12th IEA Heat Pump Conference 2017

Rebuilding Christchurch – Using Ground Source Heat Pumps

Anya Seward[1], Melissa Climo[1], Helen Rutter[2], Zeb Etheridge[3], Peter Van Meer[4], Simon Bendall[5], Brian Carey[1].

1 GNS Science, Private Bag 2000, Taupo, New Zealand
2 Aqualinc, PO Box 20462, Bishopdale, Christchurch, New Zealand
3 Environment Canterbury, PO Box 345, Christchurch, New Zealand
4 Energy Efficiency and conservation Authority, 120 Hereford Street, Christchurch, New Zealand
5 Mitchell Daysh, PO Box 245, Taupo, New Zealand

Abstract

In February 2011, Christchurch, New Zealand experienced a destructive earthquake, resulting in large areas of the central business district collapsing. The rebuild of the city presented a unique opportunity for the advancement of geothermal / ground source heat pump (GSHP) infrastructure, district energy nodes, city planning and updating building regulations. Christchurch is situated on the East coast of New Zealand's South Island, and the city overlies a series of confined aquifers ranging in depths from 5 m to greater than 200 m. These aquifers are highly productive, with yields in excess of 100 L/s possible from a single well and hence the capital cost per kilowatt of thermal energy delivered from GSHP infrastructure is significantly lower than in other parts of the developed world. Groundwater temperatures remain within the 12-13°C range providing an ideal source for heating and cooling. In the city there had been some energy use from these aquifers prior to 2011. Several incentives encouraged greater uptake of this technology, including streamlining the planning regime, re-examining potential renewable energy sources, and some funding grants. This assisted to overcome perceived barriers such as capital costs, complicated permitting, and reliability of the infrastructure in an earthquake prone region. There are a number of large new commercial GSHP projects completed or under-development across the city and this paper presents a summary of the GSHP contribution to rebuilding significant infrastructure in central Christchurch city.

Keywords: ground source heat pumps; Christchurch; New Zealand; city infrastructure; energy efficiency; incentives

1. Ground Source Heat Pumps in New Zealand

1.1. Overview of New Zealand GSHP Scene

New Zealand has a small but active ground-source heat pump (GSHP) industry, with an estimated 150 installations[1]. Applications include space heating and cooling for residential and commercial scale buildings, as well as heating swimming pools and domestic hot water systems.

The Geothermal Heat Pump Association of New Zealand (GHANZ) was established in 2012 as an industry group to collaboratively promote and monitor the development of the GSHP market in New Zealand. While a database is being established to identify and record New Zealand's GSHP installations and their characteristics[2,3], the data is still incomplete. The information at a District level can be accessed using an interactive map at http://data.gns.cri.nz/geothermal/.

At the residential scale, the industry is dominated by a few established design and install GSHP companies, most with backgrounds in heating, ventilation and air conditioning. Best estimates put the number of residential installations at around 100 in the past ten years[3].

At the commercial scale, the design and installation of GSHP systems is undertaken by engineering consultancy firms, where the energy system is usually one component of a larger building/site development project. Examples of existing large-scale installations include airports, town halls, swimming pools, schools, and office buildings. Best estimates put the number of commercial-scale installations at around 20 in the past decade[3].

1.2. Influence of New Zealand's Climate

New Zealand's climate is temperate, experiencing neither excessive heat nor extreme cold. This has led to a history of minimal investment in home/building heating, energy efficient design and construction techniques; and the population generally has lower expectations of indoor comfort levels in winter than is found in a number of other developed nations[4]. As a result, GSHP have not reached the levels of uptake experienced by European countries and North America, for example, where climate and energy effective systems are key driving factors for GSHP installation.

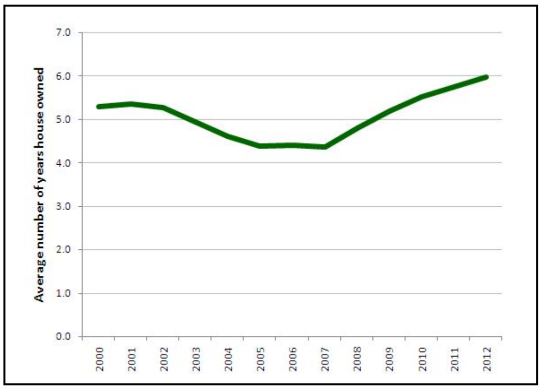
New Zealand's climate varies from warm subtropical in the north, to cool temperate in the south. The ambient air temperature fluctuates up to 20ºC between seasons and average annual temperatures range from 16ºC (in the north) to 8ºC (in the south), with some alpine areas having average annual temperatures reaching as low as 2ºC[5,6]. Ground temperatures remain relatively constant throughout the year, averaging between 12°C and 16°C, depending on location[7].

1.3. Drivers for Change & Barriers to Growth

New Zealander's expectations are changing, with central heating / air conditioning, double glazing and good insulation becoming necessities and significant in improving national health levels[8,9]. The New Zealand Government is setting new targets to accelerate the uptake of renewable low-carbon energy and reduce fossil fuel consumption[10].

Competitor technologies for GSHP include, solar (passive and circulating systems), air-sourced heat pumps, and gas based central heating systems, as well as single room heating solutions (such as wood fires, electric heaters, gas heaters, etc). GSHPs, while generally more expensive to install than other domestic heating solutions, are one of the most efficient and low-running cost, whole-home heating and cooling solutions. However, while GSHPs offer significant benefits, the key disadvantage is higher capital installation costs[4]. This can result in longer pay back periods, particularly for lower level energy users and in the circumstances where on average New Zealanders sell their houses every 4 to 6 years (Figure 1) the interest in installing capital intensive energy solutions is muted.

Fig. 1. Plot showing average number of years since houses last sold between 2000 and 2012 (www.qv.co.nz)



The New Zealand barriers to GSHP growth also includes market barriers, lack of market infrastructure, low level of consumer awareness, and consumer confidence[4]. New Zealand's quality standards, installation guidelines and accredited training certification programmes for installers are in development, and GHANZ are addressing communication, raising awareness.

The planning and regulatory framework in New Zealand as it relates to GSHP shows supportive legislative and environmental policies at national and regional levels, and generally permissive requirements for closed loop systems. However, some regional frameworks are not well suited to GSHP systems, and there is inconsistency in consenting approaches between regions and districts[11].

2. Christchurch Geology & Earthquakes

Christchurch is New Zealand's third largest city, with a population of around 380,000. It is located in the Canterbury Region, on the East coast of New Zealand's South Island.

A series of gravel aquifers underlie the Christchurch area, composed of gravel alluvium and glacial outwash deposits around 300-600 m thick [12,13]. Fan and alluvial gravel sequences form aquifers, while marine/estuarine sediments of silt, clay, peat, and shelly sand act as aquitards. Six main aquifer systems are identified:

i. < 13 m Springston Formation (~10 m thick)
ii. 20-40 m Riccarton Gravels (~15 m thick)
iii. 50-85 m Linwood Gravels (variable thickness)
iv. 95-105 m Burwood Gravels (~5 m thick)
v. 115- >125 m Wainonui Gravels (~5 m thick)
vi. >150 m Aquifer No 5

The first artesian wells were drilled in the 1860s in response to a need for uncontaminated water supply[14]. The number of wells reached several thousand by the late 1980s.

2.1. Earthquake Sequence & Impacts

The Canterbury earthquake sequence commenced on 4 September 2010 with a magnitude 7.1 earthquake located approximately 35 km west of Christchurch city near the small community of Darfield. The Darfield event resulted in extensive areas of liquefaction, land damage, and widespread damage to buildings and infrastructure in the Canterbury region[15]. The impact of the Darfield earthquake was wide spread, but caused no loss of life, or building collapses. The event was followed by months of aftershocks[16] the largest of which was a 6.3 magnitude earthquake that occurred 5 months later on February 22, 2011. The earthquake occurred at 12:51 pm and had an epicenter at a shallow depth of 5 km located near the Christchurch Central Business District (CBD). The central city experienced intense shaking, with vertical acceleration reaching 2.2g. This earthquake resulted in the loss of 182 lives, extensive damage and collapse of numerous buildings in Christchurch[17]. In the aftermath, more than 1000 commercial buildings (LINZ, *per comms*) in the CBD were demolished significantly changing the city scape.

Following the demolition phase, the priority was to initiate rebuilding infrastructure, power systems, the damaged roads and underground services. The rebuilding of demolished central city buildings, would then follow.

2.2. The Christchurch Rebuild Opportunity

Christchurch City Council opened the recovery planning process up to local businesses, property owners, public sector organisation, residents and community groups. The guiding principles were[18]:

(1) To foster business investment,
(2) To respect the past,
(3) Have a long-term view to the future,
(4) Be easy to get around, and
(5) Create vibrant central city living.

The opportunity for major infrastructure re-building provided a unique opportunity for installing shared energy systems, local co-generation and micro-generation, and improved power, water and sewerage infrastructure. Longer term benefits from alternate energy systems including energy efficiency, better energy management, more resilient infrastructure and more appropriate choices for a lower carbon future could be attained[19]. Unfortunately, the processes were not set-up quickly enough, and businesses started to rebuild and apply for individual consents.

As Christchurch is located above a series of aquifers, which provide a great source of constant year-round temperature, a number of commercial organizations opted for geothermal / ground source heat pump (GSHP) systems for heating and cooling their buildings.

The advantages that GSHPs have in Christchurch include:

- timing - a $40B earthquake rebuild, during a period where interest in energy efficiency and renewable energy options is growing,
- access to the abundant aquifer resource, that has already been proven to be a viable energy source, and
- climate impacts - colder Christchurch winters mean that GSHP systems can achieve superior performance compared to air source heat pump solutions, and the planning regime does not allow for wood burning[20] because of winter air particulate issues.

While the domestic GSHP market has been active in Christchurch for a couple of decades, and continues to remain steady following the earthquakes, this paper focuses on the large-scale, commercial development which has experienced significant growth in the region since 2011.

3. Existing Large-Scale GSHP in Christchurch

Christchurch has a series of confined aquifers ranging in depths from 5 m to greater than 200 m[21,22]. These aquifers are highly productive, with yields in excess of 100 L/s possible from a single well[21]. Air temperatures in Canterbury vary between 0 and 35ºC[5], and aquifer water temperatures remain within the 12-13°C range. This makes the aquifers ideal for supporting GSHP aquifer water based systems. Additionally, Christchurch has a relatively low installation cost per kW of thermal energy delivered. It is estimated that the cost per kW of installing GSHP wells (excluding distribution pipework, controls, pumps etc.) in Christchurch is around $135/kW of heating and $215/kW cooling. This is based on a typical well yield of 50 L/s, with heating and cooling using a heat pump system but excluding free cooling which can be achieved in the Christchurch situation. The equivalent costs in London, for example, where over 35 GSHP schemes are installed[23], are around $1,500/kW heating and $2,400/kW cooling respectively.

Energy use from these aquifers was already underway prior to the earthquake, usually using aquifer thermal energy technology. One example is the University of Canterbury, where the aquifer system was used for cooling laboratories and lecture rooms[24,25]. Also, the largest and most well-known GSHP system in Christchurch is at the Christchurch International Airport[26], 12 km from the city center (Figure 2). The system, commissioned in 2011, has two 1.5 MW and one 600 kW GSHP systems providing heating and cooling requirements. The GSHP technology replaced diesel and LPG boilers as part of a wider airport upgrade. When ambient temperature permits, water from the wells is used to cool the airport with no aid from the GSHP (So called free cooling). Ground water from the onsite wells is passed through heat exchangers which increase or decrease the water’s temperature to extract or reject heat energy as is required and the water is discharged to a soak pit returning it to the ground.

Fig. 2. Images of Christchurch International Airport and part of its GSHP system (top left).

4. Incentives for GSHP Development

Several incentives were developed to encourage greater uptake of GSHP technology, including streamlining the planning regime, re-examining potential renewable energy sources, and some funding grants. This assisted to overcome perceived barriers such as capital costs, complicated permitting, and reliability of the infrastructure in an earthquake prone region.

4.1. District Energy Scheme

One option considered was to provide electrical energy, heating and cooling to the city center using a district energy scheme (DES), from a centralised plant fueled by sustainable energy sources. A network of pipes would then transport the energy from the plant into buildings around the city, enabling owners to dispense with their own plant and the associated space requirements. But, the process for developing this centralised system was too lengthy given the business and government drivers for rebuilding Christchurch. While the DES process proceeded, many key customers made independent decisions to build GSHP (or other energy) systems to meet the requirements of their own buildings. This individual emphasis was, perhaps unintentionally, supported by government grant schemes, which were not open to district energy scheme customers.

Following the earthquakes, the Christchurch City Council (backed by the National Government) established a series of incentives for rebuilding Christchurch. Relating to energy saw the establishment of the Christchurch Agency for Energy Trust (CAfÉ), to promote energy efficiency initiatives and the use of renewable energy[27]. A fund of $NZ1.8 million was made available to cover up to 30% of the capital plant costs, to a maximum of $300,000 per project. This fund sought to encourage the use of renewable energy and advanced energy efficiency measures in the central city rebuild. A number of GSHP projects received funding. The Energy Efficiency and Conservation Authority also offered grants for feasibility studies and technology demonstration[28,29] which were taken up by some developers in Christchurch. These incentives served to reduce risk and capital costs for GSHP installations in Christchurch.

4.2. Policy & Planning Regime

After the Christchurch earthquakes in 2010 and 2011, a review of the Proposed Land and Water Regional Plan was undertaken. The permitting regime, as proposed, increased complexity, cost and risk for developers seeking to utilize GSHP technology. Central Heating New Zealand Ltd and the Geothermal Heat Pump Association of New Zealand made submissions seeking to allow flexibility in depth and location of the water take and discharge, and for non-consumptive groundwater takes to be treated differently to consumptive ground water takes, i.e. not being subject to allocation zone limits or single aquifer constraints[30,25].

Prior to the earthquakes, GSHP schemes were required to obtain consent to abstract from and discharge to groundwater or surface water. The regional plan operational at that time did not allow for any new consumptive groundwater takes, and non-consumptive GSHP schemes which recharged 100% of abstracted water back to the aquifer system could potentially be consented, but subject to assessment of local drawdown and mounding effects around abstraction and injection wells.

The renewed permitting regime, streamlined the consent process for GSHP systems, and supported a flexible management approach to water / heat take from regional water sources. Subsequently there were also rules permitting certain water takes for aquifer thermal energy systems introduced that applied to an identified part of the central city. Water could be used provided it was taken and then discharged to identified aquifers and that the takes and discharges complied with other prescribed requirements. Discretionary applications can be made for permits where the use doesn't meet the specified requirements. These provisions are included in rules 9.5.15 and 9.5.16 of the December 2015, Canterbury Land and Water Regional Plan, Volume 1[31].

4.3. Earthquake Damage Exposure

The regional environmental authority, Environment Canterbury, were also proactive in assuring residents and businesses that groundwater and groundwater wells were still viable in Christchurch following the earthquakes. Two reports released in 2011 examine the earthquake impacts on groundwater[32,33] showed the limited damage and exposure that the earthquakes had caused to groundwater wells, delivering much needed assurance that these resources remained viable for both water and energy supply.

5. Christchurch's New Large-Scale GSHP Installations

There are seven new commercial-scale GSHP projects completed or under-development across the city identified in Figure 3. Table 1 provides some other details including the capacity of the systems which range from 0.5 to 3 MW. An overview of two of the completed projects is detailed in the following sections.

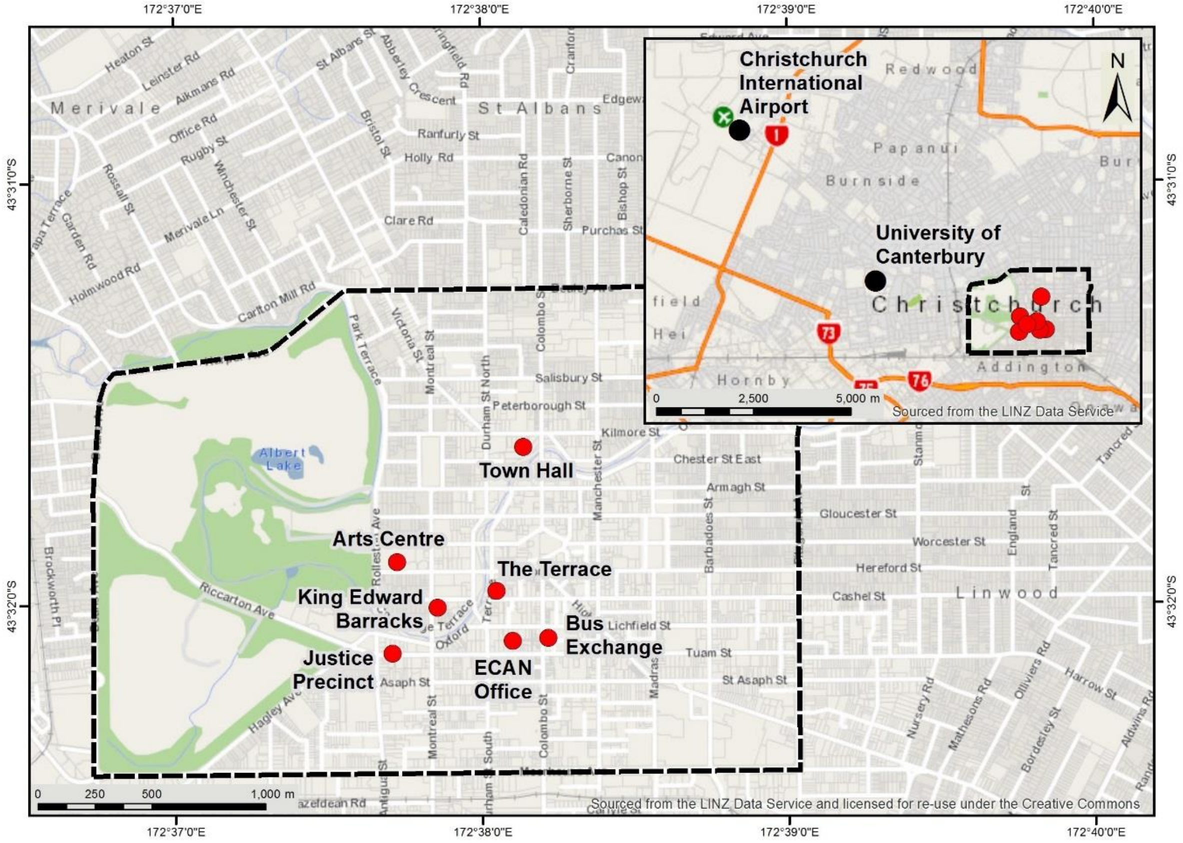


Fig. 3. Map showing location of new GSHPs in Christchurch's CBD. From Seward et al., [25]

Table 1. Large scale GSHP projects underway in Christchurch since 2011; locations are shown in Figure 2.

Project	**Building size (m^2)**	**Extraction depth (m)**	**Extraction rate (L/s)**	**Re-injection depth (m)**	**Estimated plant size**	**Completion Date**
Bus Exchange	9500	80	12	35	1.0 MW	2015
Art Centre	13000	130	80	30	1.6 MW	2016
ECan offices	8000	85	33	35	650 kW	2016
Justice Precinct	40000	150		90	3 MW	2017
The Terrace	4000	85	26	30	500 kW	2017
King Edward Barracks	30000	128	80	38	2.0 MW	2018
Town Hall	11000	80		River	1.2 MW	2018

5.1. The Performing Arts Centre

The Performing Arts Centre (Figure 3) is the city's outlet for performance including music, drama, dance and more. It comprises several buildings which have developed over time. Original construction began on the clock tower in 1877 with additional buildings including schools, and university buildings being added shortly afterwards. The buildings were converted into the Arts Centre in the 1970s.

Fig. 3. Photograph of cranes removing masonry from the Art Centre March 2011 (Margaret Low, GNS Science)

The Centre's buildings incurred fairly severe damage during the February 2011 earthquake and subsequent aftershocks. An extensive 7-year rebuild programme is currently underway to restore and modernise the establishment. The restoration includes a 1.6 MW heat pump system for heating and cooling. Water will be extracted through 2 bores about 125 m deep (Consent CRC154729)[34] at a maximum rate of 80 L/s. Water will be re-injected at similar rates at a shallower depth (30-66 m; Consent CRC154730)[34].

5.2. Christchurch Bus Exchange

The Bus Exchange (Figure 5) is a purpose built public transport facility located in the center of Christchurch's CBD. The Bus Exchange occupies approximately 3,000 m^2. Within the building there is approximately 9,500 m^2 of floor space on several levels. It caters for roughly 8.6 million bus passengers per year, approximately 1,850 buses use the facility every day[35]. The building was completed in 2015, is heated by a ground source heat pump, which extracts water from a depth of 80 m (Linwood Gravels) at a rate of up to 12 L/s (Consent CRC155593)[34] and re-injects the water at a similar rate to a depth of 35 m (Riccarton Gravels) (consent CRC167904)[34].

Fig. 5. Photograph of the Christchurch central city Bus Exchange
(Simon Devitt Photographer)

6. Summary

In February 2011, Christchurch, New Zealand experienced a destructive earthquake, resulting in large areas of the central business district collapsing. The rebuild of the city presented a unique opportunity for the advancement of geothermal / ground source heat pump (GSHP) infrastructure, district energy nodes, city planning and updating building regulations. At the commercial scale, the central city has taken an individual building/developer approach rather than that of using a larger shared district energy scheme. The significant GSHP growth has been at the commercial scale, with seven new systems to be commissioned by 2018, ranging in size from 0.5 to 3 MW that heat and cool facilities ranging in floor area from 3,000 to 45,000 m^2. It is clear that GSHP aquifer water thermal energy technology is preferred where appropriate aquifer conditions are available, such as in Christchurch, and the planning and regulatory requirements provide certainty, with permission time frames such that they can be accommodated within the building and construction timelines.

Acknowledgements

This research was supported by NZ Government-funded geothermal research funding at GNS Science. Thanks goes to all the designers and installers who provided technical information on the GSHP installations and history in Christchurch for this study.

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