An investigation into the financial and environmental suitability of ground source heat pumps for residential use in Ireland.

by

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DISSERTATION DECLARATION

This thesis has not previously been submitted to this or any other college. With acknowledged exception, it is entirely my own work.

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ABSTRACT

A ground source heat pump (GSHP) extracts heat energy from the ground for use in space and water heating systems. A GSHP requires some electrical energy to operate, but is capable of extracting up to four times as much heat energy from its source as the initial electrical energy input.

The purpose of this study is to examine the suitability of ground source heat pumps (GSHPs) for use in residential heating in Ireland, from certain financial and environmental aspects, as outlined below.

Examination of the suitability of GSHPs for use in a group of privately-owned houses found that the optimum array is an array with individual collectors and individual heat pumps. Though this option was found to be 36% more expensive than an array consisting of a shared collector and shared heat pump, low running costs and the avoidance of complications due to shared ownership make the option acceptable in the long term.

Long-term cost comparisons were carried out between GSHPs, natural gas heating and oil-fired heating systems in a single large (185m^2) house. It was found that natural gas space heating system is 8% cheaper than a GSHP system over a 20 year period. Oil fired systems are more expensive than both natural gas and GSHP.

A comparison of CO_2 emissions from GSHPs, natural gas and oil-fired systems found that GSHPs are approximately 15% cleaner than the equivalent natural gas system, and 41% cleaner than the oil-fired equivalent.

If there is an accessible seawater source available, it would be the best option as a heat source, notwithstanding the fact that a corrosion-resistant heat exchanger would be required. The benefit comes from the fact that an open-loop collector can be utilised, rather than a closed loop system.

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DEFINITIONS

Boiling point: the temperature at which a liquid changes to a gas.

Latent heat: the heat energy either given off or taken in as a substance changes state.

Seasonal performance factor: ratio of useful energy output of a device to the energy input, averaged over an entire heating season.

Specific latent heat of vaporisation: the amount of heat energy required to change 1kg of the substance from a liquid to a gas, without a change in temperature (at its boiling point).

GLOSSARY

CADDET	Centre for Analysis and Dissemination of Demonstrated Energy Technologies
CHP	Combined Heat and Power
COP	Co-efficient Of Performance
CTO	Campaign for Take Off
CORDIS	Community Research & Development Information Service
CSO	Central Statistics Office
GSHP	Ground Source Heat Pump
kg/kWh	kilograms per kiloWatt hour
kWh	kiloWatt hours
Mt	Mega tonne (equal to 10^6 tonnes)
MW	MegaWatts
REIO	Renewable Energy Information Office
RES	Renewable Energy Source
SEI	Sustainable Energy Ireland
TPER	Total Primary Energy Requirement
TER	Thermal Resistance Value

1 INTRODUCTION

Over a thousand ground source heat pumps were sold in Ireland in 2004 (Arsenal Research, 2004), an average of 0.8 per 1,000 inhabitants. A comparison of this figure with the 51,300 geothermal heat pumps sold in Sweden, an average of 5.78 per 1,000 inhabitants (Arsenal Research, 2004) illustrates the large market potential for heat pumps in this country.

The bulk of the systems sold in Ireland to residential owners were horizontal loop systems, which require large garden areas. As a rule of thumb, a garden of 200 m^2 is required to heat a house of 100 m^2 (O'Donohue, 2005). Because of this requirement, and the high cost of drilling for a vertical loop collector, owners of houses with small gardens are practically precluded from using geothermal energy.

By their very nature, houses with small gardens are built in batches together, so there are a number of possible solutions to the problem of supplying these houses with a heat pump system:

- Have a shared collector and heat pump, providing district heating to all houses;
- Have one shared collector supplying individual heat pumps in each house;
- Have a vertical collector for each house, with individual heat pumps in each house.

While a shared system might be quite acceptable for a public housing scheme, setting up a shared private scheme can give rise to problems, particularly in relation to shared ownership of equipment, ongoing management, metering and billing costs, and the difficulty in reselling property involved in such a scheme.

From an environmental point of view, it is anticipated that use of heat pumps would lead to a significant reduction in CO_2 emissions in comparison to other fuels, because of the heat pump's high co-efficient of performance of approximately 3.2, i.e. for every 100 kW of electricity used, 320 kW of heat are delivered (BRE, 2001).

1.1 Aim and objectives

The aim of this study is to determine the financial and environmental suitability of heat pumps for use in residential houses in Ireland. In order to examine the different aspects of such a study, four separate objectives were set:

1.1.1 To determine the optimum ground source heat pump (GSHP) array for a scheme of 12 privately-owned, large (185m^2) detached houses.

When determining the optimum GSHP array for such a scheme, there are three options:

- A shared collector and heat pump, providing district heating to all houses;
- A shared collector supplying individual heat pumps in each house;
- An individual collector and individual heat pump in each house.

The results sought should be general and be applicable to any similar housing scheme located anywhere in Ireland

1.1.2 To make a long-term cost comparison between using GSHPs, natural gas heating and oil-fired heating systems in a single large (185m^2) house.

The report will include data comparing the costs (such as initial outlay, running costs and projected savings over 20 years) of GSHPs for individual residential use with the equivalent natural gas and oil-fired systems.

1.1.3 To estimate the potential CO_2 emissions if all of the social housing built in Ireland in 2004 utilised GSHPs.

Calculations are carried out on the reduction in CO_2 emissions which would be achieved if the GSHP technology had been used in all of the social housing built in 2004.

3.2 The different forms of geothermal energy

Geothermal energy is loosely defined as energy which is sourced in the earth, either underground or in bodies of water. In Ireland the heat sources are usually low-grade, in which case a heat pump is used to increase the heat to more useable levels. This is generally used in the heating of residential houses, where temperatures of about 10°C are raised to 35-40°C for heating purposes (Sanner, 2002).

Heat sources at higher temperatures do not occur as frequently (e.g. warm springs), or are more costly to access (e.g. enhanced geothermal or hot dry rock systems).

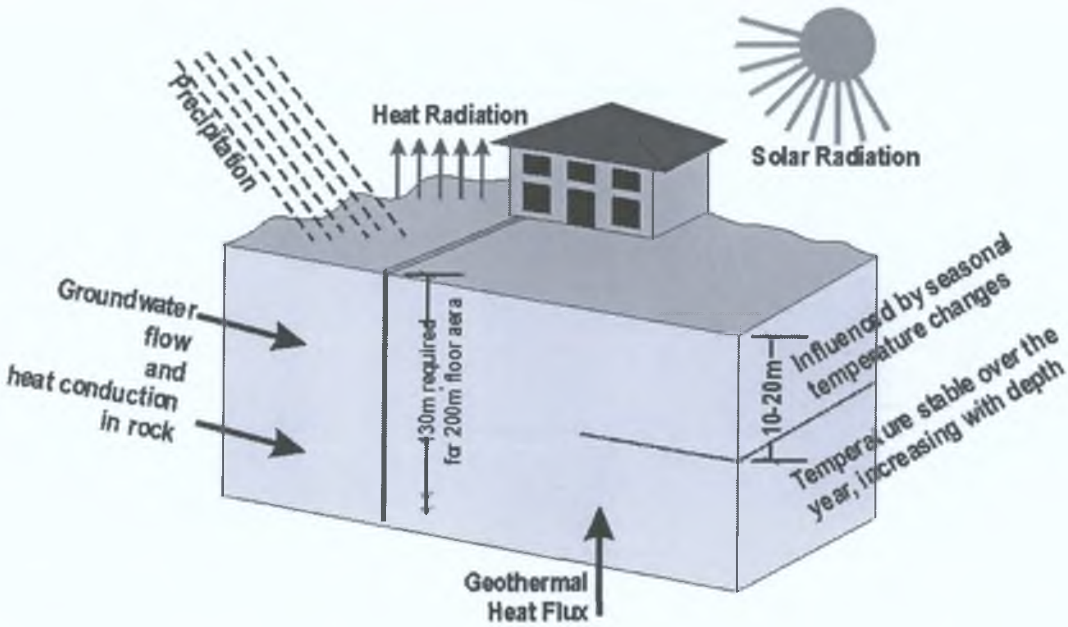

Fig. 3-2 Delivery and storage of heat energy in the ground [Sanner, 2002]

There are a number of different forms of geothermal energy, many of which are particularly suited to Irish climate, geology and soils. The different forms are listed below.

3.2.1 Shallow soil and sediment (GSHP)

Irish soils are highly suited as heat-pump collector sources due to Ireland's thick soil development and temperate, wet climate. Soil temperatures in Ireland generally range from 10°C to 11°C according to Aldwell and Burdon (1980) and vary little throughout the year at depths greater than 40cm (Goodman et al, 2004, P. 11).

3.2.2 Surface water

Goodman et al (2004, P. 11) define surface water as lakes/reservoirs, rivers and estuary/sea sources. Average surface water temperatures in Ireland vary between 5°C and 15°C throughout the year, whilst seawater varies from 8°C to 16°C.

3.2.3 Warm springs

In Ireland, warm springs generally have temperatures elevated between 3°C and 12°C above the average groundwater of the surrounding areas (Goodman et al, 2004, P. 12).

3.2.4 Gravel aquifers and urban heat island effect

Gravel aquifers alone are a good source of heat, due to the free flow of water within the bed, and the consequent good rates of heat conductivity. These aquifers, "when located in an extensive urban area such as Dublin or Cork there can be an added component of increased groundwater temperature due to the insulating effect of the buildings and infrastructure" (Goodman et al, 2004, P. 12).

3.2.5 Shallow groundwater bedrock aquifers

These aquifers are defined by Sustainable Energy Ireland (SEI, 2004) as bedrock aquifers up to 300m in depth. They are accessed through boreholes.

3.2.6 Intermediate and deep aquifers

Intermediate aquifers are defined by SEI as those at between 300m and 1500m depth, while deep aquifers are those at depths greater than 1500m. In the Aquitaine Basin geothermal source area in France, water is typically extracted from depths of 1500m to 2000m, temperatures range from 50°C - 80°C (after extraction to the surface) and flow rates average 200m^3/hour. The warmer parts of Ireland's geothermal resources compare favourably with these temperatures (Goodman et al, 2004, P. 16).

3.2.7 Enhanced Geothermal Systems (EGS) or Hot Dry Rock Systems (HDR)

This involves extracting heat from a source at 150^0C or greater at depths of 4km or greater.

3.3 Seawater as a heat source

3.3.1 Low-grade seawater temperatures

As stated in 3.1, above, surface seawater temperatures vary from 8°C to 16°C (Goodman *et al*, 2004). It is possible to get current information on seawater temperatures from the Irish Marine Weather Buoy Network (www.marine.ie), which is a joint project designed to improve weather forecasts and safety at sea around Ireland. The buoy network provides vital data for weather forecasts, shipping bulletins, gale and swell warnings as well as data for general public information and research.

According to the Centre For Analysis and Dissemination of Demonstrated Energy Technologies (CADDET, online), Stokmarknes Hospital, located in Nordland, Norway, installed a heat pump in 1987 using seawater as the heat source. The hospital has a relatively high heating need varying from 100kW to 800kW throughout the year. The heat pump plant supplies about 60% of the heat demand, with 40% supplied by two oil boilers (285+580 kW).

3.3.2 Saline geothermal fields

While it can be seen from the Marine Institute website that the five marine Weather Buoys are in low temperature areas, geothermal fields can supply seawater at much higher temperatures. The following two examples are of geothermal projects which utilise a saline geothermal field:

- At Thisted in Denmark, a district heating plant uses $200m^3/h$ of 44°C seawater from a depth of 1.25km.

- A plant at Margretheholm in Copenhagen, uses water from wells drilled to over two kilometres in depth, which produce seawater at 73°C (Lund, *et al,* 2005).

3.3.3 Collectors for use in seawater

Because of the highly corrosive nature of seawater, it is necessary in open loop collectors to restrict its circulation to within the collector circuit, and use a corrosion-resistant heat exchanger within the heat pump. Titanium plates were used in the Stykkisholmur district heating plant in Iceland, which uses saline geothermal water as a heat source (CORDIS, 2002.).

A heat exchanger for an 11kW heat pump (suitable for a 185m^2 house) would cost approximately €240 (Valizadeh, 2005).

3.4 How GSHPs work

In lay person's terms, 100 litres of fluid at 10°C is extracted from the ground and transferred to a separate, smaller system through a heat exchanger, giving 25 litres of heating fluid at 40°C, which is pumped around the house.

Popovski and Vasilevska (2003) explain the workings of a heat pump in the following way: when two separate media, at different temperatures, are put in contact with one another, there is a tendency for the heat energy to flow from the warmer medium to the cooler medium until both media are at the same temperature. A heat pump uses this fact in order to remove low-grade heat from the ground source (at this stage, the fluid is cooler than the ground source, which is 10-11°C) and deliver it to the residence (at this stage, the fluid is warmer than the ambient temperature of the room, which will be about 20°C).

In between these two stages, the fluid temperature has to be raised. How the heat pump carries out this process is illustrated in the diagram below.

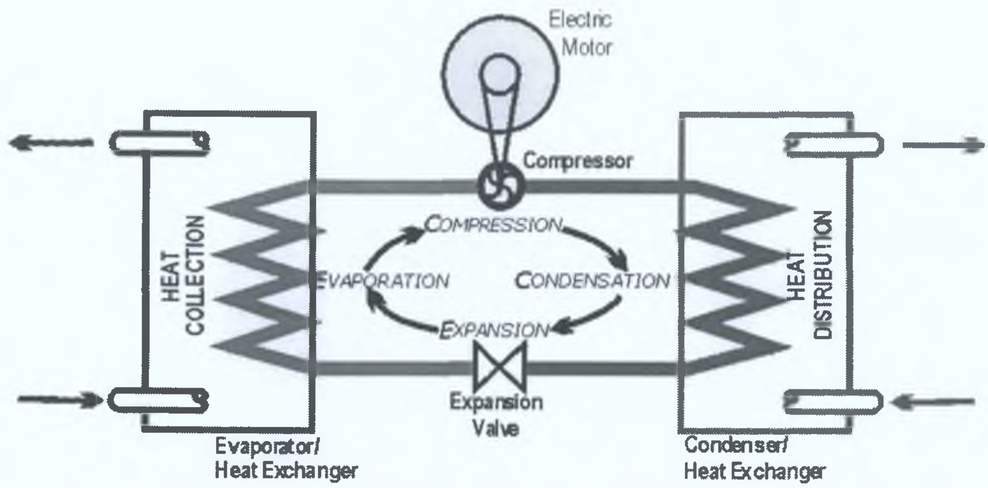

Fig. 3-3 How a heat pump works

The main components in a heat pump system are the compressor, the expansion valve and two heat exchangers referred to as evaporator (located at the heat source) and condenser (located within the building). The components are connected to form a closed circuit, as shown in Fig. 3-3 above. The circulating liquid has a high specific latent heat of vaporisation and a low boiling point.

Stage 1: Compression: Vapour from the evaporator is compressed to a higher pressure, and converted to a liquid.

Stage 2: Condensation: The liquid is pumped, under high pressure, around the building. Due to the conversion from vapour to liquid, the fluid gives off its latent heat, which is transferred into the building.

Stage 3: Expansion: The liquid passes through the expansion valve, relieving the pressure and allowing the fluid to return to the gaseous state.

Stage 4: Evaporation: In order for the conversion back to a gas from a liquid to take place, the fluid must take in heat. Thus, it extracts heat from the surrounding source.

3.5 Classification of low grade heat source systems

Rafferty, (2001) tells us that a heat pump moves heat from one place to another. Low grade heat source systems utilise low grade heat (10-11^{0}C from shallow soil and sediment and 8°C to 16°C from seawater).

These systems can be classified generally as open or closed systems:

- **Open systems:** Groundwater or seawater is used as a heat carrier, and is brought directly to the heat pump.

- **Closed systems:** Heat exchangers are located at the source of the heat (either underground or below sea level) and a form of refrigerant is circulated within the heat exchangers, transporting heat to the heat pump (Rafferty, 2001).

According to Sanner, (2002), to choose the right system for a specific installation, several factors have to be considered:

- **Local geology** (sufficient permeability is a must for open systems)
- **Hydrogeology of the land** (aquifers are ideal low grade heat sources),
- **Land area available:** in the case of horizontal loops it is generally accepted that an area of 200 m^2 is required to heat a house of 100m^2 (Donohue, 2005).
- **Existence of potential heat sources** such as previously drilled boreholes or disused mines, and
- **The heating and cooling characteristics** of the building(s).

At the design stage, the specifier will initially consider the heating requirements of the building. Knowing the rate of heat needed, the optimum heat collection system can then be specified. Since the investment costs (excl. VAT) of a heat pump system are significantly higher than the costs of a conventional oil boiler (Arsenal Research, 2004), it is important to design the optimum system for the client, i.e. the most cost-effective system available.

3.5.1 Open systems

Open systems are systems where the heat is extracted from a large available water source such as the sea, lake, river or underground aquifer. The advantage of the open system is the reduction in cost of providing and laying a closed loop piping system filled with suitable fluid. In situations where sediment is a problem, particularly in rivers, closed loop systems are utilised.

In most cases, a two-well Doublette system (see Fig. 3-4 below) is used, water being extracted from one well and returned to another well. It is important that these two wells are a sufficient distance apart that the returned water has no cooling effect on the source water to be extracted (Sanner, 2002).

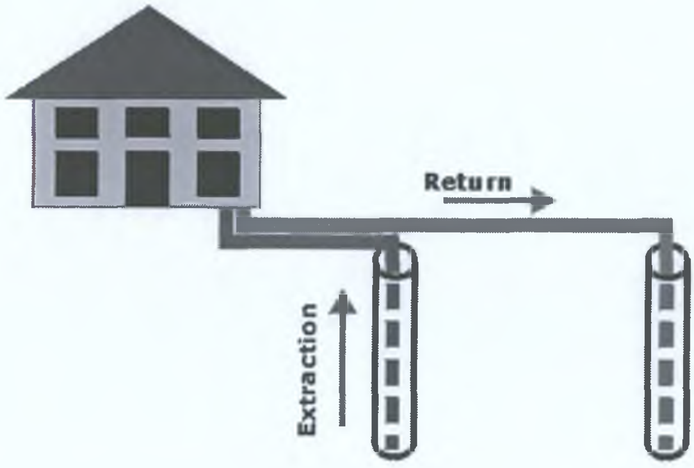

Fig. 3-4 Open loop (Doublette) system

With open systems, a powerful heat source can be exploited at comparably low cost. On the other hand, groundwater wells require some maintenance, and open systems in general are confined to sites with suitable aquifers. Sanner (2002, P.3) states that the main requirements of an open system are:

- Sufficient permeability, to allow production of the desired amount of groundwater with little drawdown.

- Good groundwater chemistry, e.g. low iron content, to avoid problems with scaling, clogging and corrosion.

3.5.2 Closed horizontal loops

According to Goodman et al (2004, P. 11), Irish soils are highly suited as heat-pump collector sources due to Ireland's thick soil development and temperate, wet climate. Soil temperatures in Ireland generally range from 10°C to 11°C.

Horizontal loops (Fig. 3-5 and Fig. 3-6) are the most common type of collector used in single residences in Ireland, due to their ease of installation. Because they are laid between 60cm and 2m underground, it is possible to lay a complete single residence array in a few hours using a small excavator.

Depending on the amount of land area available, different piping arrangements are used. Generally, where land availability is restricted, two loops can be laid at different levels, or in a trench collector formation, as shown in Fig. 3-7 (Solterra, 2005).

Because the main thermal recharge for all horizontal systems is provided for mainly by solar radiation and rainfall, it is important not to cover the ground surface above the heat collector (with buildings or paving) once the trench is refilled (Solterra, 2005).

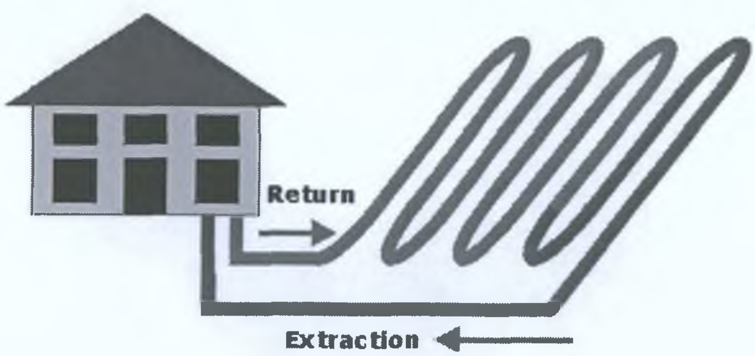

Fig. 3-5 Horizontal closed loop collector in series

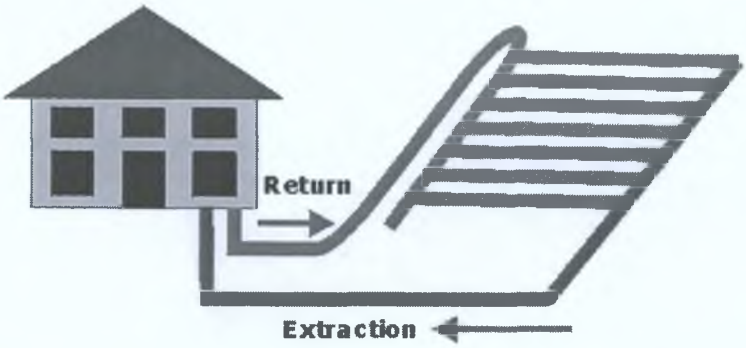

Fig. 3-6 Horizontal closed loop collector in parallel

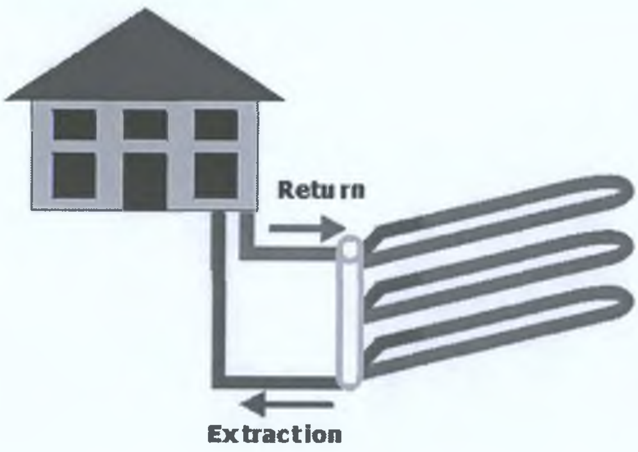

Fig. 3-7 Horizontal closed loop trench collector

3.5.3 Closed vertical loops

While a vertical loop heat exchanger (Fig. 3-8) is more expensive due to drilling costs, space considerations may render it the only choice. In a standard borehole heat exchanger, plastic pipes (polyethylene or polypropylene) are installed in boreholes, and the remaining room in the hole is filled (grouted) with a thermally enhanced grouting material (Rohner, 2003).

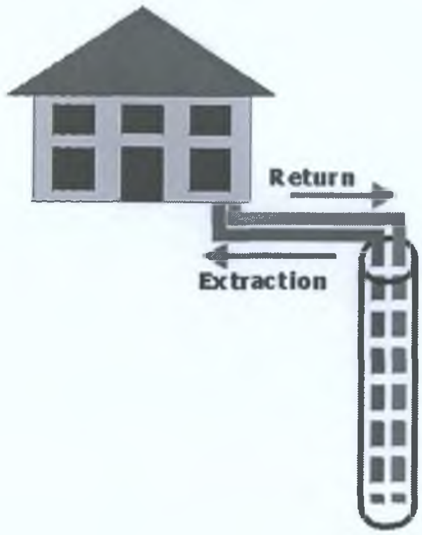

Fig. 3-8 Vertical loop collector

Double U-pipes are the most frequently used vertical loop heat exchangers in Europe. A U-pipe consists of a pair of straight pipes, connected by a 180° turn at the bottom. One, two or even three such U-pipes can be installed in one hole (Rohner, 2003).

3.6 Borehole spacing and depth

3.6.1 Borehole spacing

Sanner (2004) gives the following chart as a guideline in determining the correct spacing for vertical borehole collectors. It should be noted that this is a guideline only, since required borehole depth will vary from site to site as soil permeability varies. Soil permeability is the ease with which water moves through the soil. A quantitative measurement is made by observing the rate at which a column of water permeates the surrounding soil under saturated conditions. The measured permeability rate is related to the saturated hydraulic conductivity of the soil.

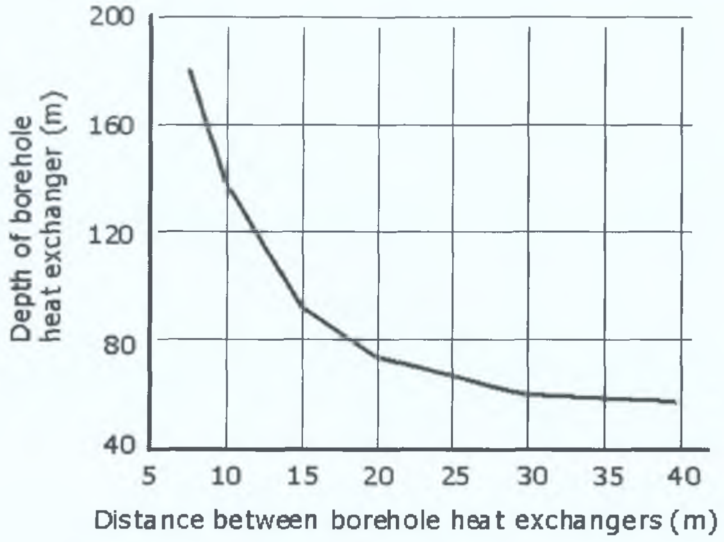

Fig. 3-9 Borehole spacing [Sanner, 2004]

3.6.2 Borehole depth

The specific heat extraction of the borehole (expressed in Watt per meter of borehole length) can be used to determine the borehole depth. It is based on geology (thermal conductivity), annual hours of heat pump operation, number of neighbouring boreholes, etc. Typical values range between 40-70 W/m (Sanner, 2004). This wide range of 40 to 70W/m is caused by variations in the soil permeability of different types of soil.

With the known capacity of the heat pump evaporator, the required length can easily be calculated:

$$\text{Borehole depth}\,[m] = \frac{\text{Heat Pump Evaporator Capacity}\,[\text{W}]}{\text{Specific Heat Extraction Rate}\,[W/m]} \quad \text{(Sanner, 2004)}$$

In general, borehole depths in Ireland for GSHPs are rarely drilled greater than 150m deep. While it is possible for deeper boreholes to be drilled, the maximum length of collector pipes available on the market is 150m.

3.6.3 Dependability of borehole heat exchangers (collectors)

Because a borehole heat exchanger is inserted vertically into the ground, there is little chance of damage, except in the connecting pipes between the collector and the heat pump. For this reason, borehole heat exchangers are considered to be dependable and, ecologically safe with a long life span (Rohner, 2003).

3.6.4 Planning guidelines for garden size

Minimum garden length between houses is generally determined by the Residential Density Guidelines for Planning Authorities (Department of the Environment and Local Government, 1999b). This document recommends a space of 22m between opposing upper floor windows, leaving two gardens of 11m length.

3.7 Space heating methods

3.7.1 Underfloor heating

Since GSHPs can only deliver heating water at a maximum 45°C (BRE, 2001) they are not suitable for use with radiators, which require temperatures of 60-70°C (BRE, 2001). Physiological factors restrict the allowable floor surface temperature to 29°C; since higher temperatures induce hot feet and feelings of discomfort (World Research Organization of New Zealand, 2002). So GSHPs are suitable for use with underfloor heating.

3.7.2 Floor coverings and underfloor heating.

The Thermal Resistance Value (TRV) of a floor covering determines the amount of heat that will flow through the floor covering with underfloor heating. Certain countries have set a limit as a guide to carpet buyers; others have not. For instance, Germany has set a TRV 0.17 m^2 K/W or less (World Research Organization of New Zealand, 2002).

Stone and ceramic tiles are most suitable for use with underfloor heating, because of their low TRV. (See Table 3-3 below). It is possible to find carpets which have TRV values below 0.17 m^2 K/W. In general, the denser and thinner the carpet, the lower the TRV (World Research Organization of New Zealand, 2002).

Covering Type	Carpet Underlay	Vinyl	Parquet	Ceramic Tiles	Stone
R Value m2K/W	0.15	0.022	0.05	0.017	0.011
TOG Value	1.5	0.2	0.5	0.17	0.11

Table 3-3 Thermal Resistance Values of some typical floor coverings (Marble Institute of America, 2001)

3.8 Case studies

The following case studies are of single and multi-house developments in temperate climates (The Heat Pump Centre, 2005). The data collected from these case studies include: type of GSHP system, borehole depth, pipe length, distribution system, heated floor area, supplementary system, and co-efficient of performance (COP).

3.8.1 79 houses, Swifterbant, the Netherlands

This is an example of a large-scale domestic heat pump project in Swifterbant, the Netherlands. Ten small collective heat pump systems provide space heating for 79 new-built houses. Each heat pump system contains a vertical heat exchanger, two heat pumps, a 700 litre storage vessel and a short distribution system.

Type Of GSHP System	Vertical loop, 158 boreholes (divided into 10 systems)
Borehole Depth	50m
Pipe Length	No data
Distribution System	Floor heating (ground floor), radiators (upper floor)
Heated Floor Area	100m per house
Supplementary System	None for heating.
Co-Efficient Of Performance	2.2

Table 3-4 Case study: 79 houses, Swifterbant, the Netherlands

3.8.2 Near Rotterdam, The Netherlands

In a project on new-build single-family houses, heat pumps with vertical ground-source heat exchangers are used for space heating, production of hot water and passive (free) cooling: direct utilisation of the cold from the ground source.

Type Of GSHP System	Vertical Loop
Borehole Depth	15-20m
Pipe Length	600m
Distribution System	Floor Heating
Heated Floor Area	120m^2
Supplementary System	None
Co-Efficient Of Performance	3.84 and 5.46 (according to the EN 255-2)

Table 3-5 Case study: Near Rotterdam, The Netherlands

3.8.3 4 bungalows, Marazion, Cornwall, United Kingdom

Four identical energy efficient bungalows have been fitted with horizontal closed-loop ground-coupled heat pumps. Each bungalow has a coil buried in the ground, and the headers from each coil are taken back into each residence such that the headers terminate in the utility room. The heat pumps provide space heating and a proportion of hot water.

Type Of GSHP System	Horizontal/slinky; each bungalow has a dedicated coil
Borehole Depth	Trench depth 1.4 m, trench length 45 m
Pipe Length	200m
Distribution System	Radiators
Heated Floor Area	68m^2
Supplementary System	Immersion heater for DHW, which raises the water temperature to 65°C at night.
Co-Efficient Of Performance	Monitoring of the system has been started by SWEB (the local energy supplier) and BRE and the results are expected to be available at a later stage.

Table 3-6 Case study: 4 bungalows, Marazion, Cornwall, United Kingdom

3.8.4 Single family home, Grafstal, Switzerland

The purpose of the project was to build a low energy and low cost prefabricated house without compromising the comfort. The house is a 3-storey building with the third floor being a loft in regular use. Due to the overall reduced energy consumption in low energy houses the proportion of the heat required for hot water increases from 30% to 40%.

Type Of GSHP System	Vertical, 32 mm diameter double U-pipe
Borehole Depth	100m
Pipe Length	4 x 100m
Distribution System	Floor heating
Heated Floor Area	174m^2
Supplementary System	Single room air heat recovery unit.
Co-Efficient Of Performance	4.6

Table 3-7 Case study: Single family home, Grafstal, Switzerland

3.8.5 Single family home, West Grimstead, Wiltshire, United Kingdom

This large, well-insulated detached single-family house in West Grimstead consists of a two-storey main house and a linked single-storey annex. A horizontal ground-source heat pump installed in January 1998 provides space heating and hot water. The annual performance factor is 3.16 and when mostly used for hot water in the summer it is 2.5. The operational experience of this low maintenance installation have been positive.

Type Of GSHP System	Horizontal/single loop (PE 32/28 mm)
Borehole Depth	Trench
Pipe Length	200m
Distribution System	Underfloor heating
Heated Floor Area	288m^2
Supplementary System	Wood-burning stoves for additional space heating in the living room and the kitchen. Contribution to the annual energy consumption is negligible.
Co-Efficient Of Performance	3.16

Table 3-8 Case study: Single family home, West Grimstead, Wiltshire, United Kingdom

3.8.6 Seawater-source heat pump - Research Centre, Trondheim, Norway.

A large capacity ammonia heat pump was installed in 1994 at the STATOIL Research Centre in Trondheim. The building houses about 500 people.

Type Of GSHP System	Open Loop
Borehole Depth	N.A.
Pipe Length	N.A.
Distribution System	No data
Heated Floor Area	28000m^2
Supplementary System	Ammonia chiller (200 kW) as back-up for cooling. No heating back up.
Co-Efficient Of Performance	4.0

Table 3-9 Case study: Seawater-source heat pump - Research Centre, Trondheim, Norway.

3.9 Social housing numbers and sizes in 2004

There were 5,146 social houses completed in Ireland in 2004 (Department of the Environment and Local Government, 2005).

According to Watson and Williams (2003), 58 per cent of Local Authority (social) rental dwellings are three bedroom. The recommended target floor area for a three bedroom, two storey local authority house if $80m^2$, as per the Department of the Environment and Local Government's Social Housing Design Guidelines (1999b).

Dwelling Type	Floor Area
4 BED (2 storey)	$100m^2$
3 BED (2 storey)	$80m^2$
3BED (2 storey)	$72m^2$

Table 3-10 Recommended space provision and room sizes for social housing (Dept. of the Environment and Local Government, 1999)

3.9.1 Housing insulation building regulations

Insulation levels for new houses built in Ireland set in the Building Regulations (Amendment) 2002, provide the following U-values:

Roof	Wall	Floor
0.16 W/m^2k	**0.27 W/m^2k**	**0.25 W/m^2k**

Table 3-11 Insulation levels building regulations

3.9.2 Social house heating

The Department of the Environment's *Social Housing Guidelines* (1999b, P.25), state that "in the absence of a local source of waste heat which can be economically utilised, natural gas should be the preferred fuel, where available." To facilitate this study, calculations are based on the assumption that all social housing built in 2004 which are located on the natural gas network are being heated with natural gas: it is assumed that all other social houses are heated with oil.

The following table (Table 3-12) lists the local authority regions in Ireland (Department of the Environment and Local Government. 2005, P.32) and estimates the number of social housing to which natural gas is available (See Fig. 3-10).

County	No. of Houses	On Gas Network*	Not on Gas Network*
Carlow	54		54
Cavan	196		196
Clare	44		44
Cork County	255	255	
Cork City Council	172	172	
Donegal	291		291
Dublin Total	1304	1304	
Galway County	193		193
Galway City Council	84	84	
Kerry	139		139
Kildare	184	184	
Kilkenny	60	40	20
Laois	263		263
Leitrim	80		80
Limerick County	113		113
Limerick City	33	33	
Longford	45		45
Louth	215	215	
Mayo	120		120
Meath	110		110
Monaghan	60		61
North Tipperary	134		134
Offaly	76		76
Roscommon	35		35
Sligo	169		169
South Tipperary	105	75	30
Waterford County	54		54
Waterford City Council	45	45	
Westmeath	146		146
Wexford	278		278
Wicklow	88	88	
Totals	**5146**	**2495**	**2651**

Table 3-12 Distribution of social housing on natural gas network.

* For counties where some but not all towns are on the gas network, exact figures for numbers of houses with access to natural gas were not available. Estimates were made in such cases.

3.9.3 Natural gas availability to new social housing in Ireland

The map below (Fig. 3-10), supplied by an Bórd Gais, illustrates natural gas availability throughout Ireland. It should be noted that the map names the town of Bandon, but locates it at Bantry. Bandon is on the gas network, but the town of Bantry is not.

Fig. 3-10 Natural gas network in Ireland [Source: an Bord Gais]

3.10 CO_2 emissions by fuel

According to SEI (2005), natural gas has the lowest level of CO_2 emissions of the three fuel types studied, at 197.78g/kWh. The table below (Table 3-13) gives values for all fuel types studied.

Fuel	CO_2 (g/kWh)
Natural Gas	197.78
Electricity	650.54

Oil	273.64

Table 3-13 CO_2 emissions by fuel type (Source: *Energy in Ireland*, 2005; SEI)

Emissions as a result of electricity generation have fallen from a 1990 level of 920g/kWh to a 2003 level of 650.54g/kWh due to:

- The addition of 2 large CCGT plants in August 2002 (392 MW) and November 2002 (343 MW)
- Increase in the gas share of the fuel mix for electricity generation from 35% in 2001 to 47% in 2003.
- A decrease in the share of fuel oil generation from 22% in 2001 to 11% in 2003.
- A decrease in the share of coal generation from 29% in 2001 to 26.5% in 2003.
- A decrease in the share of peat generation from 11.1% in 2001 to 10.4% in 2003.
- The contribution of renewables and combined heat and power (CHP) in electricity generation.
- An increase in electricity imports to 100 ktoe in 2003 (SEI, 2005).

3.10.1 CO_2 emissions in 2003

According to SEI (2005), Ireland is responsible for 66.6 Mt of CO_2 emitted in 2003. Our Kyoto target is 60.6Mt of CO_2 emissions per year by the period 2008-2012 (SEI, 2005).

3.10.2 GSHP efficiency compared to natural gas and oil

According to the BRE's *SAP Energy Rating Manual* (2001), modern gas boilers have an efficiency of 83%, compared with GSHPs which have an efficiency of 320%. In other words, for every 100kW of electrical energy used to drive the GSHP, 320kW of heating energy is gained. Standard oil boilers produced in 1998 or later have an efficiency of 79% (BRE, 2001).

4 METHODOLOGY

4.1 Various arrays of GSHP system for residential schemes.

For the purpose of this element of the investigation, a scheme of 12 privately-owned, detached two storey houses, each 185m^2 (2000 square feet) in area will be considered.

There are three different arrays to be considered when specifying a GSHP arrays for a scheme of residential houses. The three arrays will be compared and contrasted under the following headings:

- Installation Costs
- Running costs
- Market perceptions

Array 1: District heating system with shared collector and shared heat pump, and district distribution system. (Fig. 4-1)

Anticipated benefits: shared cost of drilling boreholes at the heat source, and the shared cost of installation and maintenance of the heat pump. Also, improved heat pump efficiencies.

Anticipated disadvantages: the problems of group ownership and the perceived difficulties for individual owners who want to sell their property at a later stage, presuming that potential buyers may be unwilling to get involved with such a group scheme. There is also potential for dispute over excessive usage by one resident compared to another (e.g. residence with a home maker versus a residence with two full time workers). Also, the cost of district heating piping, and the heat losses along lengths.

Array 2: A shared collector system distributing low grade heat to individual heat pumps at each house.

Anticipated benefits: shared cost of drilling boreholes at the heat source. Multiple collectors may lead to some cost savings, but they will not be significant.

Anticipated disadvantages: the problems of group ownership as stated above may be reduced since only the collector is shared, so disputes over fees such as running costs and maintenance or overuse will not arise.

Array 3: Individual collectors and heat pumps for each residence.

Anticipated benefits: reduction in cost of drilling boreholes if all boreholes are drilled at the same time and by the same contractor. Reduction in purchasing and installation of heat pumps if one supplier is used. Also, shared ground permeability tests and housing heat load calculations costs. No potential for disputes over shared costs, and no legal issues if one resident decides to sell the residence on to another party.

Anticipated disadvantages: increase in initial purchase, installation and running costs compared to Array 1 and 2.

Within these arrays, the collector, heat pump and delivery system will be described.

4.1.1 Array 1: District heating system with shared collector and shared heat pump, and district distribution system

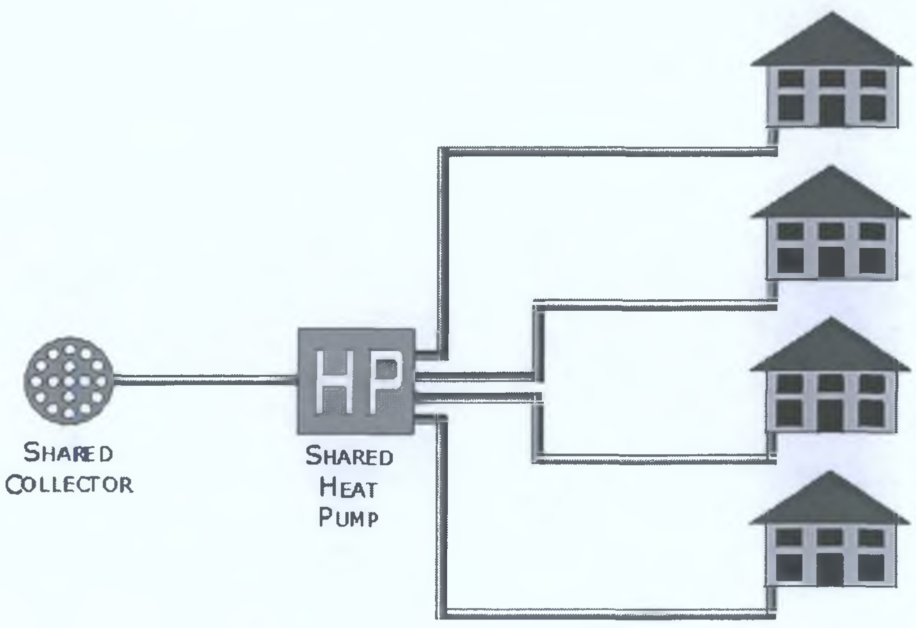

Fig. 4-1 District heating system with shared heat source and shared heat pump.

Collector: As Fig. 4-1 shows, a shared collector, made up of a collection of vertical bore hole collectors is utilised. The main advantage of this is the reduced costs for each individual member of the group of purchase, maintenance and installation of the heat pump and costs of purchase and installation of the shared collector.

Heat Pump: A shared heat pump system, often combining a number of heat pumps, is used in order to provide for maintenance, a back-up system etc. Again, economies of scale come into effect here and imply lower costs.

Delivery System: The heated water is pumped to individual houses within the residential scheme. For district heating, where pipes are transporting fluids at temperatures significantly higher than the soil through which they travel, heavily insulated pipes are used to ensure minimal heat loss between the heat pump and the house. Because the heat pump cannot efficiently provide water at temperatures above 45°C, piping distances may render this option uneconomical. District heating piping, which is specially insulated to retain the maximum heat energy, costs €54/m. (price from York Intl., Cork). For the purpose of this project, an estimated 30m. of district heating is required per house.

4.1.2 Array 2: A shared collector system distributing low grade heat to individual heat pumps at each house

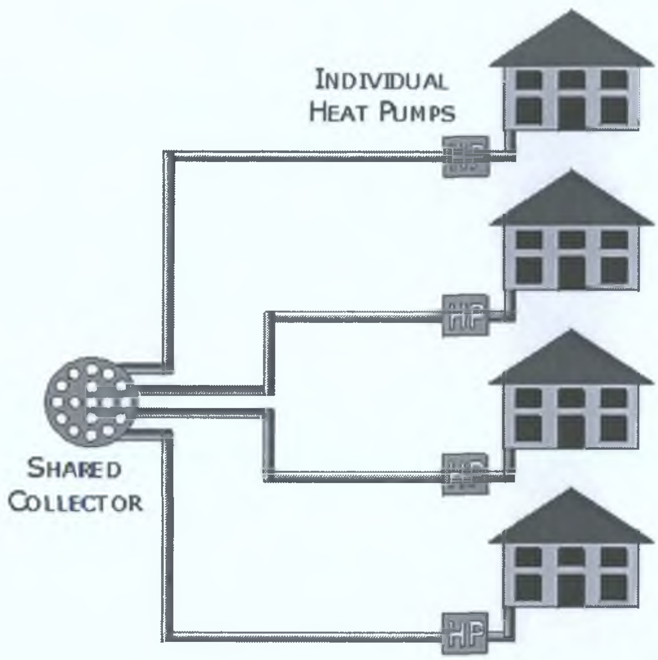

Fig. 4-2 A shared collector system distributing low grade heat to individual heat pumps at each house

Collector: The collector, as shown in Fig. 4-2 is similar to the shared collector used for option 1. (4.1.1 above).

Heat pump: In this option, individual heat pumps are used at each residence. With this option, the savings in purchasing, installation and maintenance of a larger shared heat pump is lost, but bulk purchasing and installation of all heat pump units should lead to some savings. Problems relating to shared ownership of a heat pump, such as disputes over costs, are mainly avoided.

Delivery System: The delivery system utilised in this array carries the fluid from the collector to the individual heat pumps. Since this fluid is at a low temperature before it reaches the heat pumps, there is concern that heat loss of even one degree might effect the efficiency of the system. This factor will depend on fluid temperature (anything from 5°C to 16°C, depending on whether groundwater, lakes, rivers or seawater is used, and depending on the season (Goodman et al, 2004)).

4.1.3 Array 3: Individual collectors and heat pumps for each residence

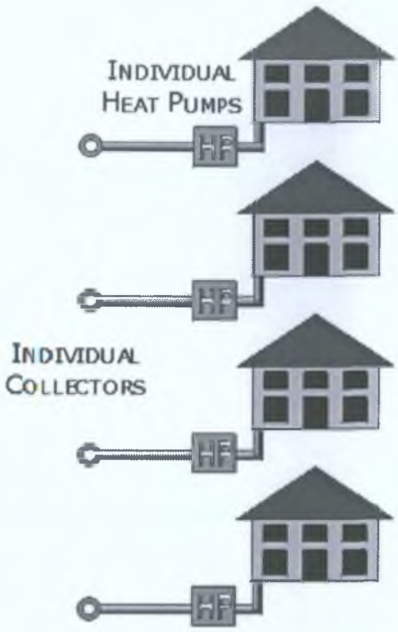

Fig. 4-3 Individual collectors and heat pumps for each residence

Collector: Individual collectors are used for each residence (see Fig. 4-1 above), avoiding any issues over shared ownership. There are possible financial savings in relation to the purchase and installation of the individual collectors, considering the fact that heavy machinery is used for the laying of both horizontal and vertical collectors. More so in the case of vertical collectors, where a major factor in the cost of drilling bore holes is the movement of the machinery to the site. Once the drilling rig is onsite, the cost of drilling per individual bore hole reduces significantly as the number of bore holes increases (O'Connell, 2005).

Heat pump: As with Array 2, above, individual heat pumps are used for each residence, losing the economies of scale in the purchase, installation and maintenance of a larger, shared heat pump system, but avoiding the problems of shared ownership.

Delivery System: In this option the delivery system is not a factor, as it is part of the heat collector.

4.1.4 Determining the heat load of a building

The heat load (the amount of heat required to maintain a building at a certain temperature) is determined using the following formula:

$Q = U * A(T_{\text{int}} - T_{ext})$, where

> **Q** = heat transfer through the exterior of the building (walls, roof, windows, etc.) Q is measured in
>
> **A** = surface areas of the exterior of the building
>
> **U** = U-value (measured in W/m^2k) – the amount of heat energy conducted per second through $1m^2$ of a wall/floor/roof/window while a temperature difference of 1°C (i.e. 1° Kelvin) is maintained between both faces.
>
> $\mathbf{T_{int}}$ = interior air temperature
>
> $\mathbf{T_{ext}}$ = exterior air temperature

4.1.5 Borehole depth

Borehole depth (equivalent to heat exchanger length) is a function of heat pump evaporator capacity and specific heat extraction rate. Typical values for specific heat extraction range between 40-70 W/m (Sanner, 2004). With the known capacity of the heat pump evaporator, the required heat exchanger length can easily be calculated:

$$\text{Borehole depth}\,[m] = \frac{\text{Heat Pump Evaporator Capacity}\,[\text{W}]}{\text{Specific Heat Extraction Rate}\,[W/m]}$$

Heat Pump Evaporator Capacity [W] = Heat Output [W] –Power Input [W]

Because the maximum length of vertical collector available on the market is 150m, all calculations are based on a maximum depth borehole of 150m. If a greater depth than that is required, a second borehole can be drilled.

4.1.6 Borehole spacing

Borehole spacing is crucial, because boreholes which are placed too close together will extract heat quicker than that heat can be replenished, thus chilling the ground and rendering the system unusable. Borehole spacing is determined using Fig. 3-9, above.

4.2 A cost comparison between GSHPs and other fuels for domestic heating.

This comparison will consider a number of factors, such as initial outlay, running costs and life expectancy of hardware. GSHPs will be compared to natural gas and oil fired space heating units. The comparison is based on using an 11kW heat pump, which will deliver 22,000 kWh, as above. Consideration will also be given to space heating components and suitable floor coverings. While these items don't impact per se on the installation and running costs of the heating system, they may affect a buyer's decision if they cannot be used with one or other of the heating systems.

4.2.1 Comparison of energy costs for domestic fuels

Figures for energy costs for domestic fuels are calculated quarterly by Sustainable Energy Ireland (SEI) (*see Appendix*).

The figures used to calculate energy costs for GSHPs are based on using 80% night-time electricity and 20% daytime electricity.

4.2.2 Comparison of hardware installation costs.

In this section, the cost of installing an 11kW GSHP and collector is compared with the cost of installing:

a) an 11kW oil fired boiler and oil storage tank

b) an 11kW natural gas burner and connection to the gas network.

4.2.3 Long term investment comparison.

Total costs, including installation and running costs for the three systems are compared in this section over a 10 year and a 20 year period.

4.3 Reduction in CO_2 emissions

In this section, the reduction in CO_2 emissions which would have been gained if all of the social housing built in Ireland in 2004 utilised GSHPs is determined. To do this, the following information is required:

- Number of houses built
- Average heating load per house
- Difference in CO_2 emissions between existing heating systems and GSHPs.

According to Watson and Williams (2003), 58 per cent of Local Authority (social) rental dwellings are three bedroom. For the purpose of this study, average social house size is assumed to be $80m^2$ (861 sq. ft.), which is the target gross floor area for a 2 story, 3 bed house, according to the Department of the Environment and Local Government, (1999b).

Heat load is estimated at a rate of $60W/m^2$ (O'Connell, personal communication).

4.4 A comparison and contrast of the use of GSHPs as against seawater heat pumps for residential use

The differences between using seawater as a heat source for a residential heat pump and using a standard GSHP are compared and contrasted, and the advantages and disadvantages of both sources are discussed.

5 RESULTS

5.1 Optimum GSHP array for a scheme of houses

The model to be considered in this section is a scheme of 12 privately-owned, detached, two storey houses, each 185m^2 (2000 square feet) in area.

5.1.1 Heat energy requirement for a 185m^2 house

Figures for the rate of heat energy required to heat a living area of 185m^2 are based on accepted estimates of 50 to 60W/m^2 for space heating requirements. (O'Connell, personal communication).

Living area: 185m^2 (2000 sq. ft.)

Heat required per square metre: 60W/m^2

Heat required per house = (heat required/m^2) x (house size)

= 60 x 185 = **11,100W**

Therefore, an 11kW heat pump is required.

With a heat load of 11kW, the recommended Solterra Heat Pump is the Solterra 400, with a Heat Output of 12kW and a power input of 3.4kW (Solterra, 2005).

5.1.2 Borehole depth

Borehole depth calculations are based on a conservative specific heat extraction rate of 40W/m (Sanner, 2002).

Heat Pump Evaporator Capacity [W] = Heat Output [W] –Power Input [W]

= 12000W – 3400W

= 8600W

$$\text{Borehole depth } [m] = \frac{\text{Heat Pump Evaporator Capacity } [\mathrm{W}]}{\text{Specific Heat Extraction Rate } [W/m]}$$

$$\text{Borehole depth } [m] = \frac{8600\,[\mathrm{W}]}{40\,[W/m]} = 215m$$

With a required borehole length of 215m, 2 boreholes will be used. Boreholes will be drilled to a depth of 125m even though this exceeds the requirements of the project, since the added cost is small and the increased length will improve system performance by supplying more energy. Because of this, borehole depths are set at 125m for all calculations.

5.1.3 Borehole costs

Boreholes cost €36 per linear metre. This includes the cost of boring the hole, the supply and installation of the heat exchanger, and all grouting and refilling (Ryan, 2005). Discounts of 20% are offered for 8 or more boreholes. One 125m borehole costs €4500. With discount applied, the cost is €3600.

5.1.4 Borehole spacing

From Fig. 3-9, boreholes of 125m depth should be spaced about 10m apart. Array 1 requires 21 boreholes, at a minimum of 10m apart. The required land area for such an array is 2,186.5m^2, (0.54 acres) as illustrated in Fig. 5-1

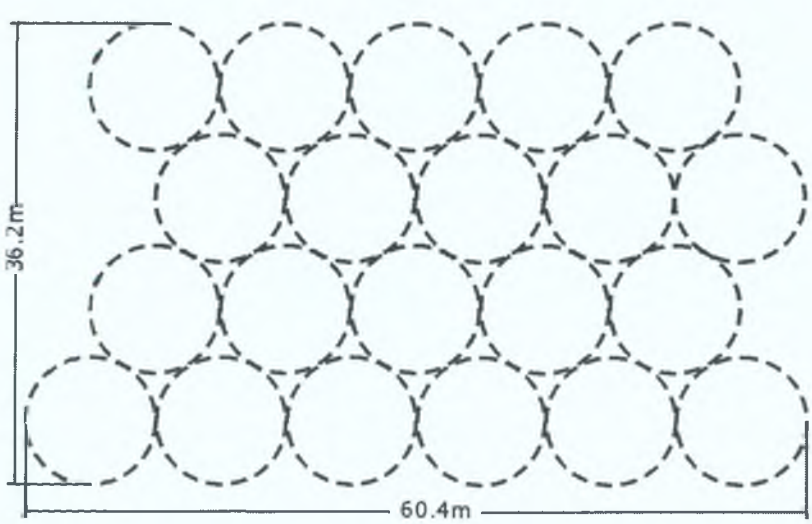

Fig. 5-1 Borehole spacing for a shared collector

Arrays 2 and 3, with privately-owned collectors, require a minimum open space area of 17m x 17m (289m^2) per house, as illustrated in Fig. 5-2

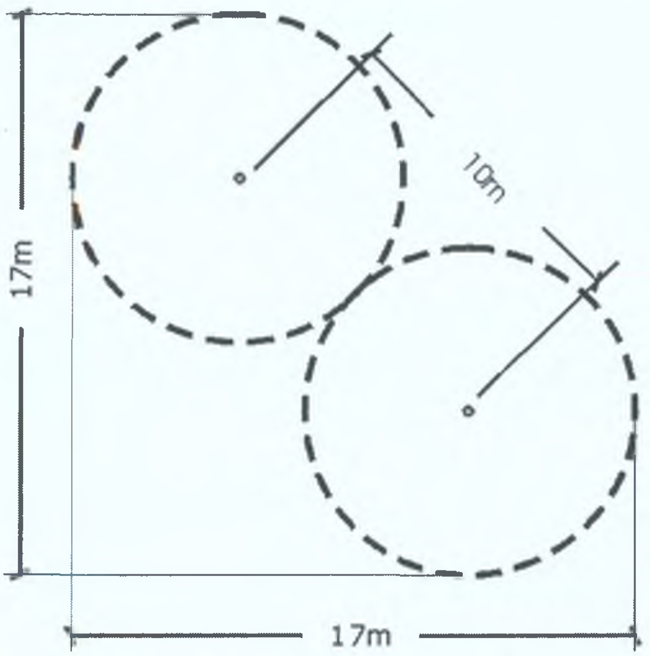

Fig. 5-2 Borehole spacing for individual collectors

5.1.5 Array 1: District heating system with shared collector and shared heat pump, and district distribution system

Item	Details	Cost (€)
Energy required:	12 x 11kW	NA
Heat Pumps	1 no. 132kW plant	24,650[1]
Borehole Depth	12 x 215m = 2580m	NA
No. of Boreholes[2]	21	75,600[3]
District heating piping	12 x 30lm	19,440[4]
Total Cost		**€119,690**

Table 5-1. Array 1 cost details.

1.Price from Valve Control Systems (2005).
2. Number of boreholes = (borehole depth) / (standard borehole depth (125m))
*3. Cost of boreholes = (no. of boreholes) x (125m) x (€36*80%)*
4. See Section 4.1.1

5.1.6 Array 2: A shared collector system distributing low grade heat to individual heat pumps at each house

Item	Details	Cost (€)
Energy required:	12 x 11kW	NA
Heat Pumps	12 no. x 11kW units	99600[1]
Borehole Depth	12 x 215m = 2580m	NA
No. of Boreholes	21	75,600
Total Cost		**€175,400**

Table 5-2 Array 2 cost details.

1. *Based on heat pump cost of €8,300, from Dunstar. Includes collector/piping costs.*

5.1.7 Array 3: Individual collectors and heat pumps for each residence

Item	Details	Cost (€)
Energy required:	12 x 11kW	NA
Heat Pumps	12 no. x 11kW units	99,600
Boreholes	24	86,400
Total Cost		**€186,000**

Table 5-3 Array 3 cost details

5.1.8 Comparison of array costs

Array	Cost (€)	Savings (€)	Savings (%)
Array 1	119690	66310	**36%**
Array 2	175400	10600	**6%**
Array 3	186000	0	**0%**

Table 5-4 Comparison of array costs

5.2 A cost comparison between GSHPs and other fuels for domestic heating.

This comparison is based on a house of 185m^2 with an energy heating requirement of 11kW, as calculated in 5.1.1. The purpose of this section is to determine the most cost-effective form of space heating over a 20 year period.

5.2.1 Calculation of annual heat load

An average estimate of space heating for a house of 185m^2 area (2000 square feet) per annum is 20,000 kWh of energy per annum (Solterra 2005). This figure is calculated assuming that a house is heated for 180 days of the year, for 10 hours each day.

Annual heat load = (heat required per house) x (heating days) x (hours per day)

= 11kW x 180 days x 10 hours

= 19980kWh (say 20000kWh) per house

5.2.2 Comparison of energy costs for domestic fuels

The following comparison is based on using an 11kW heat pump, which will deliver 22,000 kWh, as above.

Fuel Type	Fuel Cost Cent/kWh[1]	Standing Charge (€/2 months)	Co-efficient of Performance[2]	Annual Cost[3] €
Oil	5.06	Nil	79%	**1409.11**
Natural Gas	2.71	34.10	83%	**922.91**
GSHP	7.69[4]	18.82	320%	**641.61**

Table 5-5 Comparison of energy costs for domestic fuels

1 From Appendix: SEI Domestic Fuels - Comparison of costs.

2 See 3.10.2 GSHP efficiency compared to natural gas and oil above

3 Annual Cost = (Standing Charge x 6) + (Fuel Cost/Efficiency x 22000kWh)

4 Based on using 20% Day rate (13.85c/kWh) and 80% Night Saver rate (6.15c/kWh).

5.2.3 Comparison of hardware installation costs

These installation costs do not include under floor heating or radiator costs, since these costs are the same for each fuel type.

Fuel Type	Cost
Oil	€3,000[1]
Natural gas	€3,000[2]
GSHP	€10,500[3]

Table 5-6 Hardware installation costs

1 *Figure received from AMS Plumbing, Sligo*

2 *Figure received from Mowlds Heating, Dublin 12*

3 *Figure received from Dunstar, Cork*

5.2.4 Long term investment comparison.

Fuel Type	Installation Costs (€)	Annual Running Cost (€)	10 year Overall Cost (€)	20 year Overall Cost (€)
Oil	3,000	1409.11	17,091.14	31,182.28
Natural gas	3,000	922.91	12,229.13	21,458.27
GSHP	10,500	641.61	16,916.08	23,332.15

Table 5-7 Long term investment comparison

5.3 Reduction in CO_2 emissions

In this section, the reduction in CO_2 emissions which would have been gained if all of the social housing built in Ireland in 2004 utilised GSHPs is determined. To do this, the following information is required:

- Number of houses built
- Average heating load per house
- Difference in CO_2 emissions between existing heating systems and GSHPs.

5.3.1 Calculate the heat load per house

Number of social housing built in 2004: ....**5146**.

Assumed average house size: ....**80m^2 (861 sq. ft.)**

Heat required per square metre: ....**60W/m^2**

Heat required per house = (heat required/m^2) x (house size)

= 60 x 80 = **4800W**

Annual heat load = (heat required per house) x (heating days) x (hours per day)

= 4800 x 180 x 10

= 8,640kWh per house

5.3.2 CO_2 emissions calculations

197.78g of CO_2 are emitted per kWh of energy created using natural gas. 650.54g of CO_2 are emitted per kWh of energy created using electricity (See Table 3-13). As stated earlier, the efficiency of modern natural gas space heating appliances is rated at 83% by BRE, while GSHPs are rated at 320% and oil fired systems are rated at 79%.

Fuel Type	House Heat Load (kWh)	Fuel Efficiency (%)	Energy Required (kWh)	CO_2 Emissions (by Fuel) (kg/kWh)	Annual CO_2 emissions (kg)
Oil	8640	79	10937	0.274	**2997**
Gas	8640	83	10410	0.197	**2051**
Electricity (GSHP)	8640	320	2700	0.65	**1755**

Table 5-8 CO_2 Emissions Comparison

There were 5,146 social housing built in 2004. From Table 3-12, natural gas is available to 52% (2,495 houses) and it is assumed that the remainder (2,651 houses) are heated using oil. The total annual CO_2 emissions are calculated and compared to the CO_2 emissions that would be generated by the same number of houses hated with GSHPs.

Total annual CO_2 emissions per fuel type =

(No. of houses per fuel type) x Annual CO_2 emissions per fuel type (kg).

Natural gas calculations:

CO_2 emissions = 2495 x 2051 = **5,117,245kg of CO_2 emissions**

Oil calculations:

CO_2 emissions = 2651 x 2997 = **7,945,047 kg of CO_2 emissions**

Total annual CO_2 emissions for social housing = 13,062,922kg

GSHP calculations:

5164 x 1755 = **9,062,820kg of CO_2 emissions from GSHP systems**

Annual savings if GSHPs were used to heat social housing = **3,999,472kg (say 4,000 tonnes)**.

6 Discussion

This chapter consists of a discussion of the most notable findings of the data. The chapter is divided into four sections:

1. A determination of the optimum GSHP array for a scheme of 12 privately – owned, detached houses of 185m^2 area
2. A cost comparison between the use of GSHPs, natural gas and oil-fired heating systems, over a 20 year period
3. The potential reduction in CO_2 emissions if GSHPs were utilised in all the social housing built in Ireland in 2004, and
4. A comparison and contrasting of the use of GSHPs with seawater heat pumps.

6.1 Optimum GSHP array for a scheme of houses

In this section the optimum GSHP array for a scheme of 12 privately–owned, detached houses of 185m^2 area is determined. Three arrays are studied:

- Array 1: shared collector and shared heat pump, with heat distributed through a district heating network
- Array 2: shared collector and individual heat pumps, with low temperature water distributed from the collector to each heat pump.
- Array 3: individual collectors and individual heat pumps.

It was determined that Array 1 (with shared collector and shared heat pump) is 36% cheaper than Array 2 (shared collector and individual heat pumps) and 32% cheaper than Array 3 (individual collectors and individual heat pumps). So, from a financial point of view, Array 1 is the option of choice.

However, while this is the optimum array from a capital cost point of view, it should be remembered that market confidence in GSHP technology is low. Barriers within the market include a low credibility rating and low awareness of the technology (Arsenal Research, 2004). These would have to be overcome by any developer planning to build such a housing scheme.

Presuming that the developer has overcome the credibility issue, (perhaps by being contracted by a group or co-op of interested parties who want to incorporate GSHP systems into their homes), the legal issues related to ownership and maintenance of the shared systems should be easily surmounted. The legal structure could be modelled on group water schemes, for example, which are plentiful and widely accepted in Ireland. A management structure will be required to administer and manage the system, organising maintenance and administration, including billing and meter reading, where necessary.

6.1.1 Metering and billing

Water meters will be required in a system utilising a shared collector and shared heat pump (Array 1) in order to avoid the issue of running costs arising. With this option, there would be only one electricity bill and one maintenance bill. Depending on family sizes within the individual houses, and resident's occupations, usage from house to house will vary. For instance, one house may have a homemaker and infant(s) who are in all day, while another has someone working from a home office, while a third may have two professionals who are out for 12 hours of the day. Array 1, which delivers heated water to each house, requires a suitable water meter, which can be used as a basis for billing the resident. There is an issue of bill generation and collection which will have to be overcome by the management team. The costs for bill generation and collection are not included in the calculations carried out, as they would be charged on an ongoing basis.

Arrays 2 and 3 won't have the problems of bill generation and payment for running costs, since both Arrays utilise individual heat pumps, and therefore residents will be billed directly by the electricity supplier. Since the collectors themselves require no maintenance (Rohner, 2003), there is no issue for Array 2 in relation to their shared component, the collector.

6.1.2 Reselling properties

A major barrier to the use of a shared collector and heat pump is the perceived problem of re-selling the properties. When putting the property on the market for resale, the seller will be keen to make the sale as feasible as possible. Any legal or other involvements with other properties through shared systems may make a prospective buyer more reluctant. Remember that it will be difficult enough to find a buyer who is persuaded as to the cost-effectiveness and reliability of GSHP technology as a form of space heating. Taking this into account, Array 3 (individually owned collectors and individual heat pumps) may be the best choice, from a residents' point of view.

6.1.3 Number of boreholes and available garden area

The maximum borehole depth from a financial point of view is 150m (O'Connell, personal communication), implying the necessity of drilling two boreholes per dwelling, as discussed in section 5.1.3. But the garden area required for collector spacing, (10m^2 for each borehole) suggests that the option of drilling two shallower boreholes may not be feasible.

Consider Array 3, where individual heat pumps are used. A two-storey house of 185m^2, if it was square in plan, would have a footprint of circa 9.6 x 9.6 metres, suggesting a garden width of at least 10 metres. A garden width of 10 metres would need to be 20 metres long in order to facilitate two boreholes. But the Residential Density Guidelines for Planning Authorities (Department of the Environment and Local Government, 1999b) recommends a space of 22m between opposing upper floor windows, leaving two gardens with maximum lengths of 11m. The useable garden area would be further restricted by patios/paved areas.

If deeper boreholes were required in order to reduce the number of boreholes to one, costs would increase further, since the maximum length of vertical collector on the market is 150m, implying the need to have custom collectors made.

While detached houses may have sufficient garden area for two boreholes, depending on garden width and length, it is unlikely that semi-detached and terraced housing would. Since this section of the study is aimed only at 12 detached houses of 185m^2 area, no calculations were carried out to determine the number of boreholes required for an average social house size of 80m^2 (Department of the Environment and Local Government, 1999b). But considering that a house of 185m^2 requires a borehole collector of 215m, it can be assumed that a house of 80m^2 would not require a collector longer than 150m, which is the maximum available collector length (O'Connell, personal communication). If this assumption is safe, then only one borehole would be required.

6.2 A cost comparison between GSHPs and other systems for domestic heating.

The purpose of this exercise was to compare the use of GSHPs with natural gas and oil-fired heating systems, and to determine the most cost-effective heating system over a 20 year period. Other factors which are worthy of consideration by home owners making this comparison are whether restrictions would be placed on the type of space heating component (radiators or underfloor heating) which could be used, depending on the heating system installed. Types of floor covering and their suitability for use with different space heating components are also considered.

6.2.1 Long term investment comparison

Over a 10-year period, a natural gas space heating system would be 18% cheaper than a GSHP system, while over a 20-year period, there is an 8% saving with the natural gas system. Oil fired systems are more expensive than both natural gas and GSHP systems over both periods of time, though only marginally so over the 10 year period. These findings correspond with Arsenal Research's findings, where a GSHP would have a payback period of 7 years in comparison to an oil-fired system, but could not compete with natural gas because of low gas prices (Arsenal Research, 2004).

6.2.2 Electricity generation energy mix.

Since it is impossible to predict how energy (oil, natural gas and electricity) costs will vary over the next twenty years, the above financial calculations are based on current prices. Over the next 20 year period, oil prices are expected to rise at a greater rate than electricity prices (SEI 2005), as oil becomes more scarce and renewables such as wind replace oil to make up a greater proportion of the energy mix in the generation of electricity. If calculations were carried out keeping this in mind, the 20 year cost for a GSHP system would be seen to be even more favourable compared to oil-fired systems than shown. The same argument might also be put against installing a natural gas system, since there is only a finite supply of natural gas, and gas costs will rise at some point in the future as that supply becomes more scarce.

6.2.3 Space heating components

When deciding between natural gas, oil-fired and GSHP space heating systems, the resident must keep in mind that GSHPs are suitable only for use with underfloor heating, rather than radiators. GSHPs, when working at their optimum COP, provide water for heating at approximately 40-45°C (BRE, 2001). While this temperature is too low for conventional radiators (which require 60-70°C (BRE, 2001)), it is quite suitable for underfloor heating, and is the norm for GSHP space heating on the continent (World Research Organization of New Zealand, 2002). Therefore, choosing a GSHP means in effect opting for underfloor heating.

When used over underfloor heating, flooring materials should have a thermal resistance requirement of less than 0.17m^2 K/W (1.7 Tog) (World Research Organization of New Zealand, 2002). Stone and ceramic tiles work best with underfloor heating because they are good conductors of heat (Marble Institute of America, 2001), but they are not readily accepted in Ireland as floor coverings throughout a house. This again militates against the resident choosing a GSHP system. Carpets and timber flooring are more culturally accepted in Ireland as floor coverings. Certain types of carpet and timber flooring can be used with underfloor heating (World Research Organization of New Zealand, 2002).

6.3 Reduction in CO_2 emissions

In this section, the reduction in CO_2 emissions which would have been gained if all of the social housing built in Ireland in 2004 utilised GSHPs was determined. To reach this figure, an estimate was made of the number of social houses using natural gas and the number using oil, and their CO_2 emissions calculated. A calculation was then carried out to determine the CO_2 emissions had those homes been fitted with GSHPs. The difference between the two figures gives the potential reduction in CO_2 emissions.

6.3.1 CO_2 emissions reduction

If all of the social houses constructed in Ireland in 2004 incorporated GSHP systems, there would be a saving of 4,000 tonnes of CO_2 emissions a year. Ireland is responsible for 66.6Mt of CO_2 emitted in 2003 (SEI, 2005). Ireland's Kyoto target for CO_2 emissions is 60.6Mt. (Howley, M., personal communication), implying a required reduction of 6Mt. The use of GSHP systems in all social housing built in 2004 as proposed would therefore make a 0.06% contribution to reaching our Kyoto targets.

6.3.2 Social Housing Guidelines

The Department of the Environment's *Social Housing Guidelines* (1999b, P.25), states that "in the absence of a local source of waste heat which can be economically utilised, natural gas should be the preferred fuel, where available." This statement professes an acceptance of the benefits of using environmentally-friendly energy, in the form of waste heat, for social housing. While ground source heat is not waste heat per se, it is akin to it, in that it is free heat which, if it is not used, will just dissipate into the ground.

There are many other forms of heating systems available, and it would be preferable if the Guidelines rated all the commonly available fuels. For instance, should oil be used in preference to GSHPs, where there is no natural gas and no local source of waste heat? Considering the number of houses built every year and the possible benefits, both financial and environmental, it would be progressive for the Department of the

Environment to carry out a definitive study into the commonly available heating systems and rate them accordingly.

6.3.3 The cost of utilising GSHPs for all social housing

It has been determined that the use of GSHPs in social housing would provide a reduction of 4,000 tonnes in CO_2 emissions per annum, but is it financially viable? The cost comparison table (Table 5-7) shows that while natural gas is the cheapest option for single houses, (€21,458 over 20 years, compared to €23,332 for a GSHP over the same period), GSHPs are cheaper over 20 years than heating oil (€23,332 for a GSHP compared to €31,182 for oil).

The above figures pertain to single houses, but it has also been previously determined that large capital savings are made when using a GSHP system incorporating a shared collector and shared heat pump (Array 1). Since social housing is built in groups, further study needs to be carried out to determine what savings would be made if these groups used an Array 1 GSHP system. (Data on group sizes was not available at the time of this study.) This report has already found that an Array 1 system is 36% cheaper than an Array 3 system (individual collectors and individual heat pumps), but those figures were calculated for large detached houses of 185m^2. Direct comparisons cannot be made with social housing, since area size is much smaller: recommended social housing sizes are 100m^2 for a 4 bed and 80m^2 for a 3 bed house (Department of the Environment and Local Government, 1999b).

Let us consider the Swifterbant case study of 79 houses, in the Netherlands (Section 3.8.1). In this case study an Array 3 system is used, where the 79 houses of 100m^2 share collectors and heat pumps, and heat is distributed through district heating. This house size is comparable to a recommended 4 bed social housing size in Ireland. In the Swifterbant case, the COP is lower than an average single house system (2.2 compared to 3.2). It is not possible to say definitively why the COP is so low, but it may be due to losses along the district heating system. But such a poor COP implies higher running costs, which will have an effect on the long-term cost comparison with other fuels.

6.3.4 GSHPs for all new houses

If this study was extended to consider all newly built houses in the country (60,448 houses built in Ireland in 2004 (Department of the Environment, Heritage and Local Government, 2005)), an extrapolated figure of approximately 0.7% per annum would be reached. (If 5,164 social housing give a reduction of 0.06% per annum, 60,448 houses will give a reduction of 0.7% per annum. This is based on the assumption that the average house annual heat load remains the same when all private houses are taken into account, and on the assumption that there is the same proportion of houses without access to natural gas as was used in the calculations in section 3.9.3.)

Considering the fact that 46% of finished new buildings in Switzerland in the year 2002 (6,158 out of 13,500) use a GSHP as a heating system (Arsenal Research, 2004), it is not unrealistic to envision GSHPs becoming much more widespread in Ireland in the future, although it is very unlikely that they will have any major impact on our Kyoto targets, which are set for 2010.

6.3.5 Promotion of GSHPs

In its Campaign for Take Off of Renewable Heat Pumps, (Arsenal Research, 2004) Arsenal Research recommends that the Government promotes the use of heat pumps, along with offering financial incentives and public information for buyers and training programmes for specifiers and installers. Benefits would include reduction in CO_2 emissions, job creation in the sector and reduction in residential energy demand, leading to a reduction in fuel imports. Quantifying the cost of such financial incentives is beyond the remit of this report, but Arsenal Research (2004) found that the reduction of 1 tonne CO_2 emissions would cost approximately €4.50 in their 25 year Strategy B.

6.3.6 House insulation

While Irish insulation regulations for new buildings are comparable with Austrian standards, insulation quality among older houses is among the poorest in Europe (Arsenal Research, 2004). An improvement in insulation standards through retro fitting would lead to a drop in energy demand and corresponding drop in CO_2

emissions. While the Government would have to finance the promotion of such retro-fitting, proper promotion would persuade the resident of the financial benefits of fitting improved insulation, without the Government having to offer grant aid.

6.4 A comparison and contrast of the use of GSHPs with seawater heat pumps.

The use of seawater as a source of heat for residential heat pumps compares favourably with GSHPs at the same location. While this option would not be available for all houses, it is a relevant aspect of this island nation's housing, and it would be remiss of the author not to consider it. The problem of corrosion can be surmounted by the use of titanium heat exchangers, the cost of which is outweighed by savings made by not laying a closed loop.

6.4.1 Open versus closed loops

If a housing project is located close to the sea, this means that the heat pump has an inexhaustible supply of low temperature heat. In such an instance, use of seawater should be seriously considered because of the ease of extraction of heat energy through an open loop system. The alternative is a vertical or horizontal closed loop collector set in the ground, or laid on the sea bed. Closed loop ground source collectors have to work harder to extract heat from the ground than open loop collectors, since the amount of fluid flowing and bringing new heat in a closed loop is much smaller.

In open loop systems, the return feed must be returned to the sea at a great enough distance from the inlet feed (and if possible down-current) to ensure that it has no cooling effect on the inlet feed. There is also the problem of seaweed or detritus which may clog the pump. These problems are easily overcome and are outweighed by the benefits of a greater heat extraction rate, due to freely accessible heat energy in the seawater.

6.4.2 Corrosion

The most significant problem with using seawater is the problem of corrosion of parts within the evaporator/heat exchanger element of the heat pump by the seawater. To overcome this, titanium heat exchangers are generally used, as in the Stykkisholmur district heating plant in Iceland (CADDET, online). This will lead to an increase in cost, which is outweighed by the increased heat extraction rate, and savings made by not laying a closed loop.

7 Conclusions

This study has shown that GSHPs produce fewer emissions than natural gas and oil-fired heating systems. It has also shown that GSHPs are only marginally more expensive in the long-term than natural gas systems, and are significantly cheaper than oil-fired systems. Where available, seawater is a viable heat source for use with a residential heat pump.

7.1 Optimum GSHP array for a scheme of houses

For a small scheme of privately owned houses, a system including individual collectors and individual heat pumps (Array 3) is the optimum array. While it is the most expensive option to install, there are no issues with bill generation and collection and metering of district heat. This array also proves the least troublesome should a resident wish to sell the house at some stage in the future.

The optional system incorporating a shared collector and shared heat pump and district heating (Array 1) is the optimum array for a social housing scheme, because of the lower installation cost, the existing administrative structure to handle bill generation and collection and manage maintenance.

7.2 A cost comparison between GSHPs and other fuels for domestic heating.

For the individual resident, over a 10 year period a natural gas space heating system would be 18% cheaper than a GSHP system, while over a 20 year period there is an 8% saving with the natural gas system. Oil fired systems are more expensive than both natural gas and GSHP systems over both periods of time, though only marginally so over the 10 year period. Where natural gas is not available, GSHP systems are the optimum space heating system. In areas where natural gas is available, it would be the fuel of choice.

7.3 Reduction in CO_2 emissions

The use of GSHP technology in all of the social housing built in 2004 would lead to a reduction in CO_2 emissions of 4,000 tonnes per annum. It has been illustrated in this report that the cost of GSHP technology is financially comparable to natural gas technology, over a twenty year period, for single houses of $185m^2$. Since the average social housing size is $80m^2$, and they are generally built in clusters varying in size from 2 to over 100, it is not possible to conclude without further study that the long-term cost of implementing GSHP technology in this social housing would be cheaper than using natural gas. Hence, it is not possible, without further study, to state whether the reduction in CO_2 emissions would be gained without a rise in expenditure.

7.4 A comparison and contrast of the use of GSHPs with seawater heat pumps

The technology used for seawater and ground source heat pumps is the same. The only difference arises because of the corrosiveness of seawater, which necessitates the use of a titanium heat exchanger in the evaporator of the heat pump. When specifying a heat pump system for a project with a seawater source close by, the decision is between open and closed loop, rather than between seawater and the ground. The cost reduction due to the avoidance of laying a closed loop collector, and the improved co-efficient of performance of an open loop system over a closed loop system outweigh the added cost of using a titanium heat exchanger.

RECOMMENDATIONS

From the results of this study, the author recommends that the Government implement a promotional plan for GSHPs in Ireland, as recommended by Arsenal Research in their Campaign for Take Off for Renewable Heat Pumps - Strategy for Ireland (2004). The promotional plan could include PR to educate the public, training schemes for installers and specifiers, implementation of a special electricity tariff for GSHP users, and subsidies towards initial installation costs.

Furthermore, since the Department of the Environment and Local Government is involved in such a high number of house building projects each year, it would be progressive for the Department to carry out a definitive study into the commonly available heating systems and rate them accordingly. This rating should be included in their Social Housing Planning Guidelines, and a more active approach taken towards to the use of GSHPs within social housing.

Further study could be carried out to determine the optimum arrays for different size social housing schemes, and cost comparisons made between use of GSHPs and other systems for such schemes.

It is a recommendation of this report that a cost benefit analysis be carried out into the spreading of the natural gas network to the north west of Ireland, to supply natural gas to the larger towns of Castlebar, Westport, Ballina and Sligo.

Appendix

Comparison of Energy Costs for Domestic Fuels, (SEI, April, 2005).

General basis of energy cost comparison tables

The tables apply to space heating only, i.e. they do not relate to the provision of hot water or cooking.

The annual cost of heating a dwelling depends on the fuel price, its energy content, temperature levels maintained, duration of heating, weather conditions, the level of insulation and draught sealing and the seasonal efficiency of the heating system.

For clarity and consistency, these tables compare heating costs on a common base of cost per useful unit of heat output to a room or space (cent per kilowatt hour or c/kWh). This is based on the assumption that the nature of the heat output from each fuel and heating system combination can be directly compared with the alternatives, despite the fact that there are some differences in comfort and control standards, and in maintenance requirements, between the systems.

The cost of heat

Fuels are purchased by a variety of measures - in modern units of kilograms and tonnes weight, litres and cubic metre volumes, or in older units such as Btu's and therms of heat. All these can be expressed in terms of the common unit of energy, the kilowatt-hour (kWh for short), so as to enable comparisons of delivered energy costs to be made. Approximate conversion factors for common domestic fuels are given below:

Fuel	Unit Of Supply	Conversion Factor
Electricity	1 unit =	1kWh
Heating Oil	1 litre =	10.5 kWh
LPG	1 litre =	7.0 kWh
Coal	1 tonne =	8,300 kWh
Anthracite	1 tonne =	8,800 kWh (avg.)
Coalite	1 tonne =	8,400 kWh
Briquettes	1 tonne =	5,400 kWh

Domestic fuel conversion factors.

$$\text{Delivered Energy Cost} = \frac{\text{Cost per Unit of Supply (€) x 100}}{\text{Conversion Factor}}$$

Delivered Energy Cost is not the final cost of useful heat, because the efficiency with which the heating system converts the fuel into useful heat must also be taken into account.

Cost of Useful Heat (c/kWh) = Delivered Energy Cost ÷ Efficiency

$$\text{Cost of Useful Heat (c/kWh)} = \frac{\text{Delivered Energy Cost (€)}}{\text{Efficiency}}$$

Standing Charges

Standing Charges are levied on users of certain fuels - natural gas, LPG from bulk tanks and electricity. These relatively small charges are intended to recoup the capital costs of storage tanks, service pipes and cables, meters etc. which the fuel supplier has to provide irrespective of how little fuel you may use.

Capital costs and maintenance costs incurred by the consumer in providing storage for oil and solid fuel somewhat offset the fact that no standing charges are involved in the purchase of these fuels.

Seasonal System Efficiency

The efficiency ranges quoted in the tables are estimated seasonal system efficiencies. Seasonal system efficiency is the proportion of the (chemical) energy in the fuel which is ultimately converted into useful heat energy, averaged over a heating season (September to May). It depends on many factors, including appliance design, matching of capacity to load, installation and commissioning, heat distribution and control system, and patterns of operation and maintenance.

For this reason it is necessary to quote efficiency figures in terms of assumed upper and lower limits in the case of solid fuel, oil and gas systems.

The upper efficiency figure in each range represents an estimated seasonal heating system efficiency attainable using a well-designed, well-maintained and properly operated appliance or system. However, in certain instances it may be possible to exceed these quoted figures.

The lower efficiency figure in each range represents an estimated lower limit for most circumstances, taking account of the many factors which can reduce efficiency relative to its upper level: heat loss due to fouling of heat transfer surfaces, excessive appliance draught, appliance standing losses, pipe-work losses and imperfect system response. In instances of poor system design, maintenance or operation, efficiencies may fall below the lower limits quoted.

There is a lack of fully comprehensive independent data on annual system efficiencies across the set of fuels and systems commonly available in Ireland. However, the figures quoted are adjudged to be the best available.

Achieving economy in heating costs

In most circumstances, insulation and draught sealing of the dwelling should be a higher priority than choice of heating system. In a well-insulated dwelling, unit heating costs are less important, while in a poorly insulated dwelling the savings achievable by improved insulation are usually higher than those achievable through choosing an alternative heating system.

The range of heating appliances and automatic heating controls on the market has improved considerably in recent years. In some cases therefore, higher system efficiencies than those quoted in the tables can be achieved.

A variety of measures can be taken in appliance design, installation and maintenance, and in automatic controls, in order to maximise system efficiency. These include:

General maintenance

Routine servicing of fuel burning appliances is recommended.

Solid fuel

Reduce the loss of warm air drawn from a heated space, by installing an under-floor draught duct, a throat restrictor or a closed (sealed) front unit to an open fire back boiler appliance.

Daily cleaning of solid fuel boilers, particularly when burning smoky fuels, is highly recommended.

Oil

Install the boiler indoors rather than in an outdoor boilerhouse, thereby utilising heat output from the boiler and from pipe-work.

Install a balanced flue on an indoor unit to avoid drawing warm air from within the dwelling.

Gas

Install a low thermal capacity boiler such as a combination boiler which has separate circuits for heating radiators and producing instant hot water.

Install a balanced flue unit.

Install an advanced condensing boiler.

Domestic Fuels
Comparison of Energy Costs

01 Apr, 2005

NOTES

1 Estimated average price to consumers countrywide.
2 Average price delivered in Munster area
3 Prices include delivery in Dublin area only.
4 Oil prices assuming 1000L delivered Also incl. government duty 3.174cpl on kerosene and 4.736cpl on gas oil
5 These specific fuel rates incur standing charges which must be included in all total cost calculations. The equivalent two monthly charge is:
  - **Bulk LPG**, €15.23 (Incl. tank rental and maintenance).
  - **Natural Gas, Std.Rate**, €34.10 incl. VAT
  - **Natural Gas, Reducing Rate**, €6.33
  - **General Domestic Electricity**, €8.34 (average)
  - **Night Saver - Day**, €18.82 (average)
  - **Public Service Obligation (PSO) levy** (Electricity) €1.92
6 Based on consumption over 2 months
7 Connection fee for new customers within 15 metres of gas network (ex new housing) €250 incl. VAT.
8 Payment over twelve months for a minimum of 8,750 kWhs
9 Payment over twelve months for a minimum of 16,000 kWh
10 All prices are inclusive of 13.5% VAT

Fuel		Unit of Supply	Average10 Price per Unit (€)	Gross Calorific Value (kWh/unit)	Delivered Energy Cost cent/kWh	Percentage change since 1 January, 2005
Peat[1]	***Machine Turf***	**Tonne**	na	4002.6	n/a	n/a
	Briquettes, Loose	**Tonne**	na	5362.5	n/a	n/a
	Briquettes, Baled	**Bale**	3.00	67.0	4.48	-4.2%
Brown Coal	***Nuggets***	**Tonne**	225.88	5763.5	3.92	0
Coal	***Premium Coal***[2]	**Tonne**	258.63	8267.2	3.13	+0.0%
	Standard Coal[2]	**Tonne**	236.21	7900.0	2.99	-0.0%
	Standard Anthracite[3]	**Tonne**	298.04	8735.2	3.41	-0.0%
	Grade A Anthracite[3]	**Tonne**	337.32	8960.0	3.76	+0.0%
	Ovoids (Smokeless)[3]	**Tonne**	285.43	8850.0	3.23	-0.0%
Oil[4]	***Gas Oil***	**Litre**	0.534	10.55	5.06	+18.0%
	Kerosene	**Litre**	0.544	10.18	5.35	+19.0%
L.P.G.	***Bulk L.P.G.***[5]	**Litre**	0.51	7.09	7.23	-2.9%
	Bottled Butane	**11.35 kg Cylinder**	21.45	155.7	13.78	+0.4%
	Bottled Propane	**34 kg Cylinder**	56.50	471.0	12.00	+0.2%
	Bottled Propane	**47 kg Cylinder**	78.20	651.0	12.01	+0.2%
Natural Gas[7]	***Standard Rate***[5,7]	**kWh**	0.03	1.0	2.71	0
	Reducing: 0 - 585 kWh[5,6]	**kWh**	0.07	1.0	7.14	0
	next 585 kWh	**kWh**	0.05	1.0	5.35	-0.0%
	over 1170 kWh	**kWh**	0.04	1.0	3.79	0
	Economy Rate[8]	**kWh**	0.05	1.0	4.70	0
	Supersaver Rate[9]	**kWh**	0.04	1.0	3.57	-0.0%
Electricity	***General Domestic Rate***[5]	**kWh**	0.14	1.0	13.85	0
	Night Saver - Day[6]	**kWh**	0.14	1.0	13.85	0
	Night Saver - Night	**kWh**	0.06	1.0	6.15	0

Special Notes: 0

NOTES

11 Use manufacturers recommended fuel for each appliance.
12 Efficiencies quoted are seasonal efficiencies where:
   Seasonal Efficiency = Conversion Efficiency X Utilisation Efficiency
13 Delivered energy costs quoted above are for conditions stated overleaf.
14 DFE: Decorative fuel effect appliance in an open fire setting.
15 Adequate ventilation is required for flueless gas heaters.
16 Higher efficiency indicated (50-60%) applies to these fuels.
17 Higher efficiency indicated (60-70%) applies to kerosene burned in an indoor boiler.
18 These specific fuel rates incur standing charges which must be included in all total cost calculations. The equivalent two monthly charge is:
  - Bulk LPG, €15.23 (incl. tank rental and maintenance)
  - Natural Gas, Std.Rate, €34.10 incl. VAT
  - Natural Gas, Reducing Rate, €6.33
  - General Domestic Electricity, €8.34 (average)
  - Night Saver - Day, €18.82 (average)
  - Public Service Obligation (PSO) levy (Electricity) €1.92

Domestic Fuels

Comparison of Useful Energy Costs for Space Heating

1-Apr-2005

Fuel[11]	Form	Delivered Energy Cost13 (c/kWh)	Efficiency Ratings								
			90%	80%	70%	60%	50%	40%	30%	20%	10%
Peat	*Machine Turf*	n/a									
	Briquettes, Loose	n/a									
	Briquettes, Baled	4.48	4.98	5.60	6.40	7.46	8.96	11.19	14.93	22.39	44.78
Brown Coal	*Nuggets*	3.92	4.35	4.90	5.60	6.53	7.84	9.80	13.06	19.60	39.19
Coal	*Premium Coal*	3.13	3.48	3.91	4.47	5.21	6.26	7.82	10.43	15.64	31.28
	Standard Coal	2.99	3.32	3.74	4.27	4.98	5.98	7.47	9.97	14.95	29.90
	Standard Anthracite[16]	3.41	3.79	4.26	4.87	5.69	6.82	8.53	11.37	17.06	34.12
	Grade A Anthracite[16]	3.76	4.18	4.71	5.38	6.27	7.53	9.41	12.55	18.82	37.65
	Ovoids (Smokeless)	3.23	3.58	4.03	4.61	5.38	6.45	8.06	10.75	16.13	32.25
Oil	*Gas Oil*	5.06	5.63	6.33	7.23	8.44	10.13	12.66	16.88	25.31	50.63
	Kerosene[17]	5.35	5.94	6.68	7.64	8.91	10.69	13.37	17.82	26.73	53.46
L.P.G.	*Bulk L.P.G.*[18]	7.23	8.04	9.04	10.33	12.05	14.46	18.08	24.11	36.16	72.32
	Bottled Butane	13.78	15.31	17.22	19.68	22.97	27.56	34.45	45.93	68.90	137.79
	Bottled Propane 34kg	12.00	13.33	14.99	17.14	19.99	23.99	29.99	39.99	59.98	119.96
	Bottled Propane 47kg	12.01	13.35	15.02	17.16	20.02	24.03	30.03	40.04	60.06	120.13
Natural Gas	*Standard Rate*[18]	2.71	3.01	3.39	3.88	4.52	5.43	6.78	9.04	13.57	27.13
	Reducing: 0 - 585kWh[18]	7.14	7.93	8.93	10.20	11.90	14.28	17.85	23.80	35.71	71.41
	0	5.35	5.95	6.69	7.65	8.92	10.71	13.38	17.84	26.77	53.53
	0	3.79	4.21	4.73	5.41	6.31	7.57	9.46	12.62	18.93	37.85
	Economy Rate	4.70	5.22	5.88	6.71	7.83	9.40	11.75	15.67	23.50	47.00
	Supersaver Rate	3.57	3.97	4.46	5.10	5.95	7.14	8.93	11.90	17.85	35.70
Electricity	*General Domestic Rate*[18]	13.85	15.39	17.31	19.78	23.08	27.69	34.62	46.16	69.24	138.47
	Night Saver - Day[18]	13.85	15.39	17.31	19.78	23.08	27.69	34.62	46.16	69.24	138.47
	Night Saver - Night	6.15	6.84	7.69	8.79	10.25	12.30	15.38	20.51	30.76	61.52

Heating Types & Efficiencies

Room Heater		
	Peat	45-55%
	Coal	50-60%
	Gas	65-75%
Open Fire with High Output Back Boiler		
	All	35-50%
Open Fire, Solid fuel or Gas DFE14		
	All	20-30%
Oil Fired Boiler		
	Gas Oil	55-70%
	Kerosene	60-70%
Gas Fired Boiler		
	All	65-75%
Electric Fire		
	All	100%
Flueless Gas/Storage Heater		
	All	90%

NDP NATIONAL DEVELOPMENT PLAN

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