A TECHNICAL AND ECONOMIC FEASIBILITY STUDY FOR THE INTEGRATION OF GSHP TECHNOLOGY IN THE CHRISTCHURCH REBUILD

This report is submitted in partial fulfillment of the requirements for the degree in Master of Engineering Management (MEM) at the University of Canterbury, New Zealand.

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February 2014

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DOCUMENT CONTROL

Version	Prepared By	Recipients	Date Distributed	Change Description
1.0	Sam Bustard	Dale Bustard	24/01/2014	Editing and formatting.
2.0	Sam Bustard	Wayne Tobeck, Karl Maddaford	27/01/2014	Nil.
2.0	Sam Bustard	Piet Beukman	14/02/2014	Grammar. Additions/change to Section 8.0. Indicative costs added to Section 9.0.

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ACKNOWLEDGEMENTS

The author wishes to take this opportunity to acknowledge the following people:

Mr. Wayne Tobeck, (Southrim Group) who had the vision to provide the opportunity for this project in addition to continued support throughout its duration.

Associate Professor C. Piet Beukman, (Director of MEM Programme) who provided guidance and supervision from the University’s perspective.

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EXECUTIVE SUMMARY

Introduction

Following the recent Christchurch earthquakes a significant amount of land now requires site specific geotechnical investigation and foundation engineering design. This requirement creates opportunities to implement new and unique foundation designs previously not considered due to high cost compared with accepted methods.

One such foundation design proposes that an Injection Micro-Piling technique could be used to install deep piles for building foundations in both new buildings and as retrofits for buildings requiring repair. This technique could also incorporate components for the ground loop of Ground Source Heat Pump (GSHP) systems, creating geothermal piles, enabling an energy efficient method for heating buildings.

The aim of this study is to determine whether a market exists for Southrim Group (SRG) to design and install these geothermal piles in the Christchurch rebuild and if it will be legally, technically and economically feasible to pursue. A literature search has also been conducted to determine the current academic perception of GSHP system feasibility.

Three test projects were developed to test the technical and economic feasibility of GSHP systems for different applications. The Test Projects propose different building sizes and configurations requiring different heating requirements based on the following assumptions:

1. Required HVAC output capacity based on a rate of 100 W/m^2 of floor area.
2. Annual heat energy use based on a rate of 40 kWh/m^2 of floor area.

Literature Research

Despite trends indicating increased investment in energy efficient technologies primarily driven by operating cost savings, the mild NZ heating season and the reluctance of consumers to pay premiums for energy efficiency measures suggest GSHP's are unlikely to be economically attractive to residential consumers.

Large commercial installations allowing extended pay back periods may see economics improve, though ASHP's are still likely to be a more economic option.

However, with SRG's proposed geothermal pile product and the uniqueness of the market in the Christchurch rebuild, this study hopes to challenge this consensus.

Market Opportunities

The Christchurch rebuild significantly increases the size of the HVAC market and introduces new drivers in the identified segments. Opportunities for GSHP's in Christchurch include both installations in new residential and commercial buildings as well as retrofits for use with existing central heating systems such as radiators or under floor heating.

The relatively warm ground temperature of 11.6^{o} experienced in Christchurch suits efficient GSHP operation as a significant temperature gradient will exist in winter.

Changing attitudes towards sustainability and emissions are seeing traditionally favoured heating systems such as log burners become less popular. GSHP's with superior efficiency and no emissions could become a socially acceptable and desirable product for green buildings.

Legal Barriers

SRG should establish a commercial agreement with Ischebeck for IP use of their geothermal pile in NZ. A good relationship with Ischebeck *must* be maintained for the successful continuation of SRG's other business activities.

No other major legal barriers were identified however potential environmental impacts must be managed to improve Resource Consent application strength and reduce potential opposition from local Iwi.

Technical Barriers

The major technical barrier identified for SRG geothermal piles is the maximum depth limitation. Currently, no piles beyond a depth of 60m have been installed, so performance beyond this depth is unconfirmed.

When considering the constrained area of building foundations and the requirement that piles maintain a separation of at least 5m, it is considered that *geothermal piles will <u>not</u> be technically feasible for buildings greater than 2 stories high* due to requiring pile depths beyond the 60m feasible depth limit.

Economic Analysis

From the economic analysis conducted in this study using the Test Projects described in Section 1.2, it is suggested that *the NPV of Costs of GSHP installation in the current Christchurch climate is significantly more expensive than the readily available heating systems of ASHP and Log Burners over a 25 year analysis period.*

As a result, NEB's such as those identified in Section 7.5 will need to factor greatly in consumers' decision making process for potential clients to consider GSHP technology for use in their new building.

Alternatively, in certain locations of NZ, winters may see temperatures fall below the suggested threshold of -9^{o}C on enough occasions to deem GSHP systems economically viable in comparison to ASHP systems.

Conclusions

- Research has indicated that there is a large market for new HVAC systems in Christchurch due to the rebuild.
- SRG's proposed GSHP system using Ischebeck geothermal piles has been found to be legally, environmentally and technically feasible in Christchurch, **however GSHP's are not considered economically feasible.**
- The ASHP is currently considered to be the most attractive heating method in Christchurch against the assessed criteria, attributed to their significantly lower capital costs, whilst their NEBs score the same as GSHP's.
- GSHP's will likely become more economically attractive than ASHP's if operating in air temperatures below -9^{o}C.

Recommendations

As a result of this completed study, <u>*at this point and time, Southrim Group should not continue with proposed plans to enter the GSHP design and installation business in Christchurch due to the limited economic attractiveness compared with ASHP's.*</u>

The following additional recommendations would improve the attractiveness of GHSPs in NZ and would therefore likely increase their uptake in the market if SRG decide to continue with further developments.

Southrim Group should, in order of descending importance:

1. Establish a commercial agreement with Ischebeck to use the Geothermal Pile technology in NZ.
2. Establish a supply agreement with a GSHP manufacturer.
3. Embark on a marketing campaign to educate the public on SRG’s new capability and the benefits of GSHP systems.
4. Obtain specialist building energy modeling and/or GSHP design software. This is expected to cost $US525-$US4300.
5. Design and install GSHP systems to an accepted international standard such as MCS3005.
6. Include a corrosion allowance of 2mm when sizing the steel for geothermal pile applications and use a specifically designed geothermal HDPE for all other piping requirements.
7. Use inhibited propylene glycol for the anti-freeze fluid and a geothermal grout to the composition of Mix 111. This is expected to add a cost of $0.5/m of geothermal pile installed.
8. Install geothermal piles a minimum of 5m apart and at a depth no greater than 60m.
9. Independently verify the performance of any installed systems against design values.

CONTENTS

GLOSSARY OF TERMS

Antifreeze	A substance added to a solvent to lower its freezing point.
ASHP	Air Source Heat Pump.
COP	Co-Efficient of Performance. The measure of efficiency for heat pumps operating in heating mode.
EECA	Energy Efficiency and Conservation Authority.
EEI	Energy Efficiency Indicator.
HFC	Hydro Fluorocarbon. Refrigerants that are chlorine free and hence have little or no ozone depletion potential.
HVAC	Heating, Ventilation and Cooling.
GNS	GNS Science - A New Zealand Crown Research Institute focusing on geology, geophysics, and nuclear science.
GSHP	Ground Source Heat Pump. Can also be known as a Geothermal Heat Pump (GHP).
Ground Loop	The heat exchanger elements of a GSHP that are buried in the ground.
MBIE	Ministry of Business, Innovation and Employment.
Montreal Protocol	An international agreement designed to protect against ozone depletion by banning and phasing out substances known to have significant ozone depletion properties.
NEB	Non-Economic Benefits

NPV	Net Present Value.
Refrigerant	The liquid which undergoes a phase change during the vapour-compression cycle.
SRG	Southrim Group. The sponsor of this project.
TC3	Technical Category 3 (TC3). Land where moderate to significant damage from liquefaction is possible in future large earthquakes. Site-specific geotechnical investigation and specific engineering foundation design is required.
Vapour-Compression Cycle	The thermodynamic cycle which is employed in heat pumps to achieve heat exchange. This is explained in more detail in Appendix A.
WHO	World Health Organisation.

1.0 INTRODUCTION

1.1 Origin of Study

Following the recent Christchurch earthquakes a significant amount of land has become too unstable to support traditional building foundations. As a result, many new and to-be-repaired buildings now require site specific geotechnical investigation and engineering foundation design. This requirement creates an opportunity to implement new and unique foundation designs previously unconsidered due to high costs compared to traditional foundation designs.

One such foundation design proposes that an Injection Micro-Piling technique could be used to install deep piles for building foundations in both new buildings and as retrofits for buildings requiring foundation repair. This technique could also incorporate components for the ground loop of GSHP systems, creating geothermal piles, enabling an energy efficient method for heating buildings.

Current literature (1), (2) supports the conclusion that GSHP's are not economically viable in NZ with respect to the readily available heating system of ASHP's. However, given the emergence of a large HVAC market as a result of the Christchurch rebuild and the commercial and technical capabilities of SRG, this conclusion is challenged.

The purpose of this project is to confirm or deny literature conclusions for the identified opportunity by completing a feasibility study on the merits of this proposed venture. The study method that was employed involved analysing 4 main areas of the project in order to make an informed decision about its future viability. The areas of study are Market, Legal, Technical and Economic.

1.2 Difficulties and Assumptions

Traditional HVAC design requires only basic energy modeling to calculate the buildings expected peak heating load. HVAC units are then sized for this load.

However, for GSHP systems, the available energy in the ground is ***finite,*** meaning there is the potential to lower the temperature of the ground, reducing the performance of a GHSP system. To design GSHP systems with long term performance therefore, not only do peak heating loads need to be known, but annual energy consumption requirements as well.

As this study does not pertain to one particular GSHP installation, a number of assumptions have had to be made to generalize the market.

Taking a similar approach to a previous GNS study (3), a number of 'Test Projects' have been developed for this study in order to cover a range of potential GSHP installations and operating conditions. The details of the Test Projects are given in Table 1 below, with a list of the assumptions made following.

Table 1: Test Project details.

Test Project	**Sector**	**Floor Area (m^2)**	**Building Footprint Area (m^2)**	**Building Height (floors)**	**Required Heating Output (kW)**	**Annual Heat Energy use (kWh)**
1	Residential	200	200	1	20	8000
2	Commercial	800	200	4	80	32000
3	Commercial	800	800	1	80	32000

The following assumptions were made when developing the Test Projects:

1. The entire building floor area will be heated.
2. Required HVAC output capacity based on a rate of 100 W/m^2 of floor area.
3. Annual heat energy use based on a rate of 40 kWh/m^2 of floor area.

2.0 BACKGROUND

2.1 Ground Source Heat Pump Principles

In order to heat a home using a heat pump, some means is necessary to raise the temperature of the heat naturally residing in the surroundings to a level sufficient for it to be delivered to the home as useful heat (4). A heat pump achieves this via the Vapour-Compression (VC) cycle, seen in more detail in Appendix A.

Ground Source Heat Pumps (GSHP) utilise the VC cycle to provide heating for buildings by extracting low grade heat from beneath the ground and raising it to deliver to the building as useful heat.

Closed Loop GSHP systems consist of 3 main elements:

1. A ground heat exchanger which collects heat from the ground (ground loop).
2. A heat pump which raises the heat collected from the ground to a useful temperature for use within a building heating system.
3. A heat distribution system within the building by which means the heat produced from the heat pump is emitted through the building.

A schematic of a closed loop GSHP system can be seen in Figure 1 below.

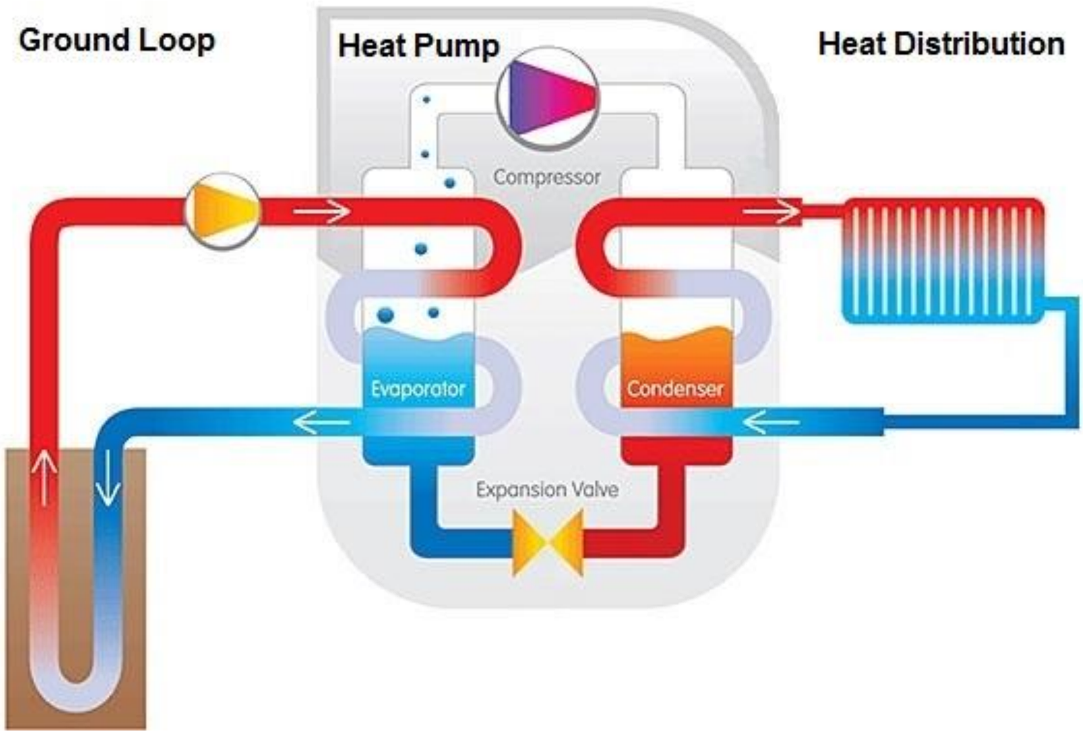

Figure 1: GSHP Schematic showing Ground Loop, Heat Pump, and Heat Distribution System. Image source: (5)

2.2 Southrim Group Capabilities

SRG have a strategic alliance with the German company Ischebeck. Ischebeck have a new product termed the 'TITAN 73/53 Geothermal Energy Pile', a schematic of which can be seen in Figure 2 below.

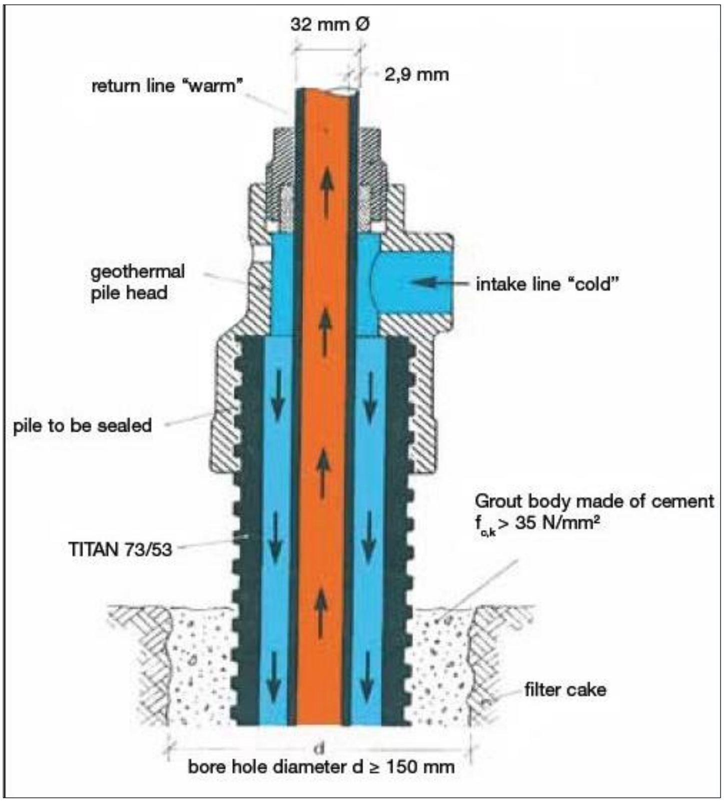

Figure 2: Ischebeck's Geothermal Energy Pile. Source: (6)

The major features of the geothermal pile are the:

1. Grout Body – The volume of cement which forms the bond between the pile and the ground.
2. Steel Tendon – The load bearing member which is a threaded hollow steel bar serving as a sacrificial drilling rod and reinforcing bar. This also acts as the outer pipe containing the ground loop working fluid.

This geothermal pile creates a coaxial, vertical closed loop system for geothermal energy applications such as the ground loop for GSHP systems. It is through the installation of this pile that SRG propose to design and install GSHP systems.

However, this product is still in its infancy, with only 4 piles installed to date in Germany. Therefore is yet to be proven technically suitable for this application in NZ. Suggested modifications to this pile for use in NZ are made in Section 6.2 of this report.

3.0 LITERATURE RESEARCH

Literature research has been conducted to gain a better understanding of trends in building energy efficient technology adoption as well as current opinions on the economics of alternative HVAC systems for both residential and commercial applications. Information was desired that quantified consumer behaviours based on Non-Economic Benefits of HVAC systems; however this has not been able to be identified. Relevant to this however is research regarding house purchase decisions and perceived resale value as a result of home energy efficient measures.

The literature review can be found in Appendix L, while key points are summarised in this section.

3.1 Trends in Building Energy Efficient Technology

- Over 60% of global organisations are investing in energy efficiency measures and over a third report investing in renewable energy projects.
- Globally, over half of organisations are planning to increase such investments.
- HVAC improvements are the 2nd most common energy efficiency improvement action.
- 34% of NZ home owners have considered changing the way they heat their home, the majority considering installing heat pumps.

3.2 Influences on Energy Efficiency Decisions

- Globally, *energy cost savings* remains the top motivator of energy efficiency decisions.
- NZ home owners, however, rank energy efficiency only 6th when considering purchasing new appliances. Non-Economic Benefits such as ‘Reliability’ and ‘Ease of Use’ and were rated higher.

3.3 Consumers Value of Energy Efficient Buildings

- Consumers are only willing to pay up to 10% premium for a house with greater energy efficiency.
- Home owners have found to be willing to pay an average of $US 7,095 in the up-front cost of a home if it saved them $US 1,000 annually.
- Research suggests features associated with greater visible quality (e.g. countertop or flooring upgrades) are perceived by most home buyers to

secure a greater resale value than features promising greater energy efficiency.

3.4 NZ Heating Requirements

- NZ experiences milder winters than experienced in Europe and North America where GSHP's are most popular. This sees considerably less heat energy used by average NZ households in comparison and will influence the life cycle costs of HVAC systems, limiting the comparisons able to be drawn internationally.

3.5 Economics of GSHP Systems

- NZ research suggests payback times of about 10 years are typically achieved for residential GSHP systems.
- Multiple sources suggest that while GSHP's offer lower operating costs, their significantly higher capital costs deem ASHP's more economically attractive in NZ.

3.6 Barriers to Energy Efficient Technology Adoption

- Awareness – Over half of NZ respondents to recent research had not heard or read about GSHP technology
- Cost premium – A quarter of global organisations cited lack of funding as their top barrier to pursuing energy efficient projects

3.7 Conclusions

Given the low heating requirements expected in NZ and the reluctance of consumers to pay premiums for energy efficiency measures with long payback periods, current literature suggests GSHP's are unlikely to be economically attractive to residential consumers. Large commercial installations allowing extended pay back periods may see economics improve, though ASHP's are still likely to be a more economic option.

However, with SRG's proposed geothermal pile product and the uniqueness of the market in the Christchurch rebuild, this conclusion is challenged.

In support of this, the purpose of this study is to either confirm or deny this conclusion. The following sections detail the completion of this action by analysing the Market, Legal, Technical and Economic feasibility areas.

4.0 MARKET OPPORTUNITIES

4.1 Market Segments & Drivers

Two sectors exist in the HVAC market, giving rise to four identified market segments as seen in Table 2 below. Specific market drivers have been identified that may increase the market potential in these segments.

Table 2: Market Segments and drivers which may influence consumer behaviour

Sector	Segment	Market Drivers
Residential	New Build	• Over 11,000 homes destroyed (7) • Christchurch clean Air Zones (8)
	Retrofit	• Over 10,500 homes zoned TC3.
Commercial	New Build	• Over 1230 commercial buildings destroyed (7) • $1.8 million fund for renewable and advanced energy efficiency measures (9) • EECA Business Commercial Building Design Advice programme (10)
	Retrofit	• CCC and EECA free energy efficient consultancy advice (11)

Additional drivers that act across the entire HVAC market in Christchurch are explored further in the following sections.

4.2 Rebuild Trends

Christchurch new dwelling consents averaged 167 per month in 2013, demonstrating the number of HVAC installations that will be occurring in Christchurch (12). Trends in earthquake related building consents issued can be seen in Figure 3 below.

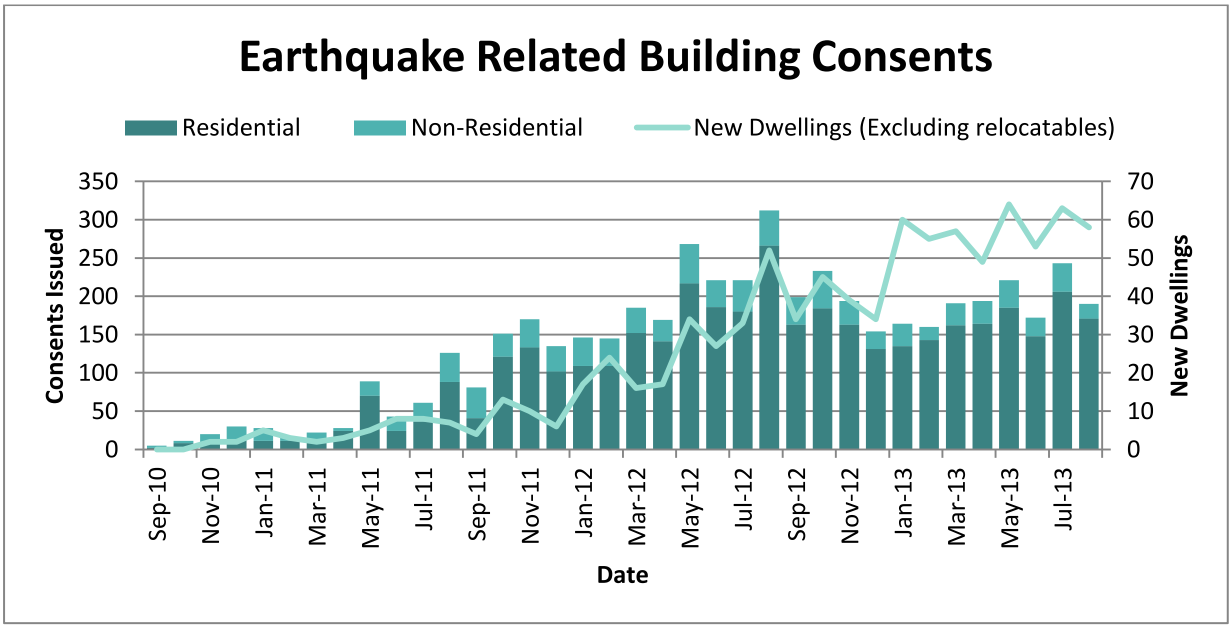

Figure 3: Christchurch rebuild trends. Source: (12)

4.3 Climate

The Christchurch mean daily *minimum* temperature of 7.3°C (13) suggests significant heating is required to achieve WHO recommendations of 18°C in occupied rooms of a building.

With an average ground temperature below 8m in Christchurch estimated at 11.6°C, the operation of GSHP is likely to reach the higher end of efficiency as a significant temperature gradient is likely to exist between ground and air temperature during winter, as seen in Figure 4 below.

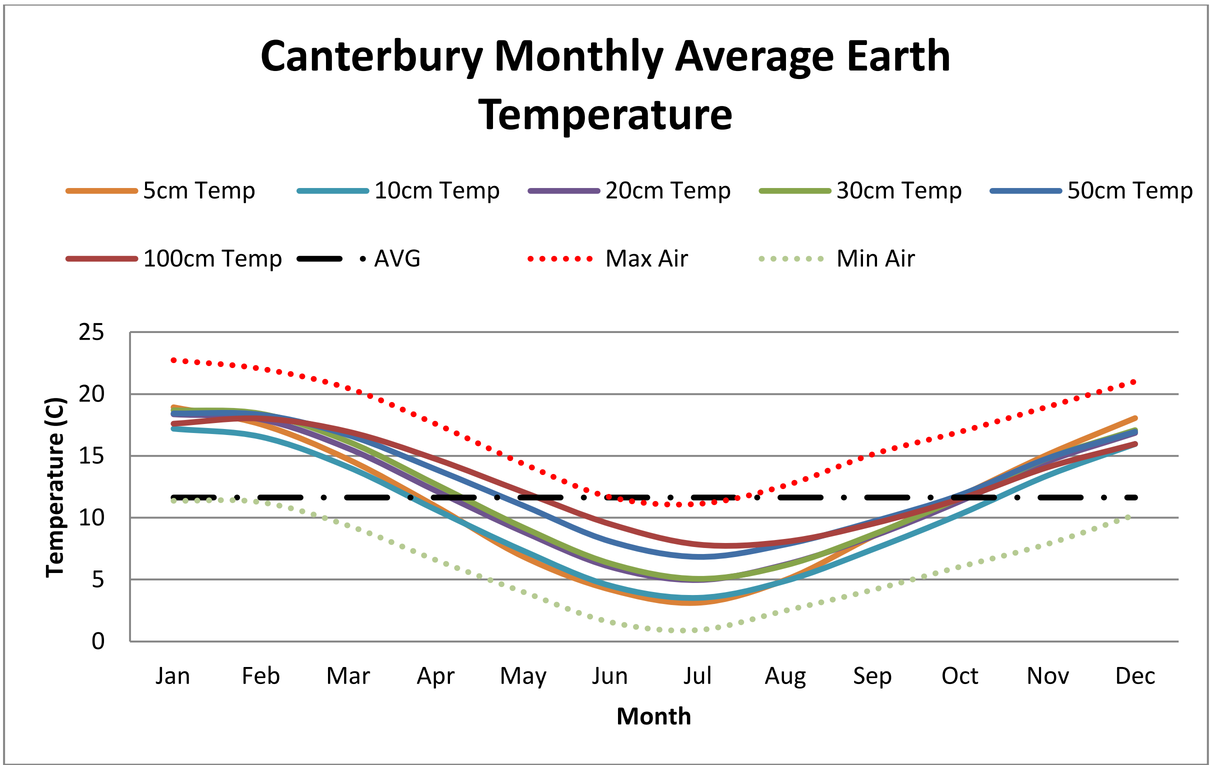

Figure 4: Christchurch ground temperature gradient. Data Source: (13)

4.4 Competing Technologies

Currently the favoured fuel for heating purposes in the residential sector is wood, as seen in Figure 5. However, current global focus on emission reductions and Christchurch Clean Air Zones have seen wood burners fall in popularity, with the majority of home owners considering changing heating methods preferring heat pumps.

Electricity, natural gas and coal are the major fuel sources for the commercial sector, however, given the trends of the commodity prices of natural gas and coal (as seen in Appendix B) and recent international trends towards 'green' buildings and renewable energy, there exist drivers for change in this sector also.

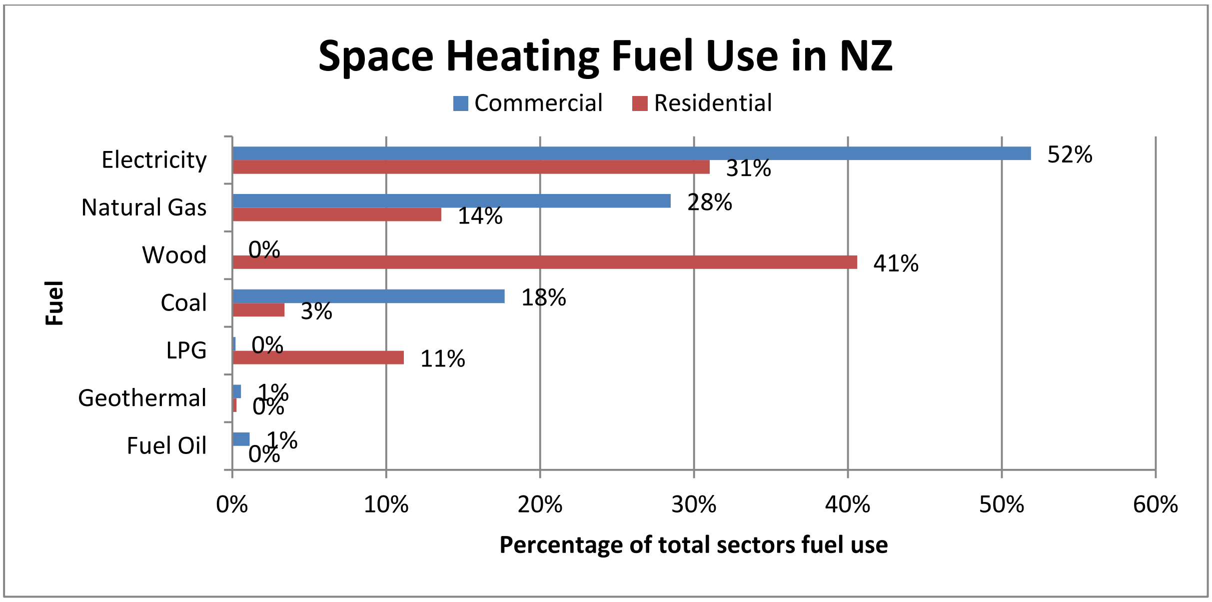

Figure 5: Current energy sources for common HVAC systems. Source: (14)

4.5 Market Conclusions

The Christchurch rebuild significantly increases the size of the HVAC market and introduces new drivers in the identified segments. Opportunities for GSHP's in Christchurch include both installations in new residential and commercial buildings as well as retrofits for use with existing central heating systems.

The relatively warm ground temperature of 11.6^{o}C expected in Christchurch suits efficient GSHP operation, as a significant temperature gradient will exist in winter.

Changing attitudes towards sustainability and emissions are seeing traditionally favoured heating systems such as log burners become less popular. GSHP's with superior efficiency and no emissions could become a socially acceptable and desirable product.

5.0 LEGAL BARRIERS

5.1 Patents

Ischebeck currently hold a patent for their 'Geothermal Energy Pile' filed with the European Patent Office in 2009, patent number: EP 2060860 A2. This provides protection for this product in the majority of Europe; however no patents have been filed in other countries.

Southrim would need to establish a commercial agreement with Ischebeck in regards to the geothermal pile intellectual property rights in NZ.

5.2 Resource & Building Consent

The installation and operation of GSHP's are regulated in NZ by the Resource Management Act (RMA) 1991 and the Building Act 2004. (3)

Table 3 lists some common GSHP installation activities that may trigger the need for resource consent.

Table 3: Potentially regulated activities during GSHP installation.

System Type	Configuration	Regulated Activities	TA Potentially Regulated Activities
Closed loop	Horizontal	Earthworks	-Maximum volume of earthworks -Compliance with district plan performance standards for associated structures
Closed loop	Vertical	Bore drilling	-Compliance with district plan performance standards for associated structures

Building Consent will be required as the proposed SRG product of a Geothermal Pile is coupled with a building's foundation.

5.3 Environmental Considerations

5.3.1 Refrigerant

The main environmental concern of a heat pump unit is the refrigerant. The Montreal Protocol signed in 1987 sees NZ agree to phase out the common GSHP refrigerant R22 by 2030. Many GSHP manufacturers have already begun changing to HFCs, which pose no harm to the ozone layer, and this should be confirmed as the case for any sourced GSHP units for this project.

5.3.2 Grout

Geothermal heat pumps with vertical boreholes could result in groundwater contaminated by surface water infiltration, inter-aquifer flow, or antifreeze leakage if the borehole grout fails. To improve the environmental attributes of SRGs GSHP product, the grout used should be tested to prove hydraulic conductivity of less than 10^{-7} cm/s (15).

5.3.3 Antifreeze

Research suggests that inhibited propylene glycol should be used for GSHP applications that require antifreeze addition, based on its low health, fire, and environmental risks (16).

5.4 Cultural Considerations

5.4.1 Iwi Management Plan (IMP)

The IMP is a planning document by the six groups that represent the tribes who hold rights over lands and waters within the Canterbury region (17). This document has 6 sections that may be of significant importance to GSHP's in this region which are detailed in Table 4 below.

Table 4: Implications of the IMP

Subject	Section	Purpose
Climate Change	R3.4 (b)	To support the reduction of emissions as a response to climate change.
Unnatural Mixing of Water	WM10.3	The unnatural mixing of water is likely to be culturally unacceptable where it involves: (i) direct mixing between glacial, rain or spring fed waters, (iv) direct mixing of water from different aquifers.
Earthworks	P11.1	To assess proposals for earthworks with particular regard to: (b) Potential effects on waterways and wetlands (e) Proposed erosion and sediment control measures; and (f) Rehabilitation and remediation plans following earthworks
Energy	P17.4	To require that local authorities develop and implement effective policies requiring the use of renewable energy and energy saving measures in residential, commercial, industrial and other developments.

As evident from the table, the IMP presents both risk and opportunity for the uptake of GSHP technology in the Canterbury region.

5.4.2 Treaty of Waitangi

Claims have been brought under the Treaty of Waitangi regarding geothermal resources in the past. However, these have yet to be resolved (3). As such, the approach by the Crown and Iwi to resolve these claims is yet to be determined. The outcome may have an effect on the proposed project and development should be noted by SRG.

5.5 Legal Conclusions

- A commercial agreement will need to be reached with Ischebeck for IP use in NZ. A good relationship with Ischebeck *must* be maintained for the successful continuation of SRG's other business activities.
- Resource consents are likely to be required; however vertical systems such as geothermal piles breach fewer regulated activities than horizontal arrangements. Resource consent application should occur as soon as possible to reduce chances of project delay due to consent issues.
- Building Consents will also be required. With new builds, the geothermal pile consent should be included in the overall building consent to remove any stand alone costs.
- To reduce potential environmental impacts it is suggested that the anti-freeze used should be an inhibited propylene glycol and GSHP units used should use the Montreal Protocol compliant R22 refrigerant. Additionally, grout should be tested and confirmed to have hydraulic conductivity below 10^{-7} cm/s.
- Culturally, water use is a highly contentious issue. GSHP's do not specifically use water, but they can have an interaction with aquifers. Again, environmental impacts should be minimised, while it is also suggested that local Iwi should be consulted during the planning phase of any major GSHP projects to gain permission and advice in regards to both the IMP and the Treaty of Waitangi.

6.0 TECHNICAL BARRIERS

6.1 Introduction

As detailed in Section 2.2, SRG has a commercial relationship with Ischebeck which could give SRG the capability to install Geothermal Piles for GSHP systems in NZ. However, this product is yet to be proven technically suitable in NZ.

Section 6.2 of this report identifies barriers that could prevent the successful application of the Ischebeck Geothermal Piles in NZ and makes recommendations to address these, while Section 6.3 uses the Test Projects described in Section 1.2 to determine in what situations geothermal piles for GSHP systems may be technically feasible.

6.2 Ischebeck Geothermal Piles in NZ

6.2.1 Pile Depth

Currently, the greatest pile depth achieved using SRGs current Injection Micro-piling technique is 60m.Therefore, it is suggested any proposed geothermal piles requiring depths greater than 60m should be deemed technically unfeasible.

6.2.2. Pile Durability

As identified in Section 5.2, geothermal piles will be subject to Building Code requirements. Clause B2 of the NZ Building Code requires a minimum life of 50 yrs for elements that provide structural stability, such as the proposed geothermal pile.

Research suggests a corrosion rate of approximately 0.04mpy of the steel tendon when used with inhibited propylene glycol antifreeze, as suggested in Section 5.3.3. Therefore a 50 year life corrosion allowance of 2mm should be included when sizing the steel tendon during geothermal pile design.

6.2.3 Grout Performance

As mentioned in the Section 5.3.2, vertical boreholes may pose environmental threats if the grout fails. Studies have shown that superior environmental and thermal performance of grout can be achieved using a composition known as Mix 111 which is detailed in Table 5 below. (15)

Table 5: Ingredients to make 1m^3 of Mix 111 grout

Constituent	Cement	Water	Sand	Bentonite	Super-plasticizer
Amount	587.7 kg	323.3 kg	1251.8 kg	6.5 kg	8.8 litres

6.2.4 Thermal Interference

To minimise thermal interference and likelihood of ground temperature reduction, research suggests that vertical boreholes be placed a minimum of 5m apart. (18)

6.3 GSHP Application

The UK Department of Energy and Climate Change recently developed the Microgeneration Installation Standard MIS3005, detailing a process for designing GSHP systems.

It is suggested that SRG adopt this standard to evaluate and design potential GSHP projects. The working sheet from this standard can be found in Appendix C, while a simple flow chart has been developed to assist with the completion of this process, shown in Appendix D.

From applying the developed flow chart process to the three Test Projects as described in Section 1.2, it can be concluded that SRGs proposed geothermal piles are only likely to be technically feasible for single or 2 story buildings. *It is considered unlikely that SRG geothermal piles will be technically feasible for buildings greater than two stories high*, due to required pile depths being greater than the 60m feasible limit. The results from the analysis can be seen in Table 6 below.

Table 6: Results of Test Project technical feasibility analysis

Test Project	**1**	**2**	**3**
Floor Area (m^2)	200	800	800
Building Footprint Area (m^2)	200	200	800
Heat Pump Capacity (kW)	20	80	80
No. of Piles	15	15	45
Required depth of piles (m)	26.2	105	35
Heat pump manufacturer required flow rate (l/min)	91	364	364
Pumping energy consumption (kW)	0.34	1.61	1.84
Feasible (Yes/No)	Yes	No	Yes
Notes		Exceeds maximum feasible pile depth of 60m	

Sensitivity analysis was conducted to evaluate the effect of changes to the assumptions listed in Section 1.2 on Test Project feasibility, and can be seen in

Appendix E. This analysis suggests that Test Project 2 would remain unfeasible, despite significant changes to the assumed variables, while Test Projects 1 & 3 would remain feasible.

6.4 Technical Conclusions

- Projects requiring geothermal piles beyond a depth of 60m should be deemed not feasible due to the limitations of the injection micro-piling technology.
- A corrosion allowance of at least 2mm wall thickness should be used when designing the steel tendon for geothermal piles.
- A thermally enhanced grout similar in composition to that of Mix 111 described in Section 6.2.3 should be used.
- Design of the ground loop should follow accepted standards such as MIS3005 described in Section 6.3.
- Geothermal piles should be placed a minimum of 5m apart.

When considering the constrained area of a building's foundation and the requirement that piles maintain a separation of at least 5m and be a depth no greater than 60m, it is considered unlikely that geothermal piles will be technically feasible for buildings greater than 2 stories high.

7.0 ECONOMIC ANALYSIS

7.1 Introduction

A Net Present Value (NPV) of costs approach was chosen for comparing alternative building heating systems for the Test Projects described in Section 1.2.

The NPV analysis uses a discount rate of 1.3%, the current average annual inflation rate in NZ (19). GSHP systems were compared with 7 traditional heating methods found both residentially and commercially, outlined in Table 7 below.

Table 7: Heating Systems for Economic Analysis

Fuel Source	Heating System
Electricity	ASHP, GSHP, Oil Column
Gas	Flued Burner, Central Boiler
Wood	Log Burner, Pellet Fire
Diesel	Central Boiler

Non-Economic Benefits (NEBs) were also quantified for the alternative systems which are detailed in Section 7.5.

7.2 Costs

7.2.1 Operating

The operating costs of the HVAC systems were calculated using 2011 research (20) adjusted for 2013 fuel prices. The results can be seen in Figure 6 below.

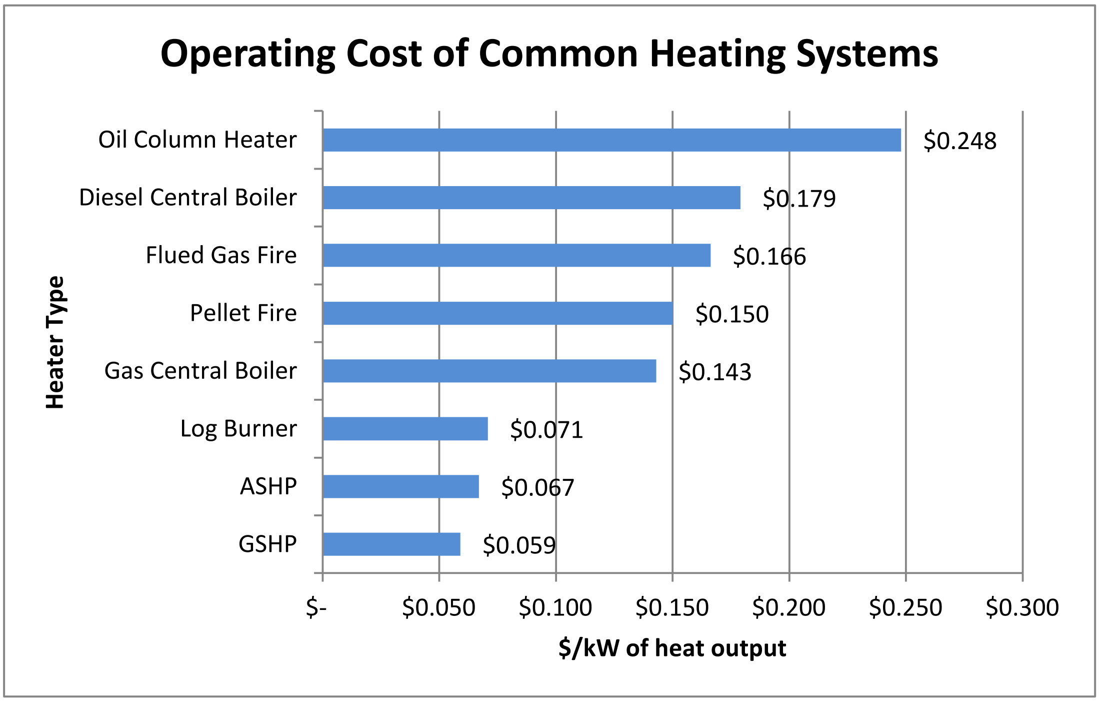

Figure 6: Operating cost of common heating systems. Source: (20)

Fuel price inflation was also been considered in this analysis, and was applied annually in the NPV calculations. The calculated annual fuel price inflation rates are shown in Table 8 below calculated from MBIE and Statistics NZ data (21) (22) (23).

Table 8: Annual inflation of Fuel Prices (%)

Fuel	Electricity	Diesel	Gas	Wood	Pellets
Annual Inflation (%)	6.34	8.87	10.73	3.64	5.96

7.2.2 Capital

Capital costs of various HVAC systems were calculated from NZ retail prices. A cost per heat output capacity ($/kW) rate was calculated for each system as seen in Table 9. Raw data and the source of information can be seen in Appendix J.

Table 9: Capital costs of heating Systems ($/kW heat output)

System	ASHP	Oil Column Heater	Flued Gas burner	Gas Central Boiler	Diesel Central Boiler	Log Burner	Pellet Fire	GSHP
Unit Cost ($/kW)	382	93	662	141	169	138	625	825

7.2.3 Installation

GSHP's installation costs include ground loop installation in addition to the unit installation. GSHP additional installation costs that will be faced by SRG have been estimated from typical values and detailed in Table 10 below.

Table 10: GSHP Ground Loop Installation Costs

Item	HDPE Pipe	Propylene Glycol	Ground water pump	Geothermal Grout	Hydronic piping
Cost	$1.78 /m (24)	$1500 / ton (25)	$950 ea (26)	Bentonite $0.3 /kg (25) Super plasticizer $1.2 /l (27)	$416 /kW (28)

Quoted installation costs for traditional HVAC systems standardised as a cost per heat output ($/kW) rate can be seen in Table 11 below.

Table 11: Alternative heating system installation costs

Method	ASHP	Oil Column Heater	Flued Gas Burner	Gas Central Boiler	Diesel Central Boiler	Log Burner	Pellet Fire
Installation Cost ($/kW)	136 (29)	0	190 (29)	912 (30)	1105 (30)	99 (31)	175 (32)

7.2.4 Summary

A summary of costs for each heating system can be found in Table 12 below. This data forms the inputs for the NPV of Cost analysis, and is also forms the base case of the sensitivity analysis found in Section 7.4.

Table 12: Summary of costs of considered heating systems

Heating System	ASHP	Oil Column Heater	Flued Gas Burner	Gas Central Boiler	Diesel Central Boiler	Log Burner	Pellet Fire	GSHP
Unit Cost ($/kW)	382	93	662	141	169	138	625	825
Installation Cost ($/kW)	129	0	190	912	1105	99	175	578
Operating Cost ($/kWh)	0.067	0.248	0.166	0.143	0.179	0.071	0.150	0.059
Annual Op. Cost Inflation (%)	6.34	6.34	10.73	10.73	8.87	3.64	5.96	6.34

7.3 NPV Analysis

Test Project 1 NPV analysis used a 10 year period, reflecting residential consumer's short expected payback period (33) while Test Project 2 & 3 used the expected GSHP unit life of 25 years (34) as the analysis period.

Figures 7 & 8 display graphically the results of the cost benefit analysis for Test Projects 1 and 2 & 3 respectively, while Tables 14 & 15 in Appendix F show the raw data results. GSHP's results are shown in bold.

Test Project 1, based on a typical residential installation, GSHP systems were only found to be a cost effective alternative to gas and diesel central boilers and flued gas burners. In larger installations with extended payback periods, as demonstrated by Test Projects 2 & 3, GSHP's were found to be a cost effective alternative to all systems except ASHP's and Wood Burners.

This supports the findings of the literature research, where both Goetzler et al. (2009) and Suggate (2011) suggest that while GSHP's have lower operating costs, the significantly higher capital costs deem ASHP's more economically attractive.

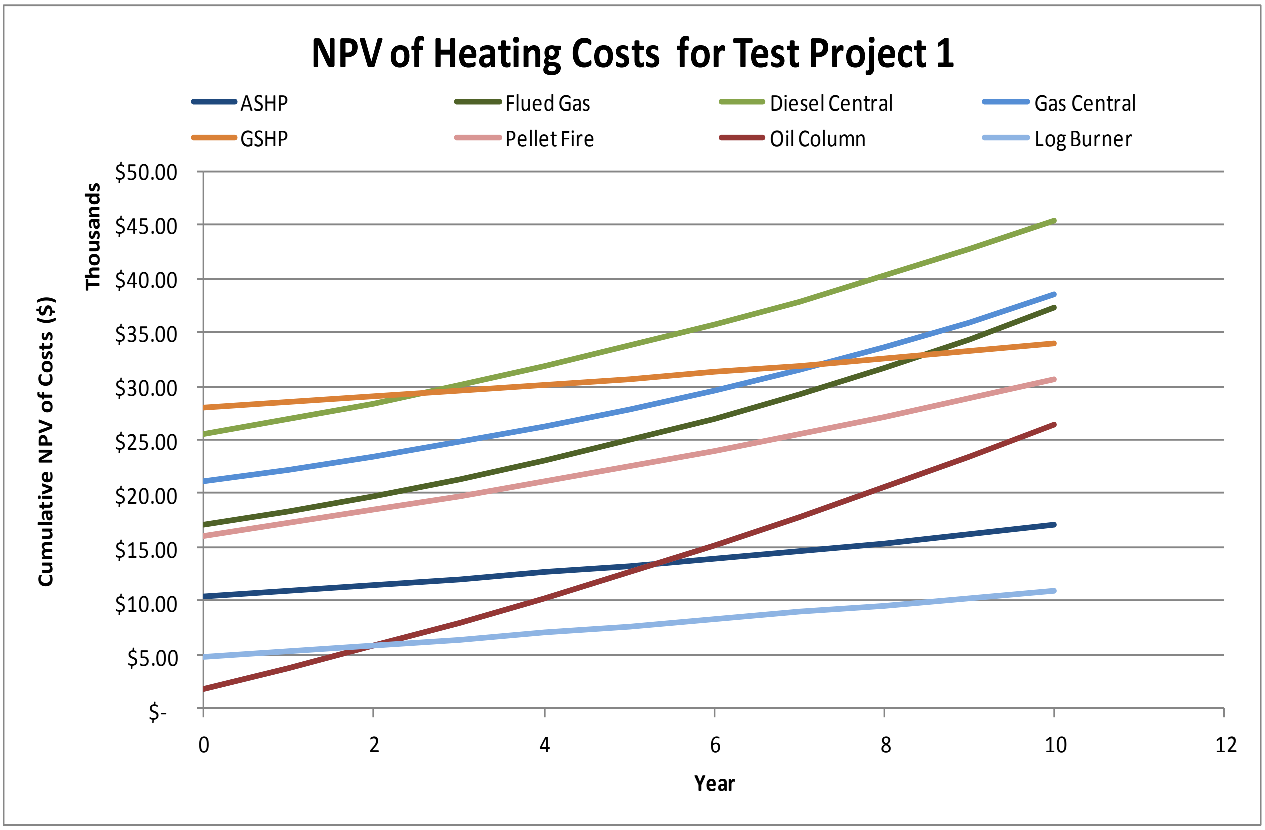

Figure 7: NPV of Costs of Test Project 1

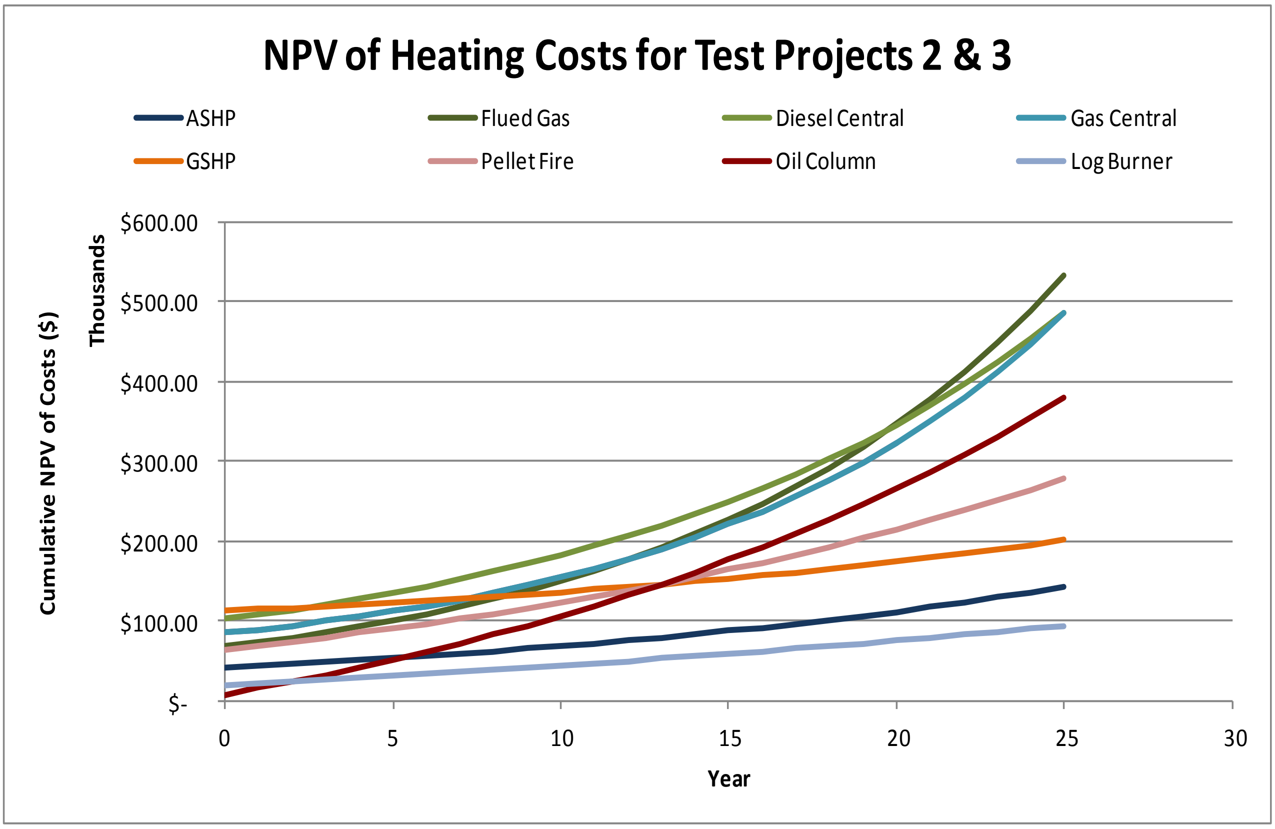

Figure 8: NPV of Costs of Test Project 2 & 3

7.4 Sensitivity Analysis

In order to quantify uncertainty in the GSHP system cost estimates, a sensitivity analysis was conducted for Test Projects 2 & 3 to determine the resulting change in NPV of Costs. The capital costs, installation costs, and operating costs of the GSHP system were varied ±30% of the base case costs found in Table 12. The results of the sensitivity analysis can be seen in Appendix G.

From this analysis, the greatest influence on the NPV of costs is found to be the annual operating cost. However a 30% increase in this variable only translates to a 13% increase of project NPV. This is encouraging, as electricity prices are expected to continue to rise, however the high energy efficiency of GSHP's dilute this effect on the overall NPV of costs.

It can also be seen that base cases would need to vary significantly more than 30% to deem GSHP's more economically viable than ASHP, which is considered unlikely.

7.5 Non-Economic Benefit Analysis

Literature research (Appendix L) has revealed that consumers are also influenced in their decision making by Non-Economic Benefits (NEBs). Suggested NEBs that may factor into consumers decision making process in regard to HVAC systems are proposed in Appendix H.

Each HVAC system has been scored against the identified NEBs to quantify these factors. The cumulative score of each HVAC system is seen in Table 13.

Table 13: NEB Evaluation matrix score

Heating System	ASHP	Oil Column Heater	Flued gas Burner	Gas Central Boiler	Diesel Central Boiler	Log Burner	Pellet Fire	GSHP
Total Score	13	12	8	9	9	4	4	13

As can be seen from the NEB analysis, GSHP's and ASHP's score the maximum, while Log Burners and Pellet Fires score the minimum.

This confirms that GSHP's may be more desirable compared to Log Burners, which will help to reduce the economic advantage Log Burners have over GSHP systems, however the attractiveness of ASHP's remains.

7.6 Comparison Between ASHP & GSHP

By all methods of comparison in this study, ASHP's are viewed favorably over GSHP's. This conclusion is echoed by the literature research in Appendix L.

Traditionally, GSHP's have been most popular in Scandinavian countries where particularly cold winters are experienced. GSHP's become favourable over ASHP's in cold climates, as unlike ASHP's, the efficiency of GHSPs is independent of the outside air temperature.

In an effort to determine in what situations GSHP's may be more economically attractive than ASHP's, the change of NPV of Costs for Test Project 2 & 3 has been analysed in respect to varying the assumed COP of the ASHP system to determine the operating temperature that GSHP's become an economically viable alternative. The results of this can be seen in Figure 9 below.

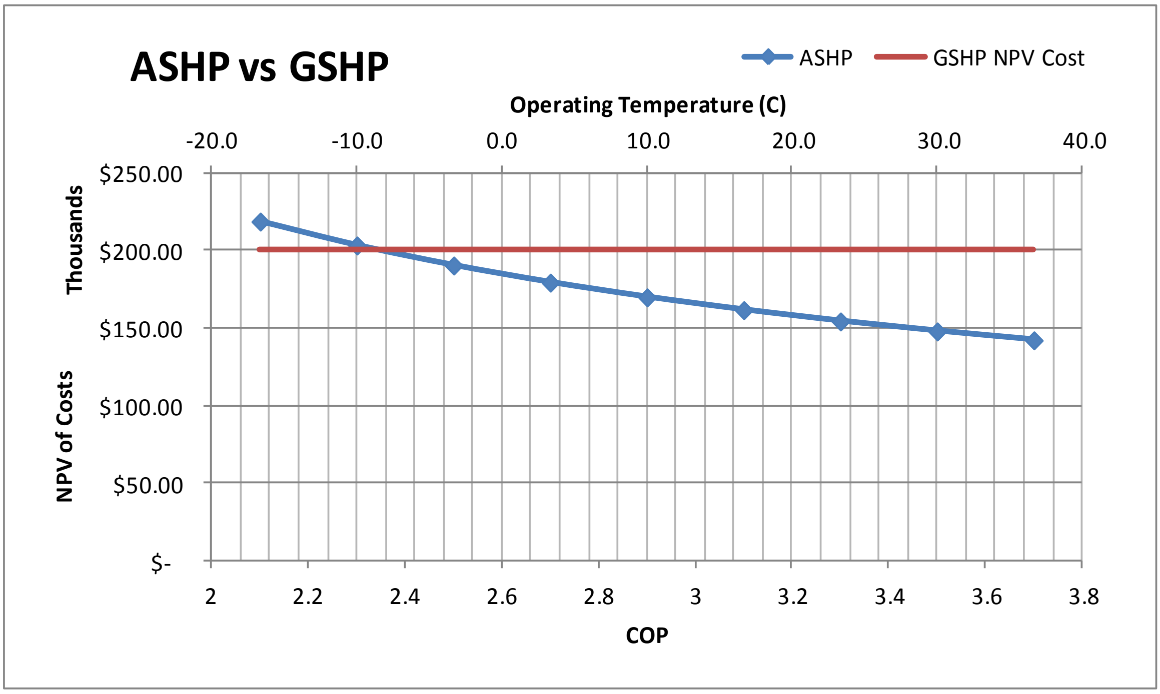

Figure 9: Economic effect of ASHP COP changes

GSHP's are seen to become more economically attractive than ASHP's in Test Projects 2 & 3 at an outside air temperature of approximately -9°C.

It is therefore suggested that GSHP's will remain un-economic in Christchurch as the average July daily minimum temperature is approximately 1°C (35). However GSHP's may be an economically attractive alternative to ASHP's further south or inland where colder temperatures are expected.

7.7 Economic Conclusions

The economic analysis conducted in this study contains a number of assumptions in regard to system and operating costs, system size, operating conditions, and consumers' decision making processes. Ideally, analysis of potential HVAC systems should occur on a case by case basis, where more accurate information is available on the assumptions stated above. The suggested process for completing an economic analysis on a case specific basis has been developed as a flowchart and can be seen in Appendix I.

Nonetheless, the economic analysis conducted in this study using the Test Projects described in Section 1.2 found that although GSHP systems achieve the lowest operating costs, the NPV of costs of GSHP systems is still significantly more expensive than ASHP's and Log Burners.

The lower operating cost cannot realise life cycle cost savings due to the high capital cost of GSHP systems and the relatively low heat energy requirements of NZ buildings as a result of relatively mild winters expected for most of NZ. This result agrees with previous research, and suggests GSHP systems will not be attractive to consumers on an economic basis alone.

However, NEBs are known to factor into consumer's decision making process. The quantitative results of a NEB evaluation suggests that GSHP's are more desirable than Log Burners on a non-economic basis; however the financial value of this to the consumer has not been quantified. ASHP's score the same as GSHP's in this analysis, confirming their attractiveness compared to GSHP's.

From Figure 9 it can be seen that to realise economic benefits from employing GSHP's over ASHP's for Test Projects 1 & 2, an expected air temperature of approximately -9^{o}C would be required. Although this is unlikely to be encountered in Christchurch, further south or inland GSHP's may become an economically attractive alternative to ASHP's.

8.0 STUDY CONCLUSIONS

Research has indicated that the Christchurch rebuild has developed a large market for new HVAC systems. Additionally, there are significant market drivers present in each identified market segment, which could increase uptake of GSHP systems.

Changing attitudes towards sustainability and emissions also see traditionally favoured heating systems such as log burners becoming less popular. GSHP's, with superior efficiency and no emissions, could become a socially acceptable and desirable product.

The relatively warm ground temperature of 11.6^{o}C expected in Christchurch suits efficient GSHP operation, as a significant temperature gradient will exist in winter. However, the mild *air temperature* expected in winter limits the amount of heating buildings require. As a result, the operating costs of HVAC systems are small compared to capital costs in this climate, making lower capital cost systems such as ASHPs more economically viable over their lifetime than capital intensive GSHPs.

SRG's proposed GSHP systems using Ischebeck geothermal piles have been found to be legally, environmentally and technically feasible in Christchurch, though as mentioned, economic benefit is not achieved in respect to ASHPs over the systems life.

Therefore, the main factors influencing consumer behaviour to install GSHP systems are currently Non-Economic Benefits (NEBs) which, although shown to have an influence on NZ purchasing behaviour, have not been able to be quantified economically.

Due to the influence of these NEBs, some sales of the proposed GSHP product may be likely for bespoke applications where life cycle economics play a lesser role in the decision making process, though the market size of this in the Christchurch rebuild is limited, and considerable competition from established, reputable organisations for these significant projects will exist.

The ASHP is currently considered to be the most attractive heating method in Christchurch against the assessed criteria, however, it has been found that GSHP's will likely be more economically attractive than ASHP's if operating in air temperatures below -9^{o}C. This may occur in some NZ locations further inland or south of Christchurch, though further research could be undertaken to determine the existence and the suitability of GSHP's in these locations.

If the existence of this market is proved however, GSHPs would likely be the most attractive heating method available, as similar NEBs to ASHPs exist.

Apart from bespoke projects, economic life cycle analysis proves to be the best indicator of system attractiveness to the general consumer. Therefore, to further validate the findings of this study, it is suggested further research should be initiated to establish the *economic value* NZ consumers place on the NEBs of HVAC systems. This would allow for more variables to factor into HVAC life cycle economic analysis and may see improvements made in the GSHP's consumer attractiveness.

9.0 RECOMMENDATIONS

As a result of the completed study, it is suggested *at this point and time, Southrim Group should not continue with proposed plans to enter the GSHP design and installation business in Christchurch due to the limited economic attractiveness of GSHP's compared with ASHP's in the current NZ climate.*

Further research could be performed to identify potential markets in different regions of NZ where more extreme temperatures are experienced and would better suit GSHP installation.

Non-Economic Benefits are also known to factor into consumers' decisions when purchasing energy efficient technologies. As a result, GSHP sales may also be possible in applications where these NEBs factor greatly into the decision making process.

The following recommendations would improve the attractiveness of GHSPs in NZ, either economically or otherwise, and would therefore likely increase their uptake in the HVAC market if SRG decide to continue with further developments in the future. SRG must assign responsibility for the implementation of these recommendations.

Southrim Group should, in order of descending importance:

1. Establish a commercial agreement with Ischebeck to use the Geothermal Pile technology in NZ. This would resolve any IP issues and maintain a positive relationship with Ischebeck.
2. Establish a supply agreement with a GSHP manufacturer, as better prices would be achieved than through current NZ GSHP wholesalers. This would lower capital costs and make GSHP's more economically attractive.
3. Embark on a marketing campaign to educate the public on SRG's new capability and the benefits of GSHP systems. This will increase consumer awareness of the proposed product and likely increase the value consumers place on the NEBs of GSHP systems.
4. Purchase specialist building energy modeling and/or GSHP design software to assist in the design process. This will also allow design optimization, lowering costs which improve the economics of GSHP systems. This is expected to cost $US525 - $US4300 as detailed in Appendix K.

5. Design and install GSHP systems to an accepted international standard such as MCS3005. This will help with quality control and will build consumer confidence in the new product.
6. Include a corrosion allowance of 2mm when sizing the steel tendon for geothermal pile applications and use a specifically designed geothermal HDPE for all other piping requirements to ensure design life of 50 years is achieved by the geothermal pile.
7. Use inhibited propylene glycol for the anti-freeze fluid and a geothermal grout to the composition of Mix 111 to improve performance and reduce the likelihood of adverse environmental effects. Using the economic data from Table 10 in Section 7 of this report, implementing this is expected to cost an addition $0.5/m of installed geothermal pile.
8. Install geothermal piles a minimum of 5m apart to avoid ground temperature reduction and no greater than 60m to keep within the capabilities of SRGs current equipment.
9. Independently verify the performance of any installed systems against design values to determine discrepancies, allowing future design improvements and increase consumer confidence.

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APPENDIX A VAPOUR-COMPRESSION CYCLE

The vapour-compression cycle is a thermodynamic cycle which is employed for use in refrigeration and heat pumps. All such systems have four components: a compressor, a condenser, a thermal expansion valve and an evaporator, as labeled in Figure 10a below.

Circulating refrigerant enters the compressor and is compressed to a higher pressure, resulting in a higher temperature. (Process 1-2).

This hot vapor is routed through the condenser where it is cooled and condensed into a liquid by exchanging heat with the medium to be heated. This is where the circulating refrigerant rejects heat from the system. (Process 2-3).

This is then routed through an expansion valve where it undergoes an abrupt reduction in pressure, evaporating the liquid to gas. The endothermic effect of evaporation lowers the temperature of the refrigerant significantly. (Process 3-4).

The cold mixture is then routed through the evaporator where it is heated by absorbing heat from the medium to be cooled. This is where the circulating refrigerant absorbs heat which is subsequently transferred elsewhere. (Process 4-1).

To complete the refrigeration cycle, the refrigerant vapor from the evaporator is routed back into the compressor.

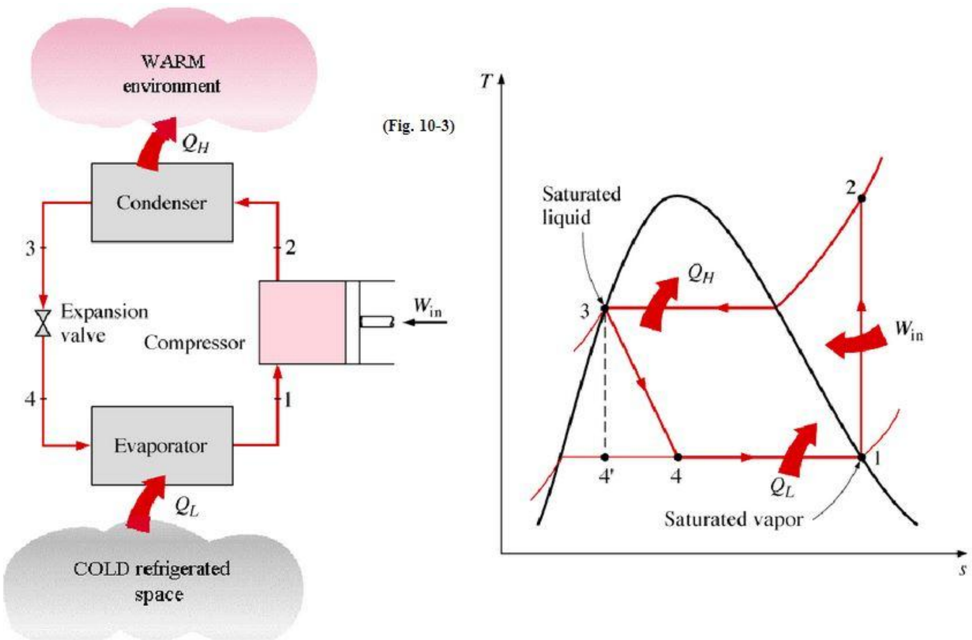


Figure 10: a) Heat pump schematic. b) Vapour compression cycle

APPENDIX B FUEL PRICES

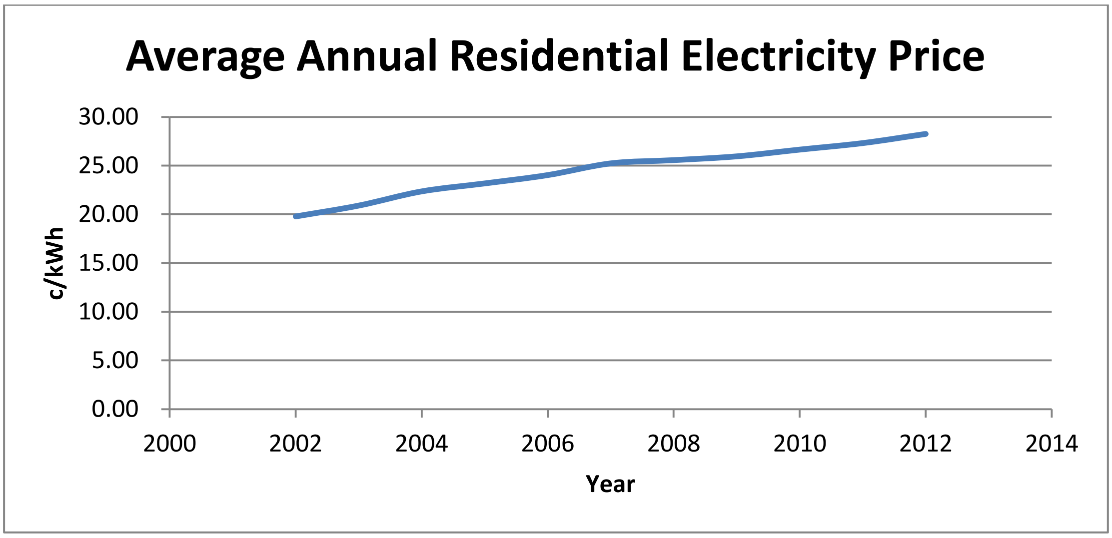


Figure 11: Past decade of electricity prices

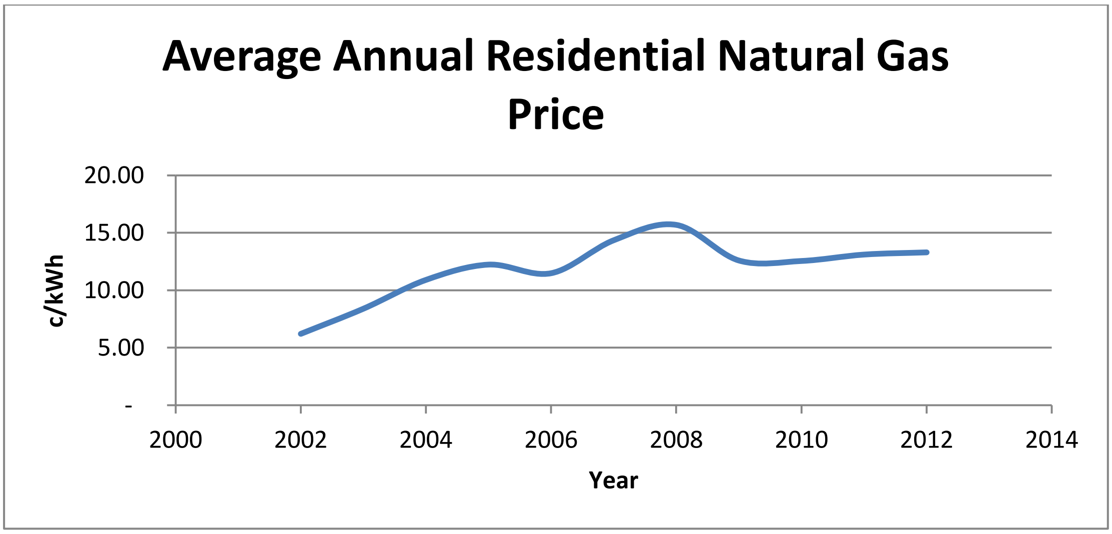


Figure 12: Past decade of natural gas prices

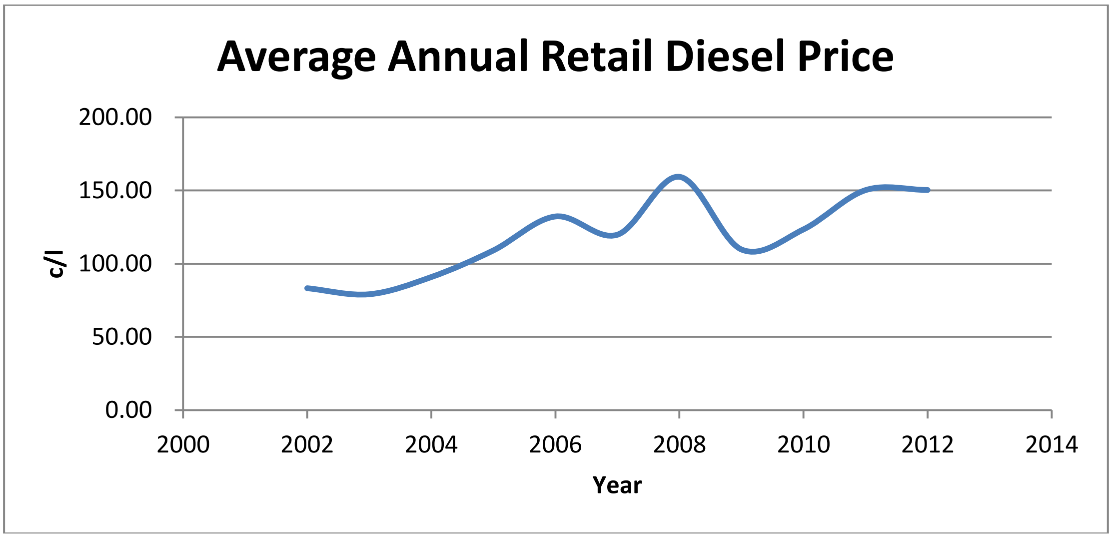


Figure 13: Past decade of diesel prices

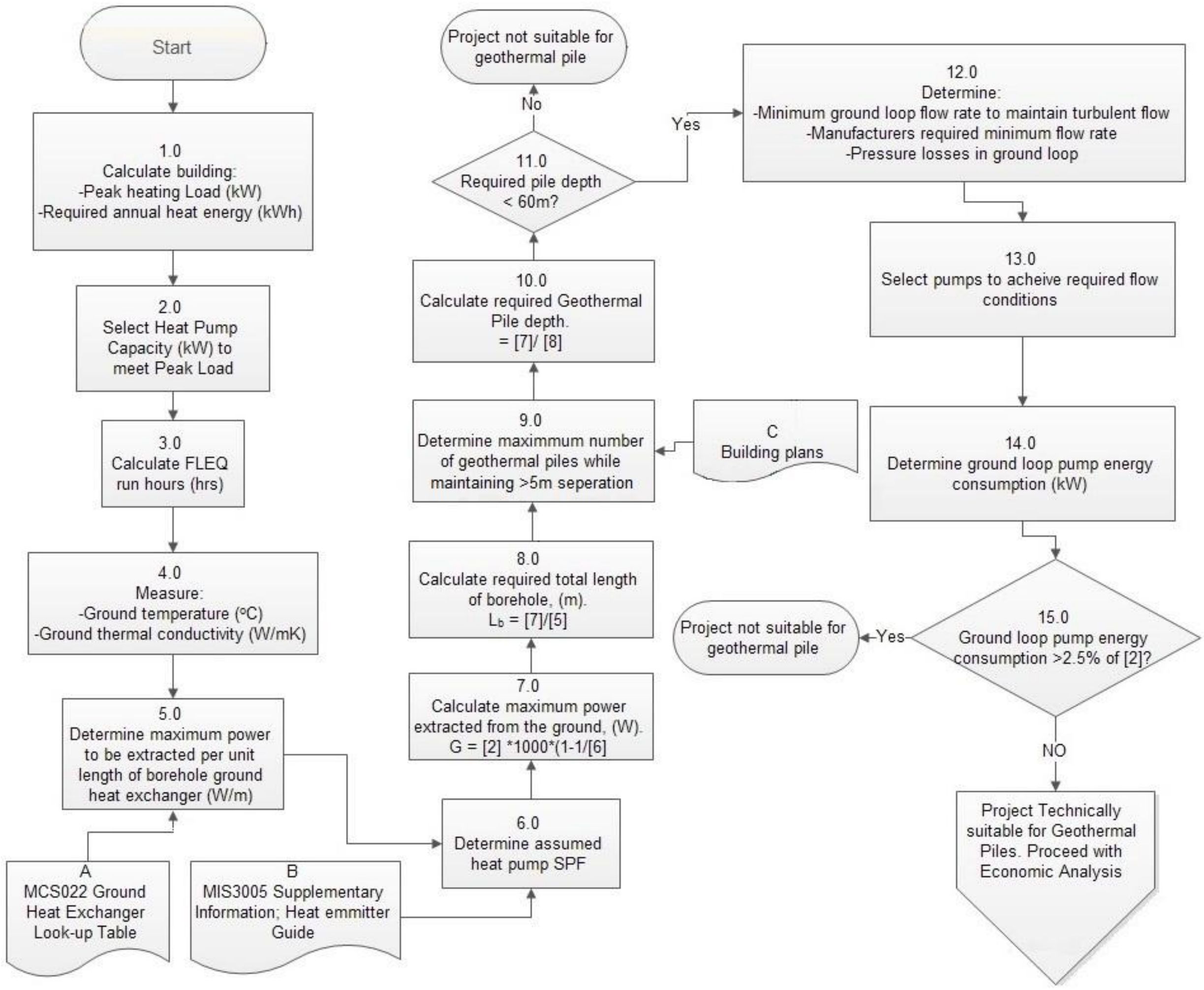
APPENDIX C MCS3005 WORKSHEET

The following sheet is provided in MCS3005 for the design of ground loop systems for GSHP installations.

Parameter	Value	Unit	Ref	Comments
Estimate of total heating energy consumption over a year for space heating and domestic hot water		kWh	[1]	(State calculation method)
HP heating capacity at 0°C ground return temperature and design emitter temperature, H		kW	[2]	
FLEQ run hours [1]/[2]		hrs	[3]	
Estimated average ground temperature		°C	[4]	
Estimated ground thermal conductivity		W/mK	[5]	
Maximum power to be extracted per unit length of borehole, horizontal or slinky ground heat exchanger (from the charts and look-up tables), g		W/m	[6]	
Assumed heat pump SPF (from heat emitter guide)			[7]	
Maximum power extracted from the ground (i.e. the heat pump evaporator capacity) G = [2]*1000*(1-1/[7])		W	[8]	
Length of ground heat exchanger calculated using the look-up tables L_b = [8]/[6]		m	[9]	(i.e. 2 no. 50m slinkies)
Borehole, horizontal loop or slinky spacing, d		m	[10]	
Total length of ground heat exchanger active elements, L_p = [9]*R_{pt}		m	[11]	(NB: does not include header pipes)
Total length of ground heat exchanger active elements installed in the ground, L_p'		m	[12]	(NB: state if proprietary software has been used

APPENDIX D TECHNICAL FEASIBILITY DETERMINATION FLOW CHART

The following flow chart was developed based on the MCS3005 worksheet seen in Appendix C.



APPENDIX E TECHNICAL SENSITIVITY ANALYSIS

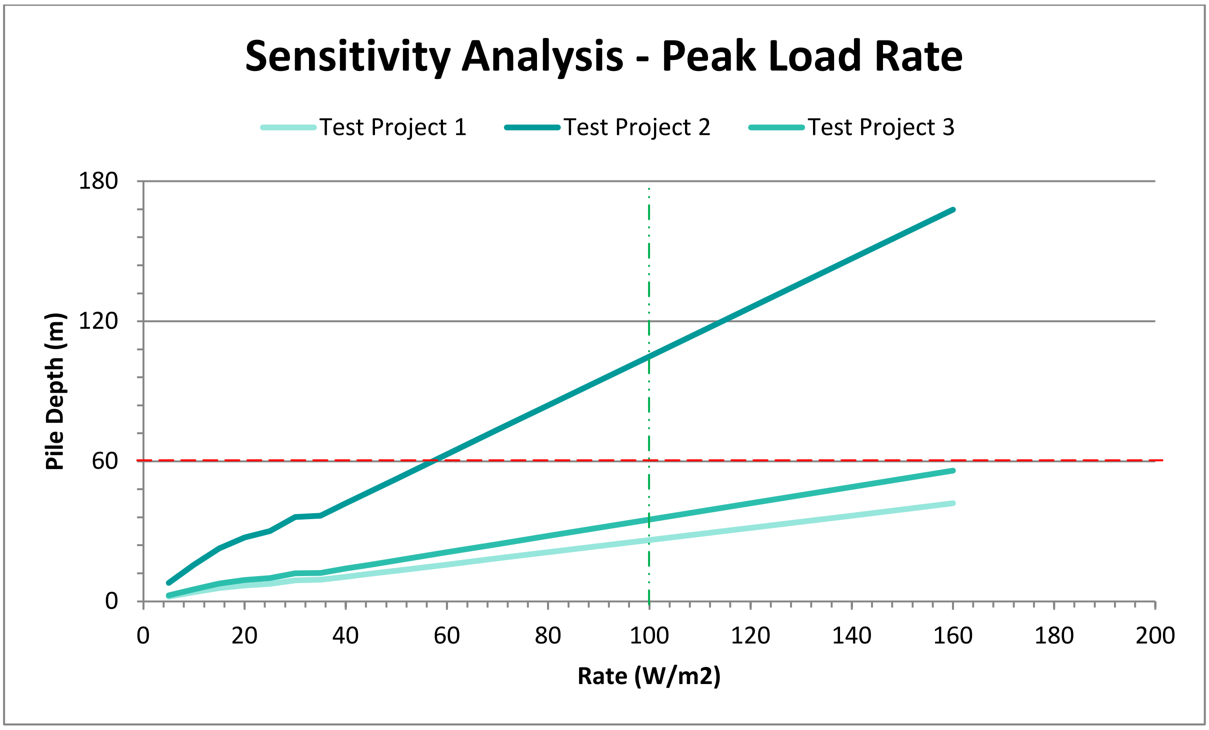


Figure 14: Sensitivity Analysis of Peak Load rate data

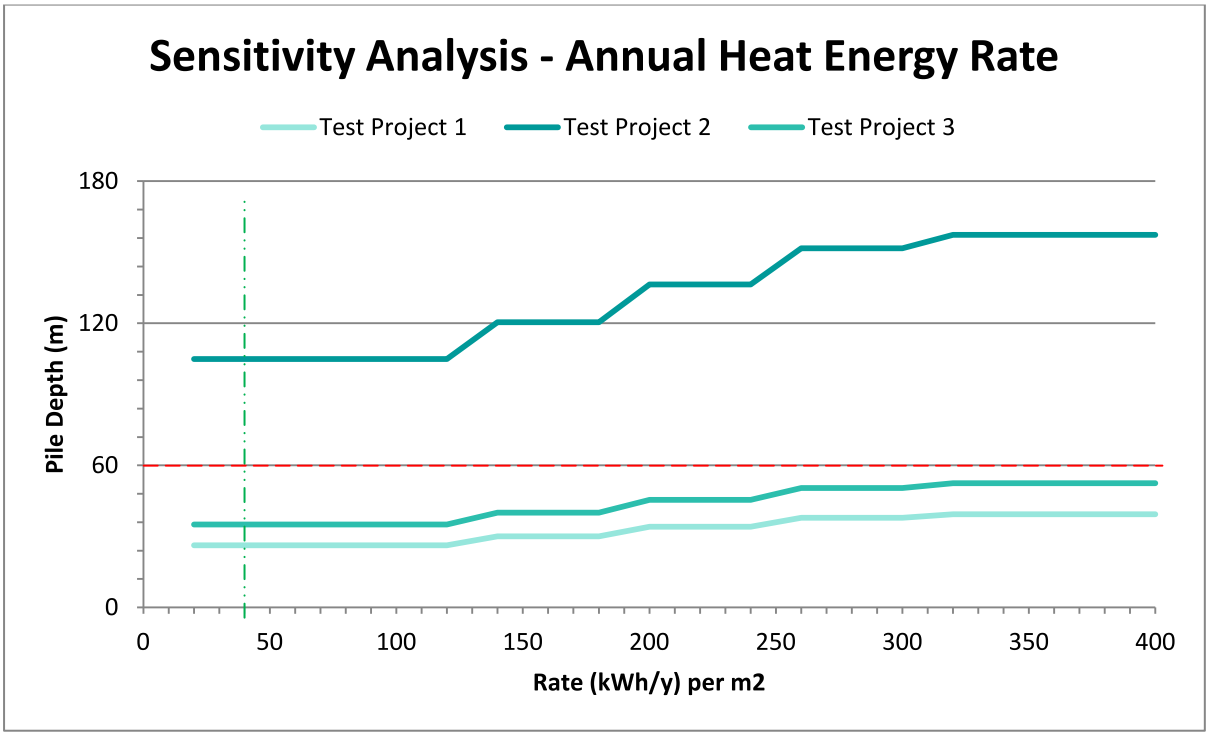


Figure 15: Sensitivity Analysis of Annual Heat Energy rate data

Key: Base case value

Feasible limit

APPENDIX F NPV ANALYSIS RESULTS

The following tables present the ranked results from the NPV of costs analysis.

Table 14: Cost Benefit analysis of test Project 1

Test Project 1. Period = 10 years. i = 1.3%				
Heating System	**Capital Cost**	**Initial Annual Operating Cost**	**Total Simple Cost**	**NPV of Costs**
Log Burner	$4,747.58	$566.66	$11,438.49	$10,960.26
ASHP	$10,366.00	$535.96	$17,544.17	$17,013.05
Oil Column Heater	$1,866.20	$1,983.04	$28,425.43	$26,460.28
Pellet Fire	$16,009.67	$1,201.44	$31,815.93	$30,651.92
GSHP	**$28,074.40**	**$472.70**	**$34,405.38**	**$33,936.94**
Flued Gas Burner	$17,057.52	$1,330.00	$39,010.64	$37,301.37
Gas Central Boiler	$21,069.20	$1,144.09	$39,953.60	$38,483.26
Diesel Central Boiler	$25,492.00	$1,432.34	$47,118.84	$45,469.65

Table 15: Cost Benefit Analysis of Test Projects 1&2

Test Projects 2&3. Period = 25 years. i = 1.3%				
Heating System	**Capital Cost**	**Initial Annual Operating Cost**	**Total Simple Cost**	**NPV of Costs**
Log Burner	$18,990.31	$2,266.65	$108,938.41	$93,567.02
ASHP	$41,464.00	$2,143.83	$164,873.25	$142,126.80
GSHP	**$112,297.59**	**$1,890.81**	**$221,141.68**	**$201,079.84**
Pellet Fire	$64,038.68	$4,805.77	$326,224.62	$278,371.22
Oil Column Heater	$7,464.80	$7,932.18	$464,079.04	$379,917.16
Gas Central Boiler	$84,276.80	$4,576.34	$586,821.28	$484,909.52
Diesel Central Boiler	$101,968.00	$5,729.35	$577,989.45	$484,930.34
Flued Gas Burner	$68,230.10	$5,320.00	$652,438.06	$533,965.63

APPENDIX G ECONOMIC SENSITIVITY ANALYSIS

In order to quantify uncertainty in the GSHP system cost estimates, a sensitivity analysis was conducted for Test Projects 2 & 3 to determine the resulting change in NPV of Costs. The capital costs, installation costs, and operating costs of the GSHP system were varied ±30% of the base case costs seen in Table 7. The results of the sensitivity analysis are shown in Figure 16 below.

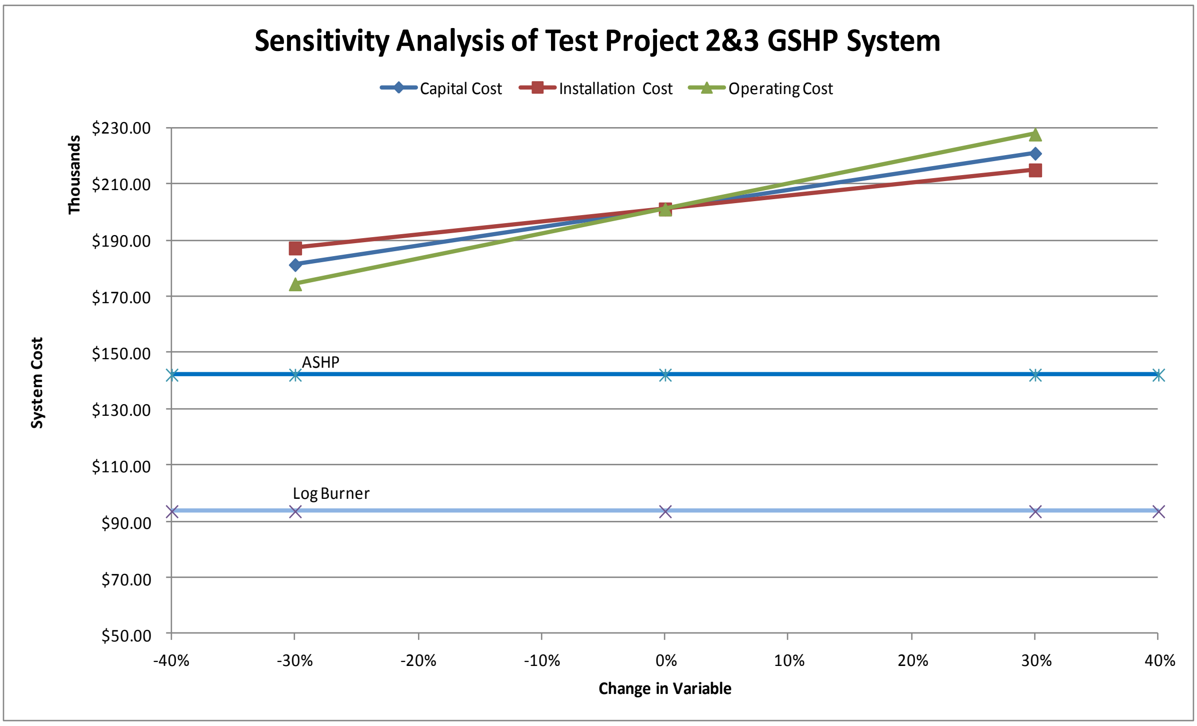


Figure 16: Sensitivity Analysis of Test Projects 2 & 3 NPV of Costs

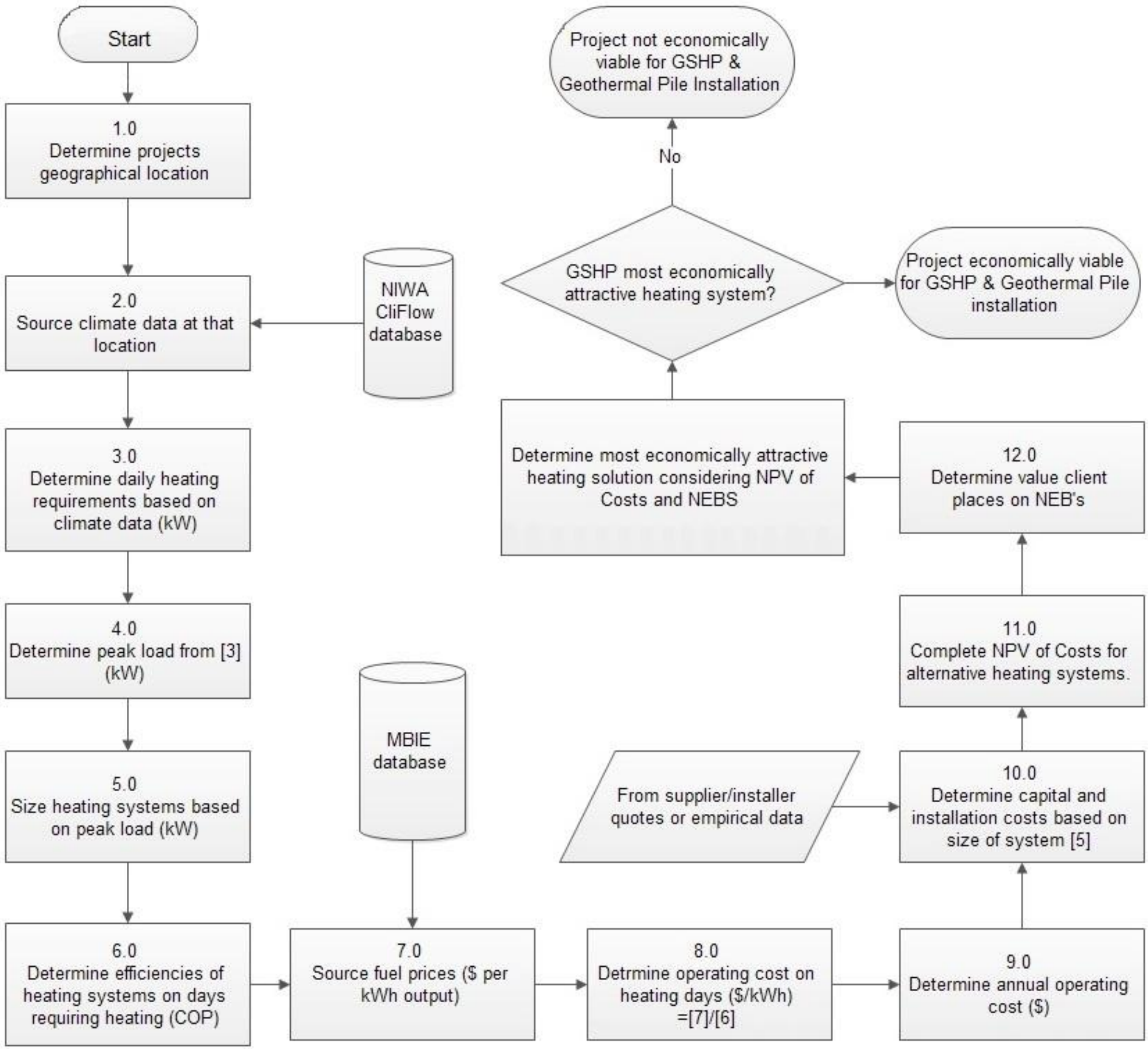
APPENDIX H NEB SCORING SYSTEM

Table 16: Suggested NEBs that factor into consumer decision process

NEB	Description	Score	Heating System
Convenience of fuel	Fuel requires purchasing, transporting and storage.	1	Log Burner, Pellet Fire
	Fuel requires ordering and storage.	2	Flued Gas Burner, Gas Central Boiler
	No fuel handling involved.	3	ASHP, GSHP, Oil Column Heater
Convenience of operation	Manual ignition and fuel input.	1	Log Burner, Pellet Fire
	Manual ignition.	2	Flued Gas Burner
	Thermostat controlled.	3	Gas & Diesel Central Boiler, Oil Column Heater
	Thermostat controlled. Programmable operating schedule.	4	ASHP, GSHP
Maintenance	Requiring waste removal and cleaning.	1	Log Burner, Pellet Fire
	Requires require systematic testing.	2	Flued Gas Burner, Gas & Diesel Central Boiler
	Devices generally maintenance free.	3	ASHP, GSHP, Oil Column Heater
Emissions	Solid particle emissions.	1	Log Burner, Pellet Fire
	Greenhouse gas emissions.	2	Gas & Diesel Boiler, Flued Gas Burner
	No source emissions.	3	ASHP, GSHP, Oil Column Heater

APPENDIX I ECONOMIC FEASIBILITY DETERMINATION FLOWCHART

The following flow chart was developed to aid in the economic analysis of specific GSHP potential projects.



APPENDIX J CAPITAL COST DATA

Table 17: Raw data and source for capital cost of alternative HVAC systems

System	Make/Model	Unit Size (kW)	Price per Unit ($)	Rate Cost ($/kW)	Data Source
ASHP	Fujitsu	3.4	1210	355.88	http://fujitsuheatpumpsauckland.co.nz/heat-pump-specials-new-zealand-auckland/
		6	2397	399.5	
		7.5	3094.5	412.6	
	Panasonic	4.9	1772.5	361.73	http://www.baybetterliving.co.nz/catalog/product_info.php?products_id=571
		6.35	2196.25	345.87	
	Mitsubishi	5.8	2183.5	376.47	http://www.heat-force.co.nz/compare-prices.php
		6.8	2517.5	370.22	
		9	3922.67	435.85	
Average		**6.2**		**382.27**	
Oil Column	DeLonghi	1	59.33	59.33	https://www.heathcotes.co.nz/products/ofrc15eccb-dimplex-1-5kw-premium-eco-column-heater
		1.2	135	112.5	
	Goldair	1.5	172.86	115.24	http://www.briscoes.co.nz/electrical/heating/oil-heaters/1023034/De'Longhi-DL2001T-Oil-Column-Heater-DL-Series---2000W.html
	Dimplex	2.4	206.8	86.17	
Average		**1.6**		**93.31**	
Flued Gas	Rinnai	5	2290	458	http://rinnai.co.nz/product_170_rinnai_symmetry_rdv3611.html
		5.7	4659	817.4	
		6	4199.5	699.9	
		6.5	3795	583.8	
		7	4401.5	628.8	
		7.5	5898	786.4	
Average		**6.3**		**662.4**	
Gas Boiler	Valiant	24	4,137.70	172.40	http://www.waterware.co.nz/central-heating/gas-boilers/central-heating-condensing/vaillant-ecotec-boiler-37kw-lpg
		37	4,846.56	130.99	
	Fondital	55	7,387.00	134.31	
		85	10,892.00	128.14	
Average		**38.4**		**141.46**	

System	Make/Model	Unit Size (kW)	Price per Unit ($)	Rate Cost ($/kW)	Data Source
Diesel Boiler	Firebird	20	4,247.00	212.35	http://www.global.firebird.ie/Portals/2/docs/WEB%2002-12-11%205098%20Firebird%20Pricelist%2012PP.PDF
		26	4,383.00	168.58	
		35	5,478.00	156.51	
		44	6,199.00	140.89	
Average		**31.3**		**169.6**	
Log Burners	Metro	11	1099	99.91	http://www.metrofires.co.nz/sites/default/files/attachments/metro-retail-pricelist-july-2013-web_0.pdf
		15	2014	134.9	
		24	3399	141.63	
	Kent	12	1399	116.58	http://thefireman.co.nz/products-page/kent-fires/
		13	1599	123	
		14	2699	192.8	
		17	2299	135.24	
	Woodsman	13.7	1999	145.91	http://www.mitre10.co.nz/shop/heating_cooling/wood_fires/woodsman_ecr_mkiii_wood_fire_131326/
		16	1849	155.6	
		18	2498	138.78	
	Masport	14	2199	157.1	
		20	2478.6	123.93	
	Osburn	21	2699	128.52	
Average		**16.1**		**138**	
Pellet Fire	Broadys	5	3,499.00	699.80	http://www.broadys.co.nz/afawcs0157265/CATID=114/ID=381/SID=859839596/Natures-Flame-Bayview.html
		6.1	4,999.00	819.51	
		6.6	6,099.00	924.09	
		8	4,499.00	562.38	
		8.2	6,499.00	792.56	
		9.5	2,999.00	315.68	
		9.5	4,299.00	452.53	
		10	4,399.00	439.90	
Average		**7.9**		**625.8**	
GSHP	DeLonghi	12	12730.26	1060.85	Quote from Central Heating NZ
		16	11801.88	737.62	
		23	13542.56	677.13	
Average		**17**		**825.2**	

APPENDIX K BUILDING ENERGY MODELING SOFTWARE

Table 18: Purchase cost of GSHP design programs from three common manufacturers.

Program Manufacturer	Product	Price	Source
Earth Energy Design	HEAT2/HEAT3 package	$2,600	(36)
	HEAT2	$1,600	
	HEAT3	$2,000	
Ground Loop Designer	Premier	$3,650	(37)
	Professional	$2,800	
	Complete Package	$4,300	
GLHEPRO	Version 4.0-120	$525	(38)
	Version 4.0-LRO	$525	
	Version 4.0-400+	$725	

APPENDIX L LITERATURE RESEARCH

There has been is a substantial amount of research conducted on the economics of alternative HVAC systems for both residential and commercial applications, however, no literature quantifying consumer behaviours based on Non-Economic Benefits of HVAC systems has been identified. Relevant to this however is information regarding house purchase decisions and perceived resale value as a result of home energy efficient measures. This existing literature on consumer decisions and economics of energy efficient technologies are reviewed in this Appendix.

Trends in Building Energy Efficient Measures

It appears that global trends are seeing a greater importance placed on building energy efficiency and investments in energy efficient and renewable technologies have become a significant global activity. Respondents in the 2012 Global EEI Survey (Institute for Building Efficiency, 2012) in general showed increasing interest in managing energy, investing in energy efficiency and renewable energy, and pursuing green buildings. Over 60% of global respondents said their organizations were investing in energy efficiency and over a third of them reported investing in renewable energy projects (Figure 17). Globally, just over half of respondents said they planned to increase such investments (Figure 18). Respondents reported their organizations took a wide variety of energy efficiency actions in the last 12 months. In all, 96% reported undertaking at least one improvement action. The most common actions taken were lighting upgrades (69%), HVAC or controls improvements (61%) and water efficiency actions (50%). This trend towards energy efficient measures is again reported by (Doody & Becker, 2010) who found that 34% of NZ respondents had thought about changing the way they heat their home. Those who were contemplating changing most commonly were thinking about installing heat pumps (77.9%), enclosed wood-burners (18.0%), central heating gas (10.1%) or gas heaters (9.4%). Thus, it is expected that there will be significant interest for new energy efficient technologies in NZ, such as GSHP’s.

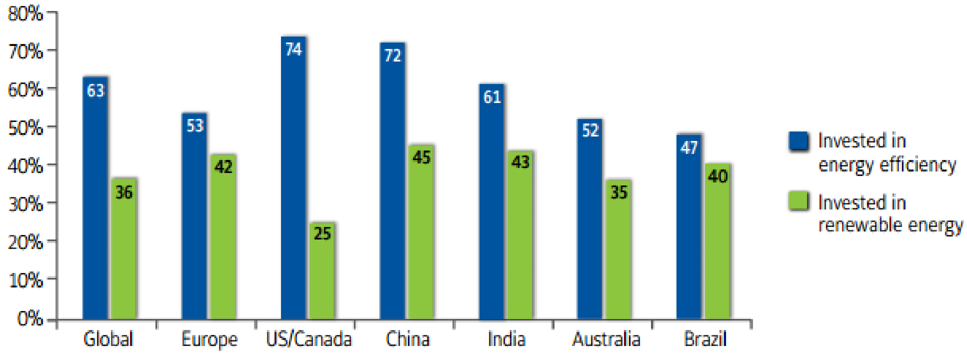


Figure 17: Investments in energy efficiency and renewables in the past year

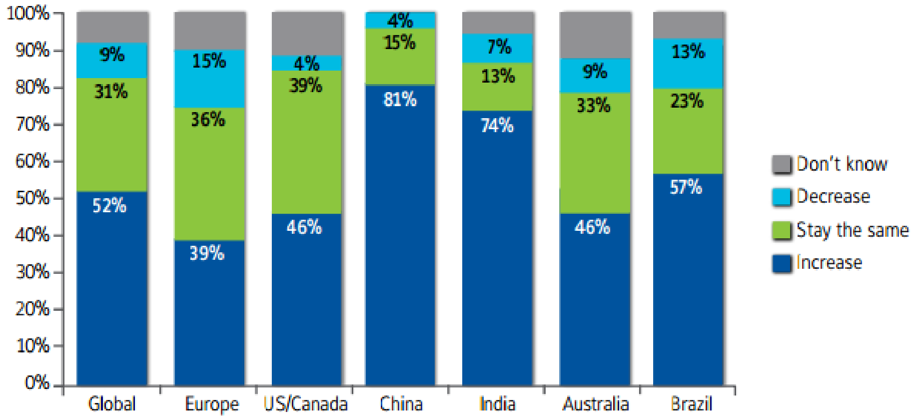
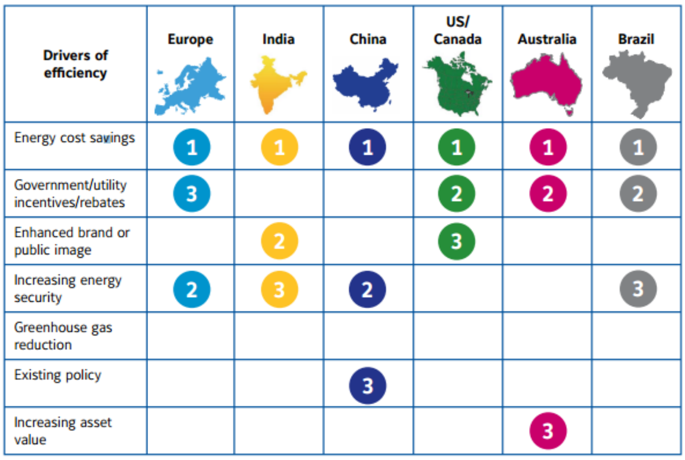


Figure 18: Plans to invest in energy efficiency and renewables in the next year

Influences on Energy Efficiency Decisions

While it appears investments in energy efficient measures are increasing, the motivation for this varies. The 2012 Global EEI survey results (Institute for Building Efficiency, 2012) indicate in all regions surveyed, energy cost savings remained the top motivator of energy efficiency decision-making (Figure 19). However locally, NZ homeowners state a number of qualities are considered important when looking to buy new appliances, of which energy efficiency ranks only 6th (Doody & Becker, 2010) (Table 18). Thus, energy cost savings achievable by GSHP systems will not likely be enough alone to generate wide spread adoption of this technology.



Drivers of efficiency	Europe	India	China	US/ Canada	Australia	Brazil
Energy cost savings	1	1	1	1	1	1
Government/utility incentives/rebates	3			2	2	2
Enhanced brand or public image		2		3		
Increasing energy security	2	3	2			3
Greenhouse gas reduction						
Existing policy			3			
Increasing asset value					3	

Figure 19: Drivers of energy efficiency decisions by region

Table 19: Percentage of respondents who considered various qualities to be important or unimportant when they were looking to buy new appliances and devices

Quality	Important (%)	Neutral (%)	Unimportant (%)
Reliability	95.2	1.9	2.9
Quality	92.4	5.1	2.4
Made to last	89.9	6.7	3.3
Will do the job	82.7	10.0	7.3
Ease of use	75.8	21.0	3.2
Energy efficiency	74.2	18.6	7.1
Price	70.3	22.8	7.0
Energy stars	69.3	20.1	10.6
Suits the room	58.7	21.5	19.8

NZ Heating Requirements

Most NZ residents heat their home during late autumn, winter, and early spring (Figure 20) (Doody & Becker, 2010). The mild winter temperatures expected in most of NZ results in NZ homes and buildings using significantly less heating than typical in Europe or North America where GSHP's are most popular and therefore expected to be economically attractive. Lind (2011) compared the heating requirements of major NZ cities with Swedish cities, where the highest occurrence of GSHP's in the world are found. (Table 19). It can be seen that significantly less heat energy is expected to be required in NZ. Even the coldest expected NZ city will require significantly less heating than the mildest identified Swedish city. This will affect the expected life cycle costs of different HVAC systems in NZ compared with Swedish observations.

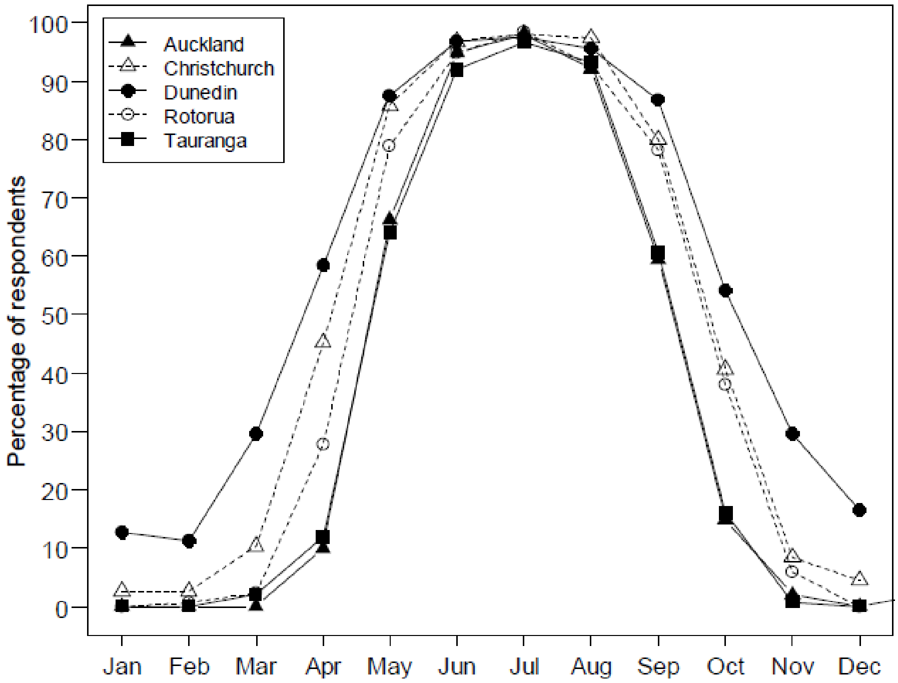


Figure 20: The percentage of respondents in different locations who actively heat their homes during different months of the year.

Table 20: Comparison of heating requirements between New Zealand and Swedish cities.

Country	**City**	**Heating Degree Days (HDD)**
Sweden	Kiruna	6385
	Stockholm	3661
	Malmo	3359
New Zealand	Auckland	1017
	Wellington	1445
	Christchurch	2347
	Dunedin	2397
	Invercargill	2510

Consumer Value of Energy Efficient Homes

Energy efficient technologies result in lower utility bills; however the willingness of consumers to pay a premium for this is low. Shelton Group (2013) found that despite just over one-third of homebuyers looking for a certified efficient home, homebuyers were only willing to pay a premium of 10% or less for it. This desire for energy efficient homes is echoed by a recent study by the US National Association of Home Builders (2012), though the unwillingness of buyers to pay a premium is magnified. 67% of buyers reported wanting an environment-friendly home, but at the same time would not pay more for such a home (Figure 21). Of those who would pay more, home buyers reported being willing to pay an additional average of $7,095 in the up-front price of a home if it saved $1,000 annually in utility costs. This research suggests that consumers do not perceive energy efficiency as a worthwhile investment if it will not pay returns in less than 8 years of living in their homes. This could be explained by Hanson, Bernstein, & Kulick (2004) who suggest features associated with greater quality such as countertop and flooring upgrades are perceived by most home buyers to secure a greater resale value than features promising greater energy efficiency.

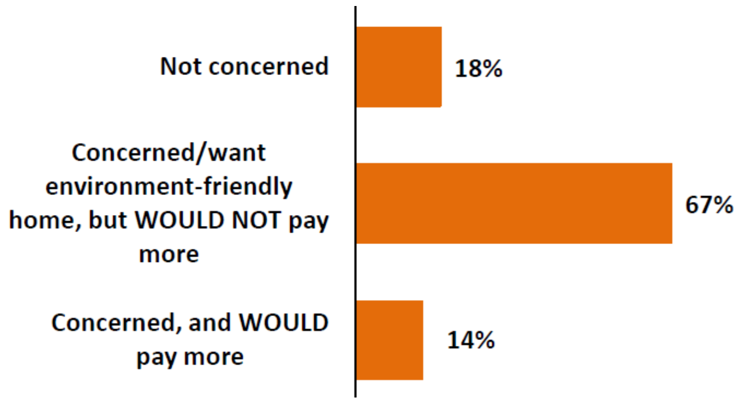


Figure 21: Level of concern about the impact of a home on the environment

Economics of GSHP Systems

As previously mentioned, energy efficient technologies require a cost premium. Goetzler, Zogg, Lisle, & Burgos, (2009) quantify typical costs of alternative HVAC systems, which show the premium associated with the energy efficient technology of GSHP's (Table 20). A recent GNS Science Case Study (Lind 2011) suggests payback times of about 10 years are typically achieved for GSHP systems. Building on this, Goetzler et al. (2009) concluded that while GSHP's offer lower utility costs, ASHP's tend to be more economically attractive. This is also the findings of NZ studies, with Suggate (2011) suggesting the high capital costs of GSHP's while experiencing only short NZ heating seasons, better economics are achieved from alternatives such as ASHP.

Table 21: Rated efficiencies and installed cost estimates for a range of residential heating technologies as of 2007.

Technology	Rated Heating Efficiencies	Typical Installed Cost (US)	Typical Installed cost (NZD)
Gas-Fired Furnace	Typical: 80% AFUE ENERGY STAR®: 90% AFUE Best Available: 96% AFUE	$24.00/kBtuh $32.70/kBtuh $44.00/kBtuh	$111.2/kW $151.5/kW $203.8/kW
Central Heat Pump (Air Source)	Typical: 7.7 HSPF ENERGY STAR®: 8.2 HSPF 2007 Best Available: 10.6 HSPF	$1450/ton $1570/ton $2300/ton	$559.9/kW $606.2/kW $888.1/kW
Ground Source Heat Pump	Typical: 3.4 COP ENERGY STAR®: 3.3 COP 2007 Best Available: 5.0 COP	$3000/ton $2830/ton $5250/ton	$1158.3/kW $1092.7/kW $2027.2/kW

Barriers to Energy Efficient Technology Adoption

Despite well documented energy efficiency advantages, awareness of GSHP systems is low. Over half of NZ survey respondents (Doody & Becker 2010) had not heard or read about GSHP's prior to completing the survey (Table 21). Goetzler et al. (2009) also identify *awareness* as a barrier to widespread GSHP adoption, listing lack of awareness and familiarity leading to perceived risks which discourage potential end users.

The cost premium of energy efficient technologies also presents a significant adoption barrier. A quarter of Institute for Building Efficiency (2012) respondents cited lack of funding as their top barrier to pursuing energy efficiency projects (Figure 22). Capital cost barriers are also identified specifically for GSHP projects by Goetzler et al. (2009). In NZ, this is echoed again by Suggate, (2011) suggesting the NZ domestic scale growth has been inhibited by high capital costs of GSHP's, with cost premiums typically 2 – 5 times over other forms.

Table 22: Percentage of respondents who have heard about different energy efficient technologies.

Technology	Yes (%)	No (%)	Not Sure (%)
Heat-pumps	97.6	1.3	1.1
Insulation	97.0	2.4	0.6
Solar-water heating	96.2	2.8	1.0
Energy-efficient appliances	95.4	2.7	1.9
Wind power	92.8	5.9	1.3
Geothermal power	81.0	15.6	3.4
Wave power	55.4	36.7	8.0
Ground-source heat-pumps	**47.1**	**42.4**	**10.5**

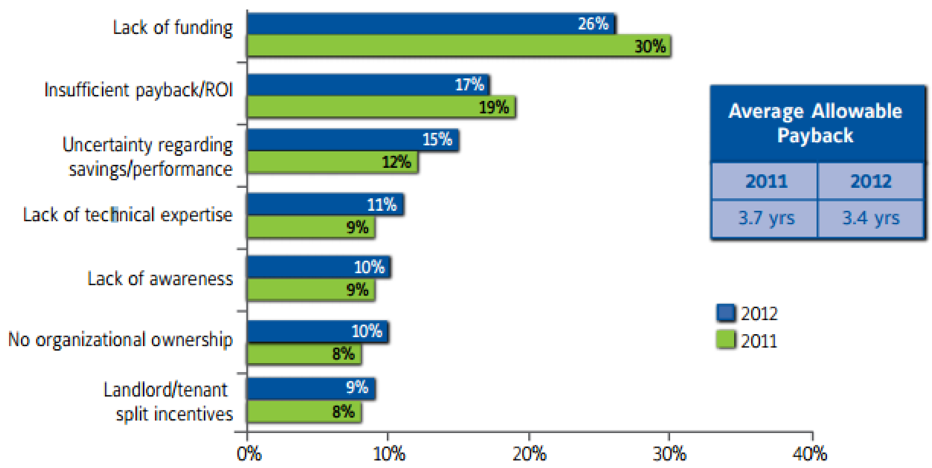


Figure 22: Barriers to energy efficient investment

Conclusions

The barriers preventing GSHP potential from being realised include high capital cost of GSHP systems, lower heat demand in NZ, and low level of awareness among the general public and decision makers in government.

Leading the market to a point where a significant number of systems will be installed will likely require an increase in support from government, learning from success in GSHP market stimulation from overseas (Lind 2011).

Until the market has reached a point where installation costs are competitive with other heating systems it is unlikely the general public will be sufficiently convinced to install units in significant numbers.

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