfied with the technical support from the heat pump installer/supplier?’.

4. How to improve the customer service

According to the discussion with colleagues from the Sustainable Investment Group in Orbit Heart of England, what aspects on the customer service and GSHP systems that tenants are not satisfied with is a special concern of the industry area. So, questions such as 'What do you think are particularly bad with your GSHP?', 'Do you satisfy with the customer service?’ and 'Would you like to give any suggestions on customer service?' were designed.

8.1 Tenants' Satisfaction with GSHP Systems

8.1.1 Satisfaction with the Level of Comfort GSHP Provides

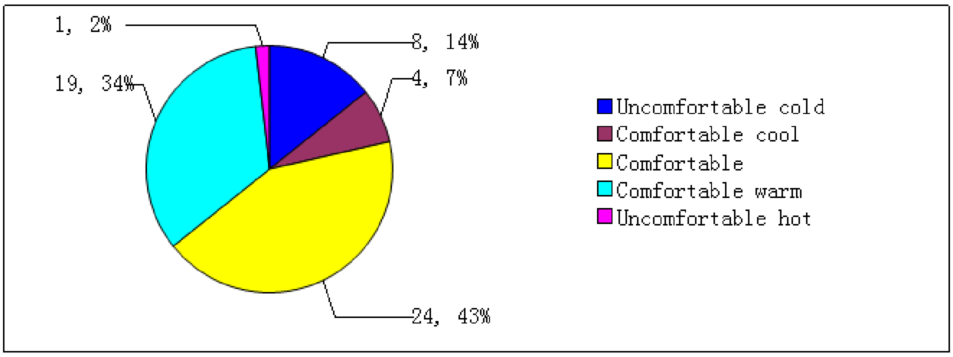

Fig. 8- 1 Comfort levels that tenants have chosen.

Fig. 8-1 shows the level of comfort in the home that tenants registered. As it can be seen, 77% of the 56 tenants who responded to this question felt comfortable or comfortably warm using GSHP systems, 4 tenants felt comfortably cool. There was a sizable amount of (14%) tenants who said they felt uncomfortably cold in their house, and one tenant felt uncomfortably hot. It indicates that the majority of tenants were satisfied with the warmth level in their house. One tenant mentioned that they felt uncomfortably cold in rooms with smaller radiators, while they felt comfortable in rooms with bigger radiators.

8.1.2 Satisfaction with Cost

Since some tenants moved into their properties after the GSHP system was installed, there were only 42 tenants who knew what percentage of their bill had been reduced or increased. As can be seen in Fig. 8-2, 77% of tenants thought their bill had been reduced to varying degrees, with 21% reporting that 1-10% had been reduced, 5% (2 tenants) reporting a reduction of 11-20%, 17% stating their bill had been reduced by 21-30%, and 19% saying 31-50% of their bill had been reduced. Only 2 tenants thought their bill had decreased more than 50%. However, the other 33% (14) of tenants complained that their bill had increased compare to before. And of these 14 tenants, there were 8 who felt comfortable or comfortably warm in their home, with 4 of them feeling uncomfortably cold, while 2 of them felt uncomfortably cool. This means there were 6 tenants who had higher bills than before, but still felt uncomfortable in their house. This is a cause for concern because it goes against the targets of saving energy and providing constant heat which GSHP is supposed to supply. Nearly all these 6 tenants complained that they found nothing good about the GSHP system at all; one even saying that he found it totally useless, although one of them mentioned it supplied constant hot water.

The design and installation of GSHP systems were carried out by different installers in these properties. An increase of bills occurred irrespective of who carried out the installation. This suggests that cost issues are probably not due to incorrect installation, but more likely the result of either how tenants use the system or the nature of the property itself.

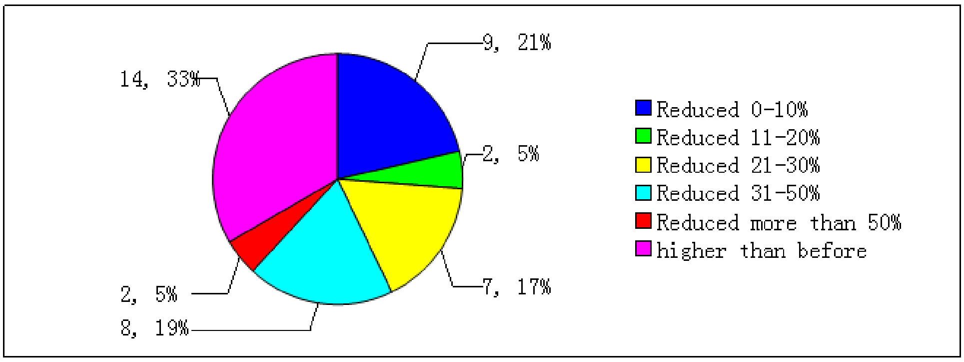

Fig. 8- 2 Bills compare with before.

8.2 How Users Control the System

Tenants' usage is one of the most important factors that impacts on the performance of GSHP systems. This section researched how tenants of Orbit Heart of England control the GSHP and what influence they may have on the system.

8.2.1 Space Heating

1) Supplementing GSHP

Table 8-1 shows the number of tenants that heat the whole property/ only heat occupied rooms with GSHP. It can be seen that most of the tenants heat the whole property with GSHP, while only 6 out of the 62 tenants just heat the occupied rooms, leaving a lot of tenants requiring Thermostatic Radiator Valves (TRV) being installed on the radiators. But installing too many TRV on radiators will throttle the water flow, and then impair the efficiency of GSHP. So good communication between installers and tenants is required before installing the GSHP system, to ensure the bigger/smaller radiator is installed in the correct room.

Table 8- 1 The amount of householders who heat the whole property/ occupied rooms

	Amount of tenants who chose this option
Heating occupied rooms	6
Heating the whole property	56

Table 8-2 describes the amount of tenants that used separate heating devices supplementing GSHP systems. 44 out of the 61 tenants only used GSHP systems in their houses, while the other 17 tenants also used extra heating devices during very cold periods. 5 tenants mentioned the devices they used, which were electric heaters (2 tenants), fan heaters, electric fire in living room and oil filled radiator respectively. In addition, 7 out of the 8 tenants who felt uncomfortably cold in their house/ some rooms chose to use extra devices to get warmer. This may indicate that the GSHP system could not meet the total heat demand in some properties.

Using extra devices may increase the energy used in the rooms being heated. Among the 7 tenants who used extra devices and felt uncomfortably cold in the house, there were 4 of them who thought their bill had increased, 1 of them said the bill was only reduced by 0-10%, while only 2 of them said they had got a reduction of 21-30% of the bill.

Table 8- 2 The amount of householders who use/not use extra heating devices expect of GSHP system

	Amount of tenants who chose this option
Use separate heating device	17
Only use GSHP	44

2) Temperature Setting for Space Heating

GSHP systems operate most efficiently when the heat loss of a property is minimized and the system is operated at a relatively low temperature constantly. Therefore, GSHP systems provide constant, reliable and efficient heating with low temperature radiators that usually operate at 45°C to 55°C. While other wet radiator systems usually have a delivery temperature of 60°C to 80°C. So some users who formerly used these conventional heating systems may have learned that it is better to turn the heating system off when they are out to save energy. But this does not apply to GSHP systems. The drop in circulating temperature would require an increase in radiator surface of 30% to 40% to maintain the same heat output and would lead to a slow warm up problem. This may cause some tenants to choose to start the GSHP system with a higher temperature than they need, and then change the operating temperature to the needed figure after the house gets warm. This action will impact on the efficiency of the system significantly.

i) Heating temperature

Table 8-3 and Fig. 8-3 together describe the tenants' responses to the question regarding what temperature they set during the heating period. There were 42 tenants who gave exact temperature figures, which are shown in Fig. 8-3. There were 12 users who reported a temperature range they set on, which is shown in Table 8-3.

Table 8- 3 The temperature that 12 tenants set in their houses

Temperature range ℃	5-20	20 in day, 15 in night	17/19	17-21	18-21	19-21	20/21	22-24	20/25	22/30
Amount of tenants	1	1	1	1	1	1	3	1	1	1

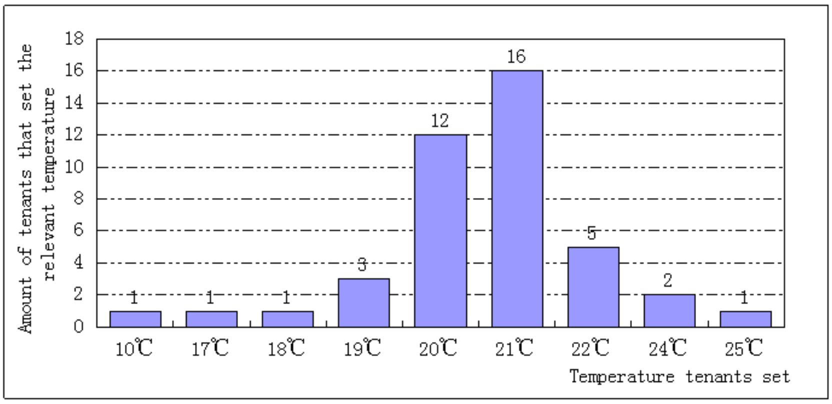

Fig. 8- 3 The temperatures that 42 tenants set in their house

It can be seen that most tenants set the heating temperature as 19-21℃. But some of them (10 tenants) made that over 22 ℃, even up to 30 ℃, which would reduce the efficiency of GSHP. 2 tenants set the heating temperature at 17-18℃, with one of them using an oil filled radiator as an extra heating device. One tenant felt comfortably warm with the temperature set at an extremely low 10 ℃, and another tenant felt comfortable with it set at a very high temperature of 25℃. There was even one tenant who said he set the temperature from 5℃ to 20℃. It indicates that although most tenants set a reasonable heating temperature for their house, there were a number of tenants who had no idea what the suitable temperature they could set.

Among tenants who set the room temperature over 22 ℃, 6 out of 12 tenants said they felt uncomfortably cold in their house/some rooms. One tenant mentioned he felt uncomfortably cold in lounge, while felt comfortable in the rest of house. Improperly deployment of radiators is likely a reason of this problem.

In addition, 11 users started the system with a higher temperature than needed, and then changed it to the required temperature when the room got warm, with 45 users starting the system with the required temperature as shown in Table 8-4.

Table 8- 4 How tenants start their GSHP systems

Start with higher temperature than needed and then reduce to the needed temperature after the room gets warm	Start with needed temperature, waiting room to get warm
11	45

Tenants choosing to start the system with a higher temperature than they needed maybe due to the slow warm up problem of GSHP or/and the moderate 'maritime' climate (mild and moist) of the UK. The moderate climate can be a hindrance to heat pump use at night, leaving tenants needing the building to be heated quickly in the morning. But this will increase the power input of the compressor and circulating pumps, reducing the system's efficiency significantly. One of the users even started the system with 25 ℃, and then changed it to 20 ℃ when it felt warm. So it is very important for tenants to understand that the hotter the circulating water, the poorer the energy-efficiency. A typical GSHP system can be illustrated by the following COP figures:

Water heated to 55° COP = 2.4;
Water heated to 45° COP = 3.2;
Water heated to 35° COP = 4.

To be comfortable with a lower operating temperature requires both good system design and correct setting of the heat pump controller.

ii) Heating times

Fig. 8-4 shows how the tenants set their heating times during day and the night, as well as when they were out.

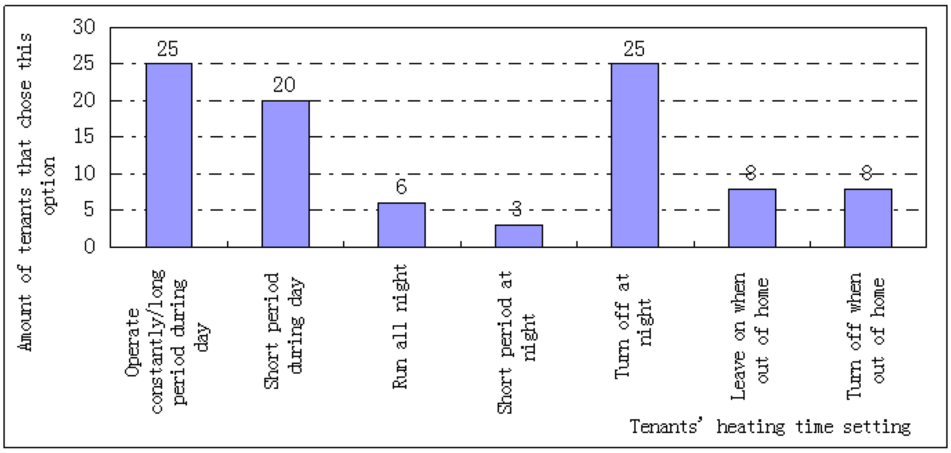

Fig. 8- 4 Tenants' heating time setting.

It can be seen that 25 tenants operated the GSHP constantly/long period during the day compared with 20 tenants who operated it for a short period in the day. Among the 34 tenants who responded to the question regarding how they ran the system at night, most of them (25 tenants) said they turned off the system, compared with 6 tenants who ran it all night and 3 tenants who ran it for a short period. 8 tenants mentioned that they left the system on when they were out, while 8 turned the system off.

As discussed above, because of the moderate climate of UK, most tenants turned off the GSHP system at night. They then often required the temperature in the rooms getting higher quickly in the morning, leading to a high start temperature setting. The actions of running the system for short periods in the day/ night or turning off when they went out will definitely reduce the system's efficiency significantly. Tenants may have believed turning the system off when the room got warm would save energy for them, as this is true for conventional heating systems. However, this is not the case for GSHP. The GSHP system is generally self-controlling, so it will turn itself on and off automatically. It is not necessarily using power all the time if the unit is switched on, especially if it is turned to 'low'.

By keeping the radiator 'warm' all day or 'hot' for just a few hours may achieve the same room-comfort. But the COP of GSHP will be improved considerably if the radiator temperature can be kept low. Experience has shown that leaving heat pumps on a low continuous setting is likely to give lower running costs for most situations.

8.2.2 Domestic Hot Water

Regarding whether the tenants tend to use more hot water than before installing GSHP, the majority of tenants said they used the same amount of hot water as before, 2 tenants even used less, which means they used the hot water more carefully than formerly. Only 2 tenants used more hot water than before, as shown in Table 8-5. This indicates that the majority of tenants are aware of the energy saving potential of GSHP.

Table 8- 5 Hot water usage situation

	Use more than before	No change	Use less than before
Amount of householders	2	52	2

Fig. 8-5 shows the frequency tenants used the immersion heater to heat the hot water. As can be seen, 73% of tenants rarely or never used the immersion heater, 2% and 7% of them used it once per month and once per week respectively. Only 18% of the tenants used it every day. And tenants who used the immersion heater every day did not report either an under-demand of hot water supply or a higher cost. It indicates that GSHP can meet most tenants' requirements on hot water usage. This can be proved by the description of tenants' opinions on GSHP systems in section 8.4.

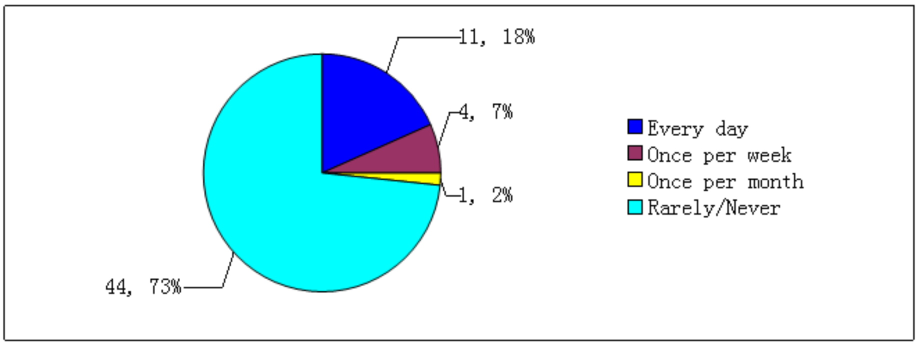

Fig. 8- 5 The frequency tenants use immersion heater for the hot water

8.2.3 Adjustment of Times for Room Heating and/or Hot Water Heating According to Weather/Season

When asked whether they changed the heat times of room heating and/ or hot water heating according to season/ weather, 44% of the tenants did not change either, 34% of tenants changed both, 18% of tenants just changed the heating times for rooms, while only 4% of tenants just adjusted the heating times for hot water (see Fig. 8-6).

As discussed in section 8.2.1.2, it is not really necessary to adjust the times for heating rooms, which may reduce the system's efficiency if it is adjusted improperly. However, 52% of tenants changed that according to season/weather. While only 38% of tenants changed the times for heating water, which helped to reduce the energy cost in the house. Since the hotter the water is heated, the lower the COP of GSHP system. An increase in time of heating hot water will definitely reduce the COP and increase the energy cost. But it is obvious most tenants are not aware of this or do not know how to adjust the times for heating water.

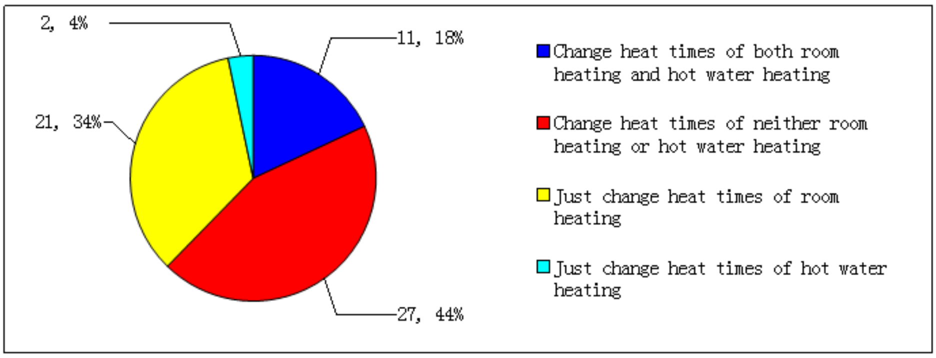

Fig. 8- 6 Whether adjust heat times of room heating or/and hot water heating

8.3 Satisfaction with the GSHP Information Provided

8.3.1 How Well can Tenants Understand or Control the GSHP

When asked how well they understand how to control the GSHP system, almost half of the tenants (47%) said they did not know too much but their knowledge was enough for them to control the system, as shown in Fig. 8-7. However, the fact they knew how to control the system does not mean they know how to control it well. 17% of the tenants felt confused about controlling the system since they only knew a little about GSHP.10% of tenants did not even know how to control the system at all. This means 74% of the tenants felt they lacked knowledge of controlling the GSHP system. There were only 26% of tenants who thought they knew how to control it well, with 4 of them saying they knew completely how to control the system and how to get the highest efficiency from it.

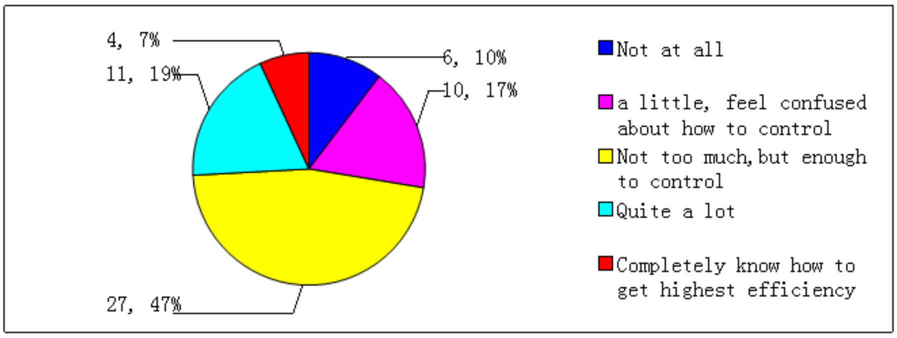

Fig. 8- 7 How well the tenants know how to control the GSHP

Fig.8-8 shows how well the tenants who were not provided any information on

GSHP knew about controlling the system. As we can see, more than 50% of them did not know or only knew a little on how to control the system, 30% said they did not know too much, only 15% stated they knew quite a lot, with nobody saying they knew completely how to get its highest efficiency. And among the 6 tenants who did not know how to control the system at all, 5 of them were not provided any information on GSHP. This indicates that enough information or education on GSHP is an essential way to assure tenants being able to control the system well.

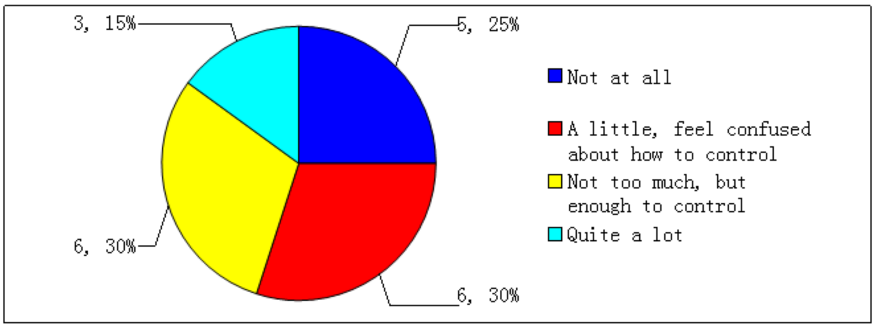

Fig. 8- 8 How well the tenants who were not provided any information know about controlling GSHP

Most of the tenants thought the GSHP was easy to control, with 16% of them thinking it was very easy, as shown in Fig. 8-9. There is a misunderstanding here, in the minds of both tenants and technology supporters. Since it is easy to control does not mean it is easy to control well to get the highest efficiency. Taking it as easy to operate, some installers maybe reluctant to demonstrate to tenants how to control the system correctly. Only 7% of tenants said the GSHP is very difficult to control, one tenant mentioned that he felt it was very difficult since he was in his 80s. 9% of the tenant thought it was a bit difficult, 23% thought it was not too easy to control. This means GSHP technology is not difficult to understand. So if installers or heat pump suppliers provide good technical support, demonstrate how to control the GSHP to get highest efficiency to tenants, most tenants will find it is easy to understand, even though many of them maybe elderly.

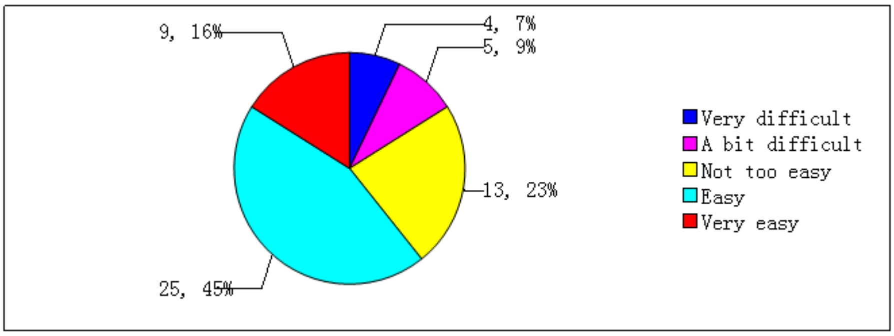

Fig. 8- 9 How easy the GSHP can be controlled

8.3.2 Information Provided to Tenants

Fig. 8-10 shows what kind of information on GSHP tenants have been provided with. As can be seen, 41% of tenants were not provided with any information on how to control or what is GSHP system, 41% of tenants were just provided with Instruction manuals/ User guide, only 7 out of 51 tenants were provided with both Instruction manuals and given a practical demonstration. Which means the majority of tenants did not get enough information on GSHP systems. 2 tenants said they got some information by other means, with one of them mentioning that somebody who knew this system gave him some written information about GSHP. This is a problem as this lack of sufficient information can, no doubt, lead to the incorrect operation of GSHP. Practical demonstration is the best way to show how to operate the GSHP, especially for elderly people, who form the majority of Orbit's residents, and who find it especially difficult to understand instruction manuals. But unfortunately, only 14% of tenants received a practical demonstration. This needs to be remedied urgently.

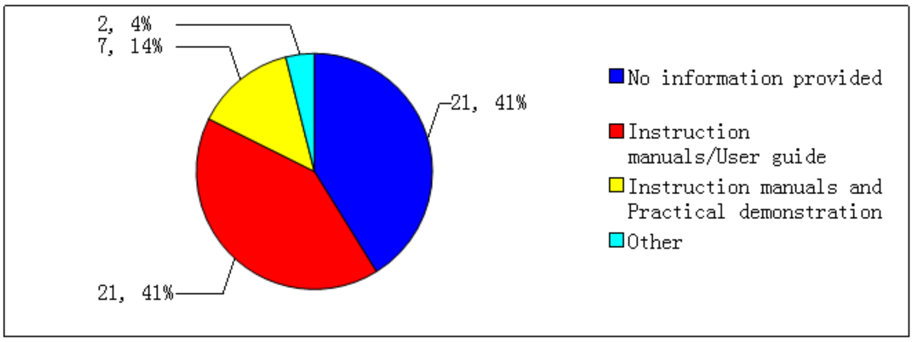

Fig. 8- 10 Information provided to tenants.

8.3.3 Satisfaction with the Technology Support

In terms of the satisfaction level of tenants with the technical support from the heat pump installer/supplier, 39% and 11% of the tenants chose 'Satisfied' and 'Very satisfied' respectively. 9% and 12% of the tenants chose 'Unsatisfied' and 'Strongly unsatisfied', with a total 21% of tenants not satisfied with the technology support. The other 29% of tenants were neither satisfied nor unsatisfied with the technical support. This indicates that the technology support still has far to go. Besides, among tenants (12) who were strongly unsatisfied/ satisfied with the technical support, half of them were not provided with any information on GSHP. 2 tenants were provided with instruction manuals, but only 4 tenants were shown how to operate GSHP. This clearly shows that providing enough information on GSHP to tenants plays a vital role in respect of technical support.

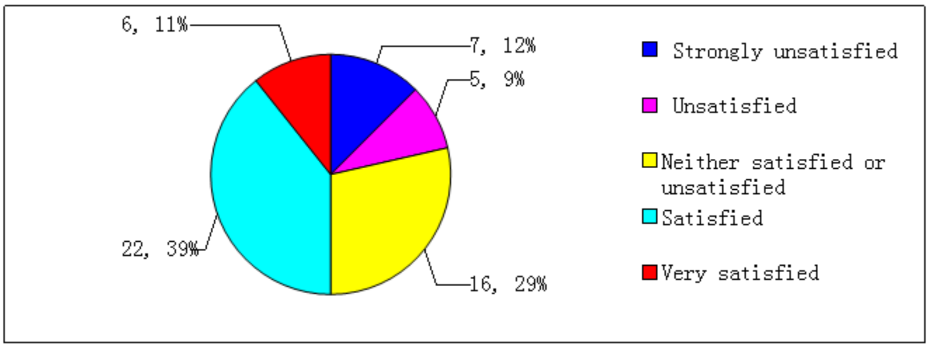

Fig. 8- 11 Satisfaction with the technical support

8.4 Tenants' Opinion on GSHP Systems

When asked if there were any problems with their GSHP systems, only 15 tenants said there were no problems at all. 42 tenants pointed out at least one problem with their GSHPs. One tenant even said it was a useless piece of equipment and had never worked since it was put in. The reported problems are shown in Fig. 8-12. Appendix XII shows the issues included in 'other problems'.

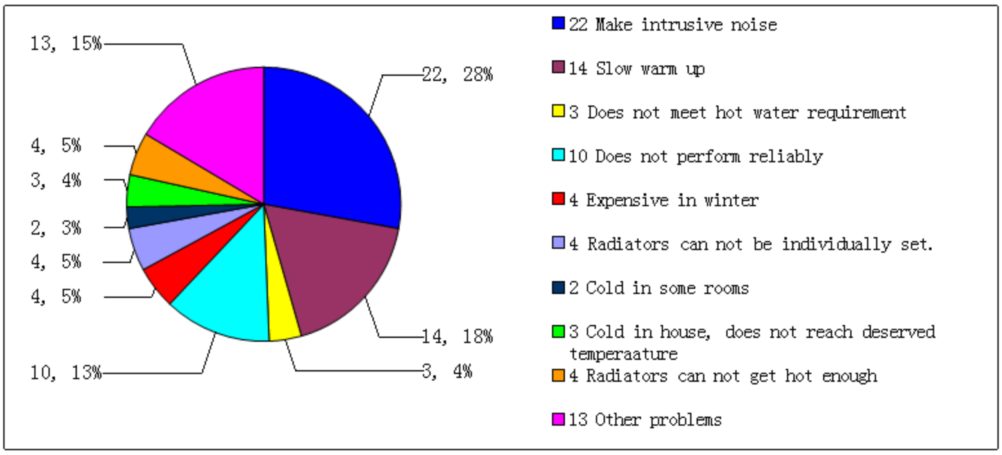

Fig. 8- 12 Problems with GSHP system in tenants' opinion

As can be seen in Fig. 8-12 and Appendix XII, 22 tenants (28%) reported the problem of 'intrusive noise', though over 90% of the heat pumps were placed outside of the house, 14 tenants (18%) complained that the system warmed the house up slowly, 10 tenants (13%) said the system could not perform reliably. These 3 points constitute the majority of the problems. 3 tenants reported that the GSHP could not meet their hot water requirements, but one of them mentioned this happened only in winter, as his family needed to have a bath, due to the lack of a shower. Two tenants said they felt cold in some rooms using GSHP. The number of tenants who reported 'GSHP is expensive in winter', 'Radiators cannot get hot enough', and 'radiators can not be individually set' respectively are 4. 'Other problems' described in Appendix XII include problems with uncovered pipes, rooms too hot at night, maintenance issues and so on.

Some problems are less acute, such as 'meter losing readings', and the problems vary dramatically with different tenants, so regular customer service and maintenance are required to address these problems. Nearly all the heat pump suppliers or GSHP installers claim that GSHP needs no or very little maintenance. It is even called ‘fit and forget’ technology. The danger here is that this can lead to contractors neglecting maintenance issues. It is also necessary that the regular maintenance service is included in the contract, and that it is made clear who is responsible for maintenance. Fast and effective maintenance should then be able to be achieved.

When asked what the good things of GSHP systems in their opinions, 8 tenants said there was nothing good about GSHP at all. on the other hand, 4 tenants said the GSHP was perfect. The other 38 tenants reported what they thought was good about their systems. These advantages are shown in Fig. 8-13.

As we can seen, 10 tenants reported the low cost of GSHP as a major advantage, 10 mentioned the heat comfort level, 6 pointed out that the system is clean and there is no dust. However, only 5 tenants say that it is easy to use, with one of them reporting they do not have to adjust the heating in cold or hot weather, since GSHP is automatic. 4 tenants appreciated the fact that they can have heat whenever they need and can turn off the system at night, 4 tenants reported the system is better than storage heaters, one of them said 'we do not have to rely on a rubbish storage heater any more'. 3 tenants were happy with the constant hot water, while another was pleased with the low running temperature.

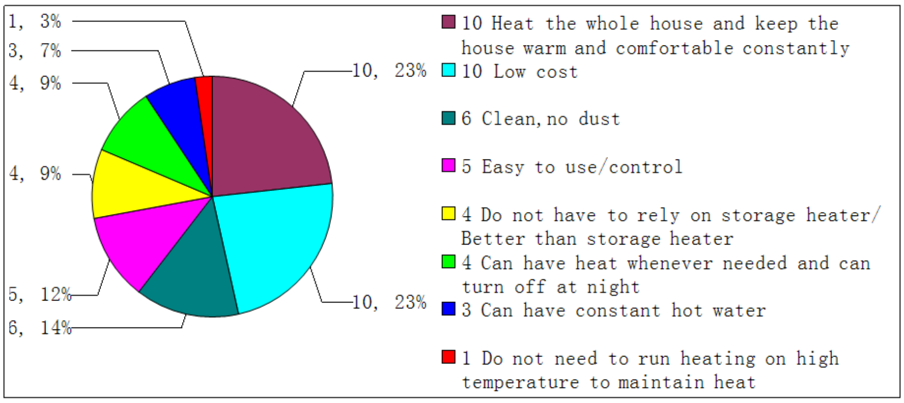

Fig. 8- 13 Good things of GSHP systems.

8.5 Tenants' Opinion on Customers Service

8.5.1 Satisfaction on Customers Service

Fig. 8-14 shows the satisfaction level of tenants with the customer service. As can be seen, most of the tenants were satisfied with this, with 22% very satisfied and 42% satisfied. But there were around 19% of tenants who were not satisfied with the customer service, 6% less satisfied still and 13% strongly dissatisfied. One tenant mentioned they were just unsatisfied with the service after the completion of GSHP, while another one said 'During installing strongly satisfied, afterwards it was a disaster'.

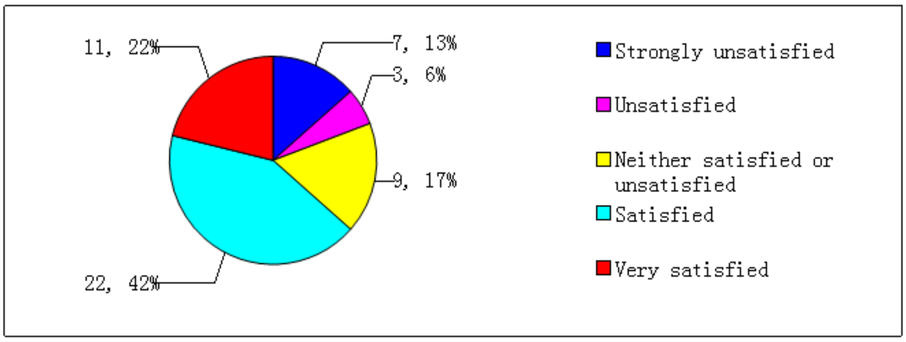

Fig. 8- 14 Satisfaction with the customers service.

8.5.2 Opinion and Advice of Tenants on Customer Service

In total 24 tenants gave their opinions and suggestions on customer service, focusing on five aspects in particular: Lack of information provided to tenants during and after installing GSHP; Lack of good communication between different departments within Orbit; Lack of good communication between different contractors; maintenance issues; and project delay.

1) Lack of Information Provided

Of the 24 tenants, 10 said they needed more information on GSHP. Some of them moved into the properties after the completion of the GSHP system. As one tenant said: 'We moved in March 2012, and other than being told 'you have ground source heating, it does something with your heating/hot water', we know nothing about how to use or control the system for optimum savings'. The others had moved in before GSHP was installed, but were not provided with enough information either. One tenant complained they were not even being told what was happening even during the installation.

According to a face to face communication with one tenant, who lives in Brailes, Oxford, in June 2012, it seems some tenants like her know very little about

GSHP. She claimed she wanted to know more about it, but when asked what in particular, she answered 'I don't know'. Then she said she wanted hot water supply all time, but did not know how to set up the heating time and also did not know how to turn off the room heating or control the heating temperature. She also complained the heat pump installer did not give her any specification or introduction to the heat pump, or show her how to use the system. She said 'He just wanted to leave and indeed left in hurry'.

A number of tenants suggested there should be someone able to go their house and explain to them how it works and how they can use GSHP to its full potential. Some of them said they needed regular customer service or a call maybe twice a year to make sure they know how to use it.

Two tenants mentioned 'Using technical language can confuse older folk', also suggesting a more comprehensive service, especially for pensioners. So it is worth noting that making both the instruction manual and practical demonstration easier to understand is very important, especially for the elderly.

2) Lack of Good Communication between Different Departments in Orbit

4 tenants reported their experience of contacting Orbit concerning GSHP issues. They thought the different departments within the housing association lacked good communication with each other. One of them said 'Whenever I ring up about Ground-source heating, customer services never know what it is and always send me the wrong contractor for repairs, which leads to a longer waiting time as the other contractor then has to be arranged'. Similar answers were given like 'Communication between departments is poor. ie speak to helpdesk and can not always get an answer', 'It would be better if the left hand spoke to the right hand instead of guessing what to do'. Another tenant complained that the 'call center' held him on the line and he was paying for the call. This indicates that good communication among different departments will help improve customer service a lot.

3) Maintenance Issues

4 tenants gave their opinions on the maintenance of GSHP. One of them reported a slow response from Orbit to their problem, as he said 'we had a power cut and the system lost all pressure. After 10 days Orbit sent an electrician. He had no idea about the GSHP system, and we were lucky a contractor was working a few doors away. This needs to be improved, as 10 days in winter would not have been good'.

One tenant reported that Orbit kept sending electricians instead of plumbers for the after care/repair to GSHP, as the first tenant above had mentioned. One tenant suggested Orbit use a firm which specializes in GSHP instead of property matters, whose representatives do not understand the system.

Another tenant said they once reported the fault at the fuse box but was told it was the meter and they have to tell the supplier of the meter, whoever that is.

These all indicate a lack of good organization and supervision of contractors. Orbit has contracted the GSHP project to different sub-contractors. The whole project is then divided into different parts, such as GSHP design and borehole drilling, heat pump and hot water cylinder planting, landscaping and gardening. Which contractor is responsible for which part of GSHP systems and what kind of problems should be make clear in the contract. And the main contractor of the GSHP project should supervise and manage the sub-contractors to deal with maintenance issues efficiently.

4) Lack of Good Communication between Tenants and Project Managers or Engineers

Some tenants' complaints have shown a lack of good communication between tenants and engineers. Since one tenant said 'there is no means available to put a gas or wood burner in as the chimney was blocked off and the use of electric fan heaters is a ridiculous cause of cost'. Another tenant suggested the thermostat should have been installed in the lounge instead of the corridor, and on each radiator there should be a thermal-static control valve installed.

These problems could be avoided if the project manager/engineer/installer communicate better with tenants and understood their requirements before installation. Regarding the thermal-static control valve on radiators, some explanation needs to be made to tenants. As mentioned in section 8.2.1.1, too many TRV will impair the efficiency of GSHP.

One tenant complained 'on a visit from Rnims the man was extremely rude and aggressive, this was reported at the time but no reply was received'. So it is necessary for the main contractor of the GSHP project to supervise the sub-contractors who are responsible for maintenance.

One tenant has even been unsatisfied with GSHP for 2 years, but he has never contacted anyone about this. As he said 'give me a phone call and I can give you 2 years worth of what is wrong with this piece of equipment. As soon as we get a frost in winter, the pump was not powerful enough to get it up to temperature as we were told, it would go to 24 ℃, As if '. Customer service really needs to be strengthened, especially after the completion of GSHP.

5) Project Delays

Nearly all tenants who complained about the length of installation time are from Brailes. 10 questionnaires were sent to tenants in Brailes, where a new GSHP project was completed in June 2012, having begun in early March. 5 gave their opinions on the GSHP project. One mentioned not being told what was happening, while the other 4 complained of complete disorganization. Two of the 4 tenants said they did not understand why it took 4 months to install the GSHP. Another tenant required the work to be finished as soon as possible, and complained he had called many times for clarification, with no result. The other one said 'Lack of supervision of staff, everyone was very pleasant and tried to help but there seemed to be little structure about the whole enterprise! And the car park has been left with a lot of equipment and mess'.

As mentioned in section 8.5.2.3, the whole project was contracted out to different companies, and each contractor was in charge of different parts of the project. This made the whole project disorganized and unsupervised, to some degree.

There was a further complication and cause for delay. Water kept emerging out form the ground when the boreholes were being drilled, and drillers had to use extra drilling techniques to address this problem. This unexpected problem should have been explained to the tenants, who were already frustrated by the delay. A better co-operation between contractors should have been achieved to ensure the work was completed efficiently.

8.6 Suggestions on GSHP Systems

According to the feedback, GSHP systems have showed varying performances. The reasons for this are not clearly known, but likely reasons uncovered in the feedback include the lack of information on GSHP provided, and the use of multiple contractors.

The following may be required to resolve the problems of GSHP operation and customer service mentioned in the feedback:

1) Design more easy-to-understand instructions or users' guides to GSHP;

2) Provide users with more education on GSHP, especially more practical demonstrations, in order to let them know how best to control and maximize the system;

3) Reduce the noise levels of heat pumps, since around two fifths of tenants have reported the problem of 'intrusive noise'.

4) Enhance the training of GSHP designers and installers to provide better system design and installation. The training should be recognised as

demonstrating competence for the Micro-generation Certification Scheme.

5) Provide GSHP users regular customer service and improved maintenance service.

6) Strengthen the supervision of the main contractor to the sub-contractors, to assure the GSHP project is completed on time and provides high-quality maintenance; or with only one contractor taking responsibility for the whole project.

7) Ensure good communication with GSHP users, understanding their requirements and suggestions on the installation process before work begins.

8.7 Survey Conclusions

The feedback showed that most tenants (three-quarters) were satisfied with the comfort of heat level, using a GSHP system, with several mentioning the constant and whole house warmth provided by GSHP. The majority of tenants agreed that GSHP meets their hot water demands. Around 67% of tenants thought their bill had been reduced with GSHP.

However, a sizable amount of tenants experienced various problems using the GSHP system, including intrusive noise, slow warm up, cold in some rooms and so on. Three quarters of tenants thought they lacked knowledge on how to control the GSHP system, with 41% of tenants not provided with any information on that. Approximately one fifth of tenants were unsatisfied with the customer service, especially after the completion of GSHP. Thus regular and improved customer service is essential.

Overall, GSHP can meet the heating and DHW demand of residential buildings with a relatively low cost. But some improvements are needed if it is to be more attractive and become a widely accepted heating system in the UK. More research is required to fully identify the reasons for the widely varying performance of GSHP and the problems with customer service during the usage of the system.

9 Conclusions

- The document review parts of this thesis introduced the working principle, types, system efficiency, CO_2 emission, cost, deployment, market barriers, and the installation process of the heat pump system.

- The field test carried out by Orbit Heart of England showed that the GSHP provided the most comfortable warmth among all the heating systems tested, with relatively low CO2 emission amount (1066.50 ppm) and low energy consumption (0.9kWh/day/m2).

- The collected bills from an Orbit's property proved that the electricity consumption of GSHP was reduced by 60.4% compared with the night storage system.

- The feedback from GSHP users indicated that most tenants were satisfied with the GSHP performance. But, a sizable amount of tenants also reported various problems of the system. The customer service after the completion of GSHP still has a far to go, especially regarding to the maintenance issues, adequate information providing, good communication with customers and so on.

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Appendix

Appendix I

20 European countries in outlook 2012 European Heat Pump Statistics

Country	Country Code	Country	Country Code

SWEDEN	SE	AUSTRIA	AT
ITALY	IT	ESTONIA	EE
FRANCE	FR	POLAND	PL
NORWAY	NO	BELGIUM	BE
SPAIN	ES	NETHERLANDS	NL
FINLAND	FI	CZECH REPUBLIC	CZ
GERMANY	DE	IRELAND	IE
SWITZERLAND	CH	HUNGARY	HU
PORTUGAL	PT	SLOVAKIA	SK
UNITED KINGDOM	UK	LITHUANIA	LT

Appendix II

Proposed national overall targets for the share of energy from renewable sources in final consumption of energy in 2020

	Share of energy from renewable sources in final consumption of energy, 2005 - percent	Target for share of energy from renewable sources in final consumption of energy, 2020 – percent

Sweden	39.8	49
Latvia	34.9	42
Finland	28.5	38
Austria	23.3	34
Portugal	20.5	31
Denmark	17.0	30
Estonia	18.0	25
Slovenia	16.0	25
Romania	17.8	24
Lithuania	15.0	23
France	10.3	23
Spain	8.7	20
Greece	6.9	18
Germany	5.8	18
Italy	5.2	17
Bulgaria	9.4	16
Ireland	3.1	16
Poland	7.2	15
United Kingdom	1.3	15
The Slovak Republic	6.7	14
The Netherlands	2.4	14
The Czech Republic	6.1	13
Hungary	4.3	13
Cyprus	2.9	13
Belgium	2.2	13
Luxembourg	0.9	11
Malta	-	10

Appendix III

Utility roles and examples **Error! Bookmark not defined.**

Utility role	Key features	Example
Early Promoter (VATTENFALL)	Involvement very early in the market in R&D Generates discussion between stakeholders Builds confidence in an unknown technology amongst end-users and installers	Vattenfall, Sweden's largest electricity provider, was an early pioneer of heat pumps, investing € 42 million during 1979-1985 to fund over 400 HP demo projects- including some very large-scale heat pumps for cities. The backing of a large trusted utility was a 'tipping point' for the Swedish market, signaling a turn-around in consumer (& installer) confidence in HP technology.
Facilitating & Incentivizing (RWE)	Not actively involved in selling but taking measures to grow the market or promote the technology (such as tariffs) Reducing customer uncertainty and perceived risk by promotion of technology.	RWE in Germany established an 'online heat pump forum'- a portal designed to provide information on HPs to end-users, and to connect end-users with installers and heat poump products. Installers pay a small fee to advertise on the portal, and are included in a database searchable by post code. Manufacturers also pay a fee and benefit from advertising direct to consumers. From the end-user perspective, a product or installer's inclusion in the portal indicates RWE's 'seal of approval', and gives confidence in the product performance/ installer ability.

Active player (British Gas)	Active in the market, selling and installing product Building installer networks and becoming involved in quality control and training provision Market facilitation and awareness raising-access to large marketing budgets Using its trusted brand to build confidence in heat pumps.	British Gas- a major energy supplier and also the UK's largest boiler installer- has a history of acting across the whole heating value chain. From provision of advice to installation BG prefers to acquire rather than outsource skills and expertise in new technologies. As such, BG acquired a heat pump installation company in 2011, 'buying in' heat pump expertise, and planning to mobilize and up-skill its large existing boiler installer workforce. Given British Gas's trusted brand as a heating systems installer, its engagement in HP s could have a profound impact on market uptake amongst end-users.

Appendix IV

Estimated Average Fuel Conversion Efficiency of Common Heating Appliances

Fuel Type - Heating Equipment	**Efficiency (%)**
Coal (bituminous)	
Central heating, hand-fired	45.0
Central heating, stoker-fired	60.0
Water heating, pot stove (50 gal.)	14.5
Oil	
High efficiency central heating	89.0
Typical central heating	80.0
Water heater (50 gal.)	59.5

Gas	
High efficiency central furnace	97.0
Typical central boiler	85.0
Minimum efficiency central furnace	78.0
Room heater, unvented	99.0
Room heater, vented	65.0
Water heater (50 gal.)	62.0
Electricity	
Baseboard, resistance	99.0
Central heating, forced air	97.0
Central heating, heat pump	200+
Ground source heat pump	300+
Water heaters (50 gal.)	97.0
Wood & Pellets	
Franklin stoves	30.0 - 40.0
Stoves with circulating fans	40.0 - 70.0
Catalytic stoves	65.0 - 75.0
Pellet stoves and boilers	85.0 - 90.0

CO_2 emissions of different heating systems

System	Primary Energy Efficiency (%)	CO_2 emissions (kg CO_2/kWh heat)
Oil fired boiler	60 - 65	0.45 – 0.48
Gas fired boiler	70 - 80	0.26 – 0.31
Condensing Gas Boiler + low temperature system	100	0.21
Electrical heating	36	0.9
Conventional electricity + GHSP	120 - 160	0.27 – 0.20
Green electricity + GHSP	300 - 400	0.00

Appendix V

Estimated installation prices for multiple installations in a new build housing development

	GSHP-Horizontal	GSHP-Borehole	ASHP
Dimplex heat pump (11 kW)	SI 11 MS	SI 11 MS	LA 11 MS
Heat pump cost	£ 3100	£ 3100	£ 5000
Ancillary items (hot water cylinder, buffer tank, manifolds, heat distribution system, etc)	£ 2350	£ 2350	£ 1850
Ground collector and installation	£ 1500	£ 3500	-
Heat pump installation and commissioning	£ 2000	£ 2000	£1000
Total (excluding grants)	£ 8950	£ 10950	£ 7850

Payback over 20 years of the GSHP system

	GSHP (with grant)	GSHP (without grant)	Condensing Gas Boiler
Life expectancy (years)	20	20	10
Capital & installation cost	£ 9000	£ 9000	£ 1500
Low Carbon Building Programme, Phase 2 (LCBP2) grant	£ 3150	-	-
Distribution system installation cost	£ 2500	£ 2500	£ 2500
Annual fuel cost	£ 378	£ 378	£ 548
Safety inspection and maintenance	-	-	£ 192

Total annual running cost	£ 378	£ 378	£ 740
Replacement cost after 10 years	-	-	£ 1500
Total cost over 20 years	£ 15918	£ 19068	£ 20297
Cost saving over 20 years	£ 4378	£ 1228	-

Appendix VI

Typical thermal properties for superficial deposits

Class	Thermal conductivity W m-1 K^{-1}	Thermal diffusivity 10-6 $m^2 s^{-1}$
Sand (gravel) Silt Clay Loam Saturated sand Saturated silt or clay	0.77 1.67 1.11 0.91 2.50 1.67	0.45 0.60 0.54 0.49 0.93 0.66

Thermal diffusivity and thermal conductivity for various rock types

Rock	Thermal conductivity W $m^{-1} K^{-1}$	Thermal diffusivity 10^{-6} $m^2 s^{-1}$

Basalt	1.8	0.685
Dunite	4.56	0.947
Granite	3.30	1.000
Granodiorite	3.18	0.719
Gneiss	3.01	1.224
Quartzite	5.03	2.952
Salt	4.87	3.020
Anhydrite	5.40	2.242
Clay	1.50	0.950
Clay marl	2.13	0.934
Limestone	2.73	1.054
Marl	2.69	1.118
Marly clay	2.30	0.894
sandstone	2.80	1.645

Appendix VII

Comparison of advantages and disadvantages of common borehole drilling methods (Illinois Department of Public Health 2011)

	Advantages	disadvantages
Percussion drilling	Simple rigs, low-cost operation	Slow, shallow depths only
Rotary drilling, direct circulation	Fast drilling, no depth limit, needs no temporary casing	Expensive operation, may need large working space for rig and mud pits, may require a lot of water, mud cake build-up may hamper development
Rotary DTH, air circulation	Very fast in hard formations, needs no water, no pollution of aquifer	Generally not used in soft, unstable formations, drilling depth below water table limited by hydraulic pressure

Rotary, reverse circulation (not described in text)	Leaves no mud cake, rapid drilling in coarse unconsolidated formations at large diameters	Large, expensive rigs, may require a lot of water

Comparison of Drilling Methods Most Commonly Used for BHEx Installation

	Drilling Method			
Parameter	**Mud-Rotary**	**Air-Rotary**	**Reverse** Circulation	**Air-Hammer**
Substrate, conditions				
Unconsolidated, soft-rock	Standard; mud helps stabilize hole	May have hole stability problems	Can be used	May have hole stability problems
Competent rock, hard- rock	Usually slower than air methods	Very fast and common	Likely to be slower than air hammer	Very fast and common
Bouldering			Good choice, unless boulders too small to cut and too heavy to lift with air	May cut through
Aquifers, other likely circulation loss situations	Can have serious trouble		Preferred	
Strengths and weaknesses				
Speed	Fast in weak rock	Fast in hard rock		Fastest in hard rock
Adaptable for slim holes	Very good	Very good	Not applicable	Excellent

Poor conditions (unstable hole, voids)	May need casing, may lose circulation	Resists circulation loss	Resists circulation loss	Resists circulation loss
Needs large air supply	Only for air-lift for mud drilling	Yes	Yes, if air-circulated	Yes
			Rare for slim holes (<8 in.)	
Sample recovery	Cuttings likely to be from mixed levels	Variable to poor	Good cuttings recovery	Variable to poor
Other Notes				
	GX almost always top-drive		Dual-tube rare for holes <8 in. diameter	

Appendix VIII

Appropriate grouting material for different geological conditions (Michigan Department of Natural Resources & Environment 2010: 8).

Geological Conditions	Recommended Grouts
Saturated unconsolidated sand, gravel, clay, or a combination thereof	Neat cement grout Cementitious grout Concrete grout Bentonite grout Thermally-conductive bentonite grout

Unsaturated, unconsolidated sand, gravel, clay, or a combination thereof	Neat cement grout Concrete grout Cementitious grout Thermally-conductive bentonite grout
Consolidated geologic formations, such as sandstone, shale, limestone, dolomite, granite, schist, or conglomerates	Neat cement grout Cementitious grout Concrete grout.
Fractured, crevised, jointed, or cavernous limestone	Neat cement grout Cementitious grout Concrete grout If lost circulation zones are encountered, grouting in the bedrock lost circulation zones may be conducted using a mixture of cementitious grout and clean peastone aggregate, or layered with a combination of either cementitious grout or neat cement grout and short intervals of bentonite chips or clean peastone aggregate
Flowing artesian groundwater, methane or other subterranean gas, or groundwater with total hardness over 500 milligrams per liter (mg.l) or chloride over 1,500 mg/l	Neat cement grout Cementitious grout Concrete grout

Appendix IX

General information of tested properties

Address	Type of dwelling	Insulation details	Floor area (m2)	No. of occupants and ages	Type of heating	Deployment start and end
2 Leam Road	2 bedroom, 2-storey semi-detached property	Loft insulation, bare floors, double glazing on windows	60	2 (both in 30s)	GSHP	Feb 19-march 5
11 Wlm Close	2 bedroom bungalow	Cavity wall and loft insulation, double glazing on windows	59	2 (83, 51)	Storage heaters and portable electric radiator	Feb 4-Feb 18
22 Town Ground	2 bedroom bungalow	Some loft insulation, double glazing on windows but poorly installed in kitchen	48	2 (60, 62)	Storage heaters, a small oil heater and an electric fire	Feb 26-march 19
30 Elliott Drive	2 bedroom, 2-storey detached property	Loft insulation, double glazing on windows	70	3 (72, 56, 25)	Gas source radiator	Feb 2-Feb 18
32 The Green	2 bedroom bungalow	Loft insulation, double glazing on windows	60	1 (45)	ASHP	Mar 23-Apr 9

Temperature and humidity range for different comfortableness levels

Temperature (℃)	
T<16	Health risk to occupants if exposed to temperature for extended periods of time
16<Tr<18	Room is cold and below ASHRAE comfort standards
18<Tr<22	Optimal comfort levels
22<Tr<27	Room is above comfort levels
Tr>27	Room is being overheated, thus energy is being wasted
Humidity	

H<45%	Room in dry humidity
45%<H<65%	Room is at a comfortable humidity
65%<H<85%	Room will feel damp-slight health risk
H>85%	Room will have problems associated with damp such as mold, also presents a health risk to occupants.

General information at 9 Elm Close

Address	Area (m^2)	Occupants	Old heating devices	New heating system	Date installed GSHP
9 Elm Close, Ilmington	59.1	2	Night Storage (Electricity)	GSHP	2010/3/11

Appendix X

Electricity consumption before and after installing GSHP

	Calculation Period	Day (kWh)	Cost split	Charges	Night (kWh)	Cost split	Charges
Electricity consumption before installing GSHP	23/04/2009-09/07/2009	417	first 153 at 22p, next 246 at 15.34p	£74.16	647	first 647 at 4.35p	£28.14
	09/07/2009-13/10/2009	519	first 180 at 22p, next 380 at 15.34p	£97.99	806	first 1145 at 4.35p	£49.81
	13/10/2009-11/01/2010	650	first 188 at 22p, next 462 at 15.34p	£112.23	3151	first 3151 at 4.35p	£137.07
	11/01/2010-19/04/2010	707	first 415 at 22p, next 292 at 15.34p	£136.09	3432	first 3432 at 4.35p	£149.29
		2293		£420.47	8036		£364.31
	Total electricity consumption	10331 kWh					
	Total electricity cost	£784.78					
Electricity consumption after installing	31/01/2011-18/07/2011	1749	first 366 at 23.94p, next 1383 at 16.69p	£318.44	513	first 513 at 4.73p	£24.26
	18/07/2011-30/09/2011	636	first 139 at 23.94p, next 497 at 16.69	£116.23	91	first 91 at 4.73p	£4.30

GSHP	30/09/2011-25/01/2012	1492	first 221 at 25.74p,net 1271 at 17.74p	£426.93	423	first 423 at 5.08p	£21.49
		3877		£861.60	1027		£50.05
	Total electricity consumption	4094 kWh					
	Total electricity cost	£911.65 (16.17% increase compare to year 2009)					
	Total cost at electricity price in 2009	£694.47 (11.51% reduction compare to year 2009)					

Appendix XI

The general information of the properties investigated in the survey.

Properties	occupants	Area (m2)	Type	Date install	Heating system
1	2	59.1	Calorex 6.5kW	2010/4/7	GSHP
2	1	59.1		2010/4/7	GSHP
3	2	59.1		2010/3/11	GSHP
4	1	62.63		2011/2/14	GSHP&PV
5	3	106.06		2011/3/31	GSHP
6	5	64.12		2010/6/30	GSHP
7	1	67.1		2011/3/17	GSHP
8	1	87.84		2011/2/14	GSHP&PV
9	2	75.8		2010/7/2	GSHP&PV
10	4	107.88			GSHP
11	2	85.23		2011/3/25	GSHP&PV
12	2	54.3		2011/2/14	GSHP&PV
13	2	60.59		2012/4/27	GSHP
14	2	73.25		2011/3/31	GSHP
15	2	60.59		2012/4/5	GSHP
16	N	60.59		2012/3/29	GSHP
17	1	45.26		2012/5/11	GSHP

18	5	No epc		2010-11	GSHP&PV
19	2	74.4		2010/6/25	GSHP&PV
20	2	84.24		2008/3/26	GSHP
21	4	65.98		2008/4/28	GSHP
22	3	71.21		2008/5/28	GSHP
23	1	64.64		2009/9/30	GSHP
24	2	62.63		2011/2/14	GSHP&PV
25	2	68		2010/5/7	GSHP
26	1	55.35		2012/5/4	GSHP
27	2	40.2		2010/5/21	GSHP&PV
28	3	74.1		2010/6/11	GSHP
29	2	60.59		2012/4/5	GSHP
30	2	60.68		2011/2/14	GSHP&PV
31	2	40.5		2010/5/28	GSHP&PV
32	3	No epc		2010/6/11	GSHP&PV
33	1	61.6		2010/3/26	GSHP
34	3	69.5		2008/8/27	GSHP
35	4	71		2010/6/30	GSHP
36	2	66.47		2008/6/26	GSHP
37	2	60.59		2012/3/23	GSHP
38	2	74.4		2010/6/12	GSHP&PV
39	N	45.26		2012/5/11	GSHP
40	2	60.59		2012/4/3	GSHP
41	1	76.2		2010-?-?	GSHP&PV
42	1	59.1		2010/3/25	GSHP
43	2	59.1		2010/4/7	GSHP
44	2	58.9		2011/2/14	GSHP&PV
45	4	59		2012/5/19	GSHP

46	2	68.32		2008/7/28	GSHP
47	4	68.03		2008/10/28	GSHP
48	2	74.2		2010/6/19	GSHP&PV
49	2	40		2010/5/28	GSHP&PV
50	N	69.49		2008/6/26	GSHP
51	2	79.2		2008/9/30	GSHP
52	1	51.04		2011/3/11	GSHP&PV
53	2	62.63		2011/2/14	GSHP&PV
54	3	76.2		2010/7/9	GSHP&PV
55	1	60.59		2012/3/30	GSHP
56	2	69.12		2008/7/28	GSHP
57	3	74.4		2010/6/25	GSHP&PV
58	2	61.7		2008/8/27	GSHP
59	N	60.59		2012/4/27	GSHP
60	3	69.49		2008/5/28	GSHP

One of the 62 filled questionnaires

Name	B. DIXON	Gender	~~Female~~/Male	Number of occupants	2.
Address	6 ELM CLOSE, ILMINGTON, CV36 4NA				

1 How do you set the heating time of Ground Source Heat Pump (GSHP) system?	[ ] Usually heat home constantly/long periods during the day [x] Usually heat home for short periods during the day [ ] Usually leave the heating on all night [ ] Usually heat home for short periods during the night [x] Usually leave the heating off all night [ ] Usually leave the heating on when out of home [x] Rarely/~~never~~ leave the heating on when out of home
2 What temperature do you set the on the thermostat controller during the heating period?	AVERAGE 22°C
3 Do you use separate heating devices in any room in addition to GSHP system in winter? (E.g. oil filled radiators, electric heaters, etc.)	[x] Yes ELEC HEATER IN LOUNGE [ ] No
4 Have you used more hot water since installing GSHP than before?	[ ] Use more than before (less carefully to use) [x] No change [ ] Use less than before (more carefully to use)
5 How would you describe the comfort levels in your home in winter.	[x] Uncomfortably cold, IN LOUNGE [ ] Comfortably cool, [x] Comfortable, REST OF HOUSE [ ] Comfortably warm, [ ] Uncomfortably hot.
6 How do you set the room temperature using thermostat controller when start your GSHP system?	[x] Start it with higher temperature than needed, and then change it to the needed temperature when the room gets warm. [ ] Start it with needed temperature, waiting the room to get warm
7 How regularly do you use an immersion heater for your hot water?	[ ] Every day [ ] Once per week [ ] 2-3 times per month [ ] Once per month [x] ~~Rarely~~/Never
8 Do you change the heat times of room heating and/or hot water depending on the season/weather?	[x] Yes, change heat times of both room heating and hot water. [ ] No, do not change heat times of either [ ] Just change heat times of room heating [ ] Just change heat times of hot water
9 What information were you provided with about how to use your GSHP system?	[x] No information provided [ ] Instruction manuals/User guide [ ] Practical demonstration [ ] Other

10 Do you heat the whole property or just heat occupied rooms?	☒ Heat the whole property ☐ Just heat occupied rooms NOT POSSIBLE TO CONTROL SEPERATE ROOMS
11 How well do you understand how to control GSHP system?	☐ Not at all ☐ A little, feel confused about controlling it ☐ Not too much, but enough to control it ☒ Quite a lot ☐ Completely know how to control to get highest efficiency.
12 Were you satisfied with the technical support from the heat pump installer/supplier?	☐ Strongly unsatisfied ☐ Unsatisfied ☐ Neither satisfied/unsatisfied ☒ Satisfied ☐ Very satisfied
13 How easy do you find it to control your GSHP? Note any aspects that make it difficult to control.	☒ Very difficult ☐ A bit difficult ☐ Not too easy ☐ Easy ☐ Very easy OVERHEATS WRONG AREAS. SEE QUESTION 19.
14 Compare with your old heating system, how much do you think your bill has been reduced with GSHP system?	☐ 0-10% ☐ 11%-20% ☒ 21%-30% ☐ 31%-50% ☐ More than 50% ☐ The bill is higher than before
15 What do you think is particularly good about your GSHP system?	HEAT WHEN REQD NOT LIKE PREVIOUS NIGHT STORE SYSTEM
16 What do you think is particularly bad about your GSHP system?	~~THE~~ RADIATORS DO NOT HAVE INDIVIDUAL TEMP CONTROLS, LOUNGE COLD BUT CORRIDOR IS SET TEMP. THIS IS A VOID.
17 Are there any of the following problems with your GSHP system? (Mention what it is if there is any other problem please).	☐ Make intrusive noise ☐ Slow warm up of heating system ☐ Does not meet hot water requirement ☐ Does not perform reliably ☐ Other problems
18 Were you satisfied with the customer service during the installation and after the works were complete?	☐ Strongly unsatisfied ☐ Unsatisfied ☐ Neither satisfied/unsatisfied ☐ Satisfied ☒ Very satisfied
19 Would you like to give any suggestions about customer service?	INSTALL THERMOSTAT IN LOUNGE NOT CORRIDOR. AND INSTALL THERMOSTATIC CONTROL VALVES ON EACH RADIATOR

Appendix XII

The issues included in 'other problems' of GSHP

Problems	The number of times mentioned
There is no power cot	1
Pressure drops, system needs topping up	1
Wastes water, since approximately 1 Gallon water is wasted before hot comes through.	1
Pipes not covered in inside property.	1
No means available to put a gas or wood burner in as the chimney has been blocked off	1
The thermostat timer only works when it wants and the water thermostat light is on constantly so I have had to cover it up as it disturbs sleep.	1
Too hot at night	1
Meter loses the readings	1
Freezes at low temperature	1
Possible subsidence and -- due to borehole at side of property.	1
Not everyone knows how to repair it when there are faults.	1
Maintenance engineers do not know enough	1
Slow to repair when it is broken	1