A Practical Guide to Exploiting Low Temperature Geothermal Resources

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GNS Science Report 2006/09

June 2006

BIBLIOGRAPHIC REFERENCE

Thain, I., Reyes, A.G. and Hunt, T., 2006. A practical guide to exploiting low temperature geothermal resources, *GNS Science Report 2006/09*. 76p.

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ISSN 1171-2425
ISBN 0-478-09907-X

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ABSTRACT

New Zealand has 435 MWe installed capacity for geothermal power production, the 7th largest in the world. However at 310 MWt it is only 13th in the world for direct heat utilization despite its vast resources. At present the main uses for direct heat in the country includes industrial process heat (67%), agricultural drying (9%), bathing, swimming and balneology (9%), space heating (8%), fish and animal farming (6%) and greenhouse heating (1%).

More than 90% of the annual energy from direct heat uses in New Zealand is derived from wastewater from geothermal power stations (cascade); and little is made use of other sources such as hot spring systems. There are more than 100 warm to hot springs found all over New Zealand that could be harnessed directly or by drilling wells. However, less than 20% of these hot springs are being used at present.

With the increased availability and efficiency of ground source or geothermal heat pumps, for space heating and cooling and domestic use, a number of low grade geothermal sources in New Zealand can be exploited including the natural conductive heat flux in the ground, below a few metres from the surface, where temperatures remain constant at 12°-15°C throughout the year.This is the most pervasive source of low temperature heat in the country. Other sources are warm waters from flooded abandoned mines and abandoned oil, gas and water wells. The cost of installing a domestic geothermal heat pump is twice that of a natural gas-fired system, at about $12,000.00, although operating costs are lower for a heat pump with an annual cost saving of nearly $800.00.

Kiln-drying of timber is a direct heat application cascaded from geothermal power production in Kawerau. In the kiln high temperature water of 80-140°C, circulated in heating tubes, heats the air to the required drying schedule temperature. As the circulating air picks up moisture from the timber, part of the air is vented and replaced by dry air from outside. It takes about 570 kW of thermal energy to dry one cubic metre of Radiata pine lumber. The rate of applying this energy to the timber dictates the drying schedule, type of kiln used and the quality of lumber product.

Another direct heat use, cascaded from the production of geothermal power in Mokai and Poihipi, is greenhouse cultivation of vegetables and orchids. The greenhouse heating system is dictated by the type of crops being grown. To heat a greenhouse the temperature of the geothermal water should be between 60-80°C. The quantity of hot water required depends on the optimum growing temperature for the crop, size of greenhouse and the lowest outside temperature in the area.

In installing a direct heat use system the following are required: borehole with casing, downhole and circulation pumps, transmission and distribution pipelines, peaking and back-up plants and various heat exchange mechanisms.

KEYWORDS

Geothermal, low-temperature, direct heat applications, ground source heat pump, timber drying, greenhouse, calculations, installation.

1.0 SOURCES OF GEOTHERMAL ENERGY

Geothermal energy is **clean**, **renewable** and **versatile**

The heat generated internally in the Earth (Figure 1), mainly by the decay of radioactive elements in the rock, is continually conducted slowly to the surface along a geothermal gradient which is normally 15° to 30°C/km. Superimposed over this natural heat flow in localised areas are high temperatures associated with volcanic activity. This occurs where two tectonic plates move apart (divergent boundary), such as mid ocean ridges; collide (convergent boundary), such as in New Zealand, where one plate is subducted beneath another; or in "hot spots" under mid ocean volcanic islands such as Hawaii, Iceland or Samoa.

The total heat energy above 15°C in the Earth's crust is estimated to be about 5 x 10^{24} kilojoules which is an enormous quantity, and could more than provide for the total annual energy needs of the world. However, not all this energy is accessible.

A geothermal resource is a volume of rock where heat can be economically harnessed for conversion to electricity or direct heat utilization. Heat is mined from liquid and vapour circulating in pores and fractures in the rock or directly from the rock.

Heat stored in the fluids is more easily extracted. The amount of fluid in a rock is determined by its porosity. In volcanic rocks the porosity may be as high as 40% near the surface, decreasing to <5% at a depth of several kilometres. In sedimentary rocks, such as sandstones and mudstones, the porosity may be up to 20%. For a given temperature the higher the amount of fluid stored in porous rocks the higher the amount of extractable heat. Permeability, in the form of rock fractures and faults, enhances extraction efficiency.

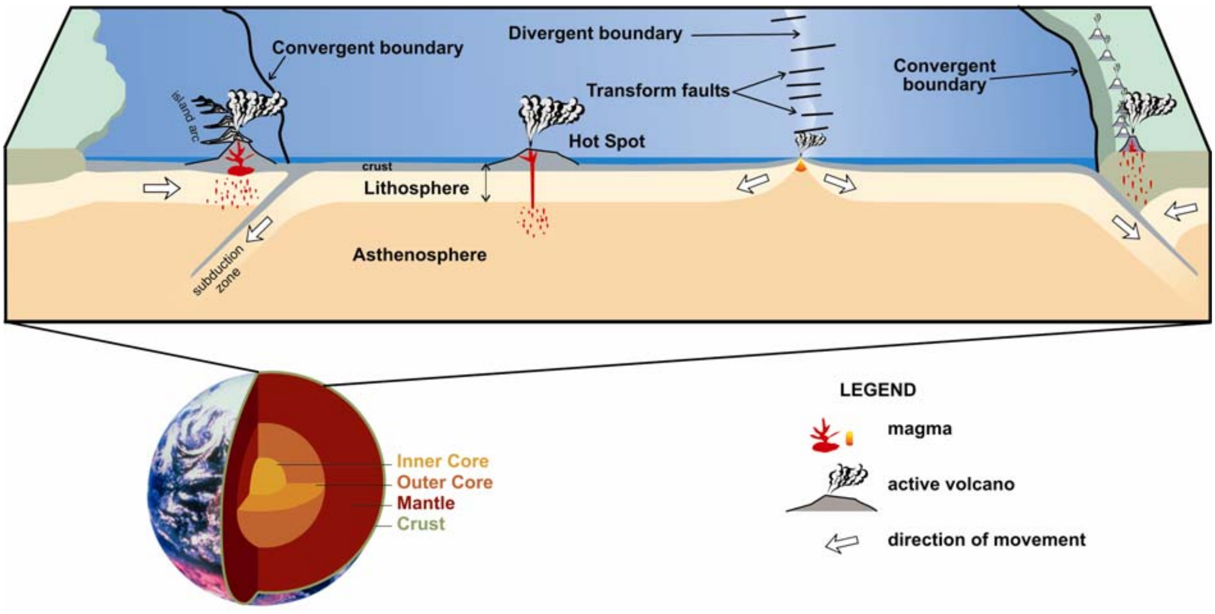

Figure 1. Layers of the Earth and typical tectonic settings for geothermal systems.

Heat can be extracted directly from the rock by pumping groundwater, or other liquids such as antifreeze, through a heat exchanger between two or more wells or in U-shaped pipes.

Geothermal resources, based on fluid discharged from depth, are generally classified as:

- Low temperature <150°C
- High temperature >150°C

The conversion of heat to electricity is the most optimal use of a geothermal resource. Electricity is generated using steam and/or binary cycle systems depending on the temperature and pressure of the resource. Steam coming directly from a well, at >235°C, or >180°C water flashed to steam, drives turbines to generate electricity. Binary cycle systems can use 75°C – 220°C water, from a geothermal reservoir to vaporise a lower boiling temperature working fluid (e.g. isopentane, ammonia) that would then spin a turbine.

So far, 24 countries harness electricity from geothermal systems and have a total installed capacity of about 8932 MWe. Spent geothermal waters from steam turbines are either discharged at the surface or reinjected into the subsurface at a distance from reservoirs from which they were derived, depending on geological setting, water quality, local environment and council regulations.

Low temperature geothermal resources are pervasive and are increasingly utilized throughout the world (Figure 2). From 2000 to 2005, the number of countries using low temperature geothermal resources increased from 58 to 72, with installed capacity doubling to 27,825 MWt. The thermal energy used increased by 40% within the same span of time, to 261,418 TJ/yr (72,622 GWh/yr).

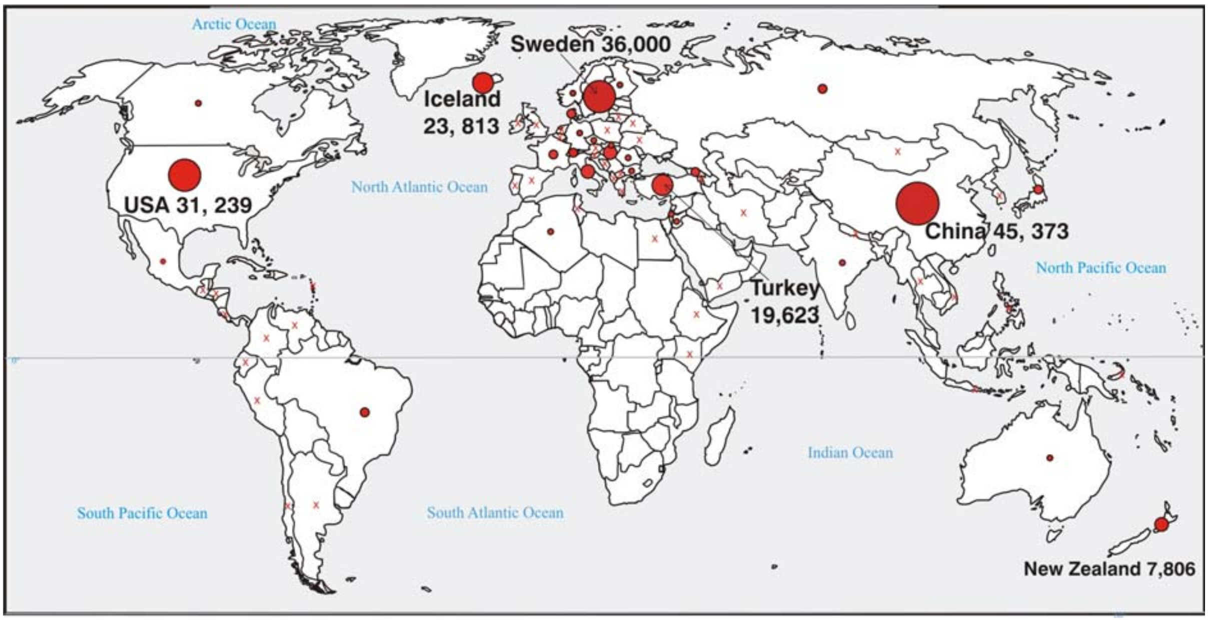

Figure 2. Countries using low temperature geothermal resources. The five main users are China, Sweden, USA, Iceland and Turkey. Consumers with >1000 TJ/yr are indicated with solid circles and those with <1000 TJ/yr by x. Data from Lund et al., 2005.

1.1 ADVANTAGES OF USING GEOTHERMAL ENERGY

Geothermal energy production generally has a well-deserved image of an *environmentally friendly* energy source when compared with fossil fuels and nuclear energy.

Low cost
Generally, once the capital cost of installing the well and piping has been covered, the running costs of a geothermal plant are lower than for other energy sources and maintenance can usually be done by the user. For operations in rural areas, the cost of installing geothermal may be similar to, or even cheaper than, setting up fuel storage facilities or constructing power or gas lines from the nearest retail source.

Independence
Having direct control over the energy source provides certainty, and avoids economic shocks of sudden increases in energy costs or changes to the conditions of use.

Minimal Environmental Impact

- One of the least polluting forms of energy.
- Low levels of chemicals in low temperature geothermal fluids - little impact on ecosystems.
- Less atmospheric emissions compared to diesel and fossil fuels, especially CO_2.
- Modest land requirements.
- Can co-exist with other land uses.

2.0 NEW ZEALAND'S GEOTHERMAL RESOURCES

In 2005 New Zealand produced nearly 76 PJ of geothermal energy with about 90% harnessed for electricity generation and only 10% for direct utilization of heat. The installed capacity for geothermal power generation is 435 MWe, the 7th largest in the world, which provides about 6.5% of the power needs of the country. In contrast New Zealand is ranked 13th in the installed capacity for direct heat utilization at about 310 MWt, consisting of 67% industrial process heat, 9% agricultural drying, 9% bathing, swimming and balneology, 8% space heating, 6% fish and animal farming and 1% greenhouse heating.

Exploration and development of the vast low temperature geothermal potential of New Zealand has been marginal because of the abundance of high temperature geothermal resources, the wide-spread availability of cheap hydro-generated electricity and natural gas, and the generally moderate climate. However, recent increases in the cost and uncertainty of future conventional energy supplies and the need to reduce greenhouse gas emissions causing climate change have made the exploitation of low temperature geothermal resources imperative.

Currently more than 90% of the annual energy from direct uses of geothermal resources in New Zealand is derived from wastewater from geothermal power stations which is only a small fraction of the potential of New Zealand.

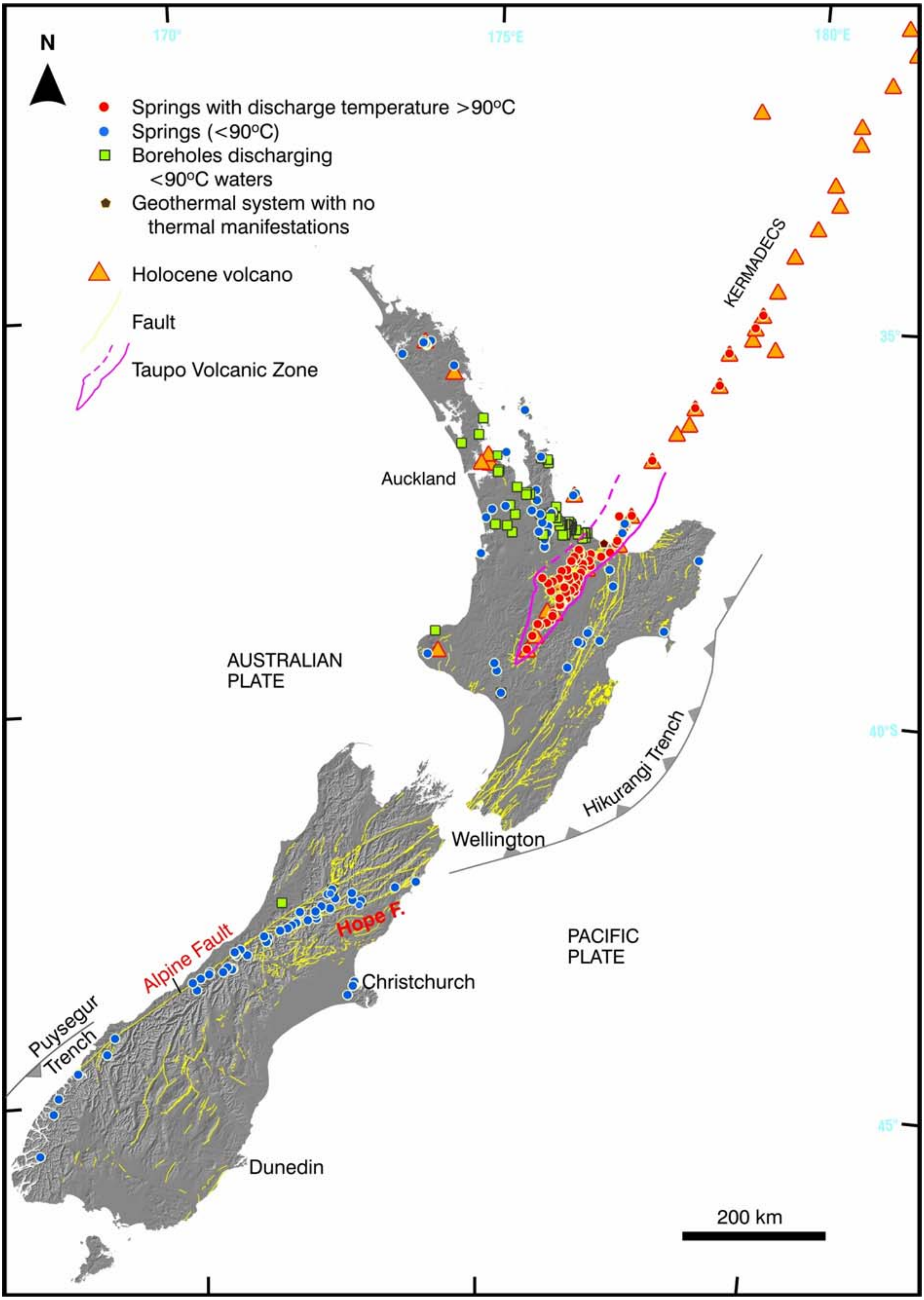

Figure 3. Distribution of hot springs, drillholes discharging hydrothermal fluids, active volcanoes and the main active fault zones in New Zealand. (Reyes and Christenson, in prep; faults from www.gns.cri.nz and other GNS databases.

Warm to hot springs (just above ambient to 100°C), that can be used for direct heat applications, are found in more than 150 locations in the North and South Islands, outlying small islands of the North Island and the Kermadecs (Figure 3). Warm waters are also discharged from some water or oil and gas wells. Less than 20% of these discharging thermal waters are being exploited. A conservative estimate of the stored heat energy in hot spring systems outside the Taupo Volcanic Zone (TVZ) is 4 to 5 PJ. Estimates of stored heat in the TVZ is about 75000 to 75500 PJ.

Typical geothermal resources of New Zealand are closely related to the country's natural geothermal gradient and its geological setting characterised by volcanism, frequent active tectonism manifested by earthquakes along active fault zones and by rapid uplift of mountains.

In active volcanic areas waters are heated by shallow magma chambers. These hot waters rise to the surface, are diluted by shallow cold groundwater and then emerge often some distance away from the high temperature source due to topography. These warm-water outflows occur in the **Taupo Volcanic Zone** and **Ngawha in Northland**. In the **Coromandel** and parts of the **Waikato**, some low temperature springs may be related to extinct volcanic activity where waters are heated at depth by remnant heat from crystallized magma.

In zones of active faults and rapid land uplift, rainwater or seawater percolating to depths of several kilometres becomes warmed by the natural thermal gradient. These heated waters rise rapidly along fractures or faults and emerge at the surface as warm springs, or diffuse into the near-surface groundwater. Such resources are widespread along the **Alpine and Hope Faults of the South Island** and in the **East Coast of North Island.**

There are a number of atypical geothermal sources in New Zealand that have hardly been explored, much less exploited. The most pervasive source of low temperature heat in the country is the natural thermal gradient in ground, below a few metres from the surface, where temperatures remain constant at 12 - 15°C throughout the year and could be harnessed for space heating or cooling using geothermal or ground source heat pumps.

Geothermal energy can also be harnessed from old unused coal mines, abandoned oil and gas wells, water wells, and wells drilled below 3500 m, outside typical geothermal areas, such as onshore sedimentary basins. In New Plymouth 29°C water, from the Bonithon-1 abandoned gas well drilled to 916 m, is used in swimming pools and for bottling mineral water. In Papamoa, where the thermal gradient is nearly 1.5 times normal, groundwater heated to 25°C in a 230 m deep well is used by Highway Fisheries to quarantine and raise tropical fish.

Many operating coal mines in the West Coast of South Island in New Zealand, for example, need to be de-watered. The water pumped out is warm and can be used with a heat pump for heating in winter and cooling in summer. It is estimated that about 50 - 75 MWe can be harnessed from about 85 onshore abandoned oil and gas wells in the country and 200 - 300 MWe is possible by drilling deep wells in onshore sedimentary basins. With new technology available New Zealand's subsurface has become one big geothermal source (Reyes, 2006).

3.0 APPLICATIONS FOR LOW TEMPERATURE GEOTHERMAL RESOURCES

For centuries, low temperature geothermal waters have been used for a wide range of domestic, agricultural and industrial applications that involve heat, known as *direct use*. The applications vary according to the temperature of the water available and are summarised in the Lindal Diagram (Figure 4).

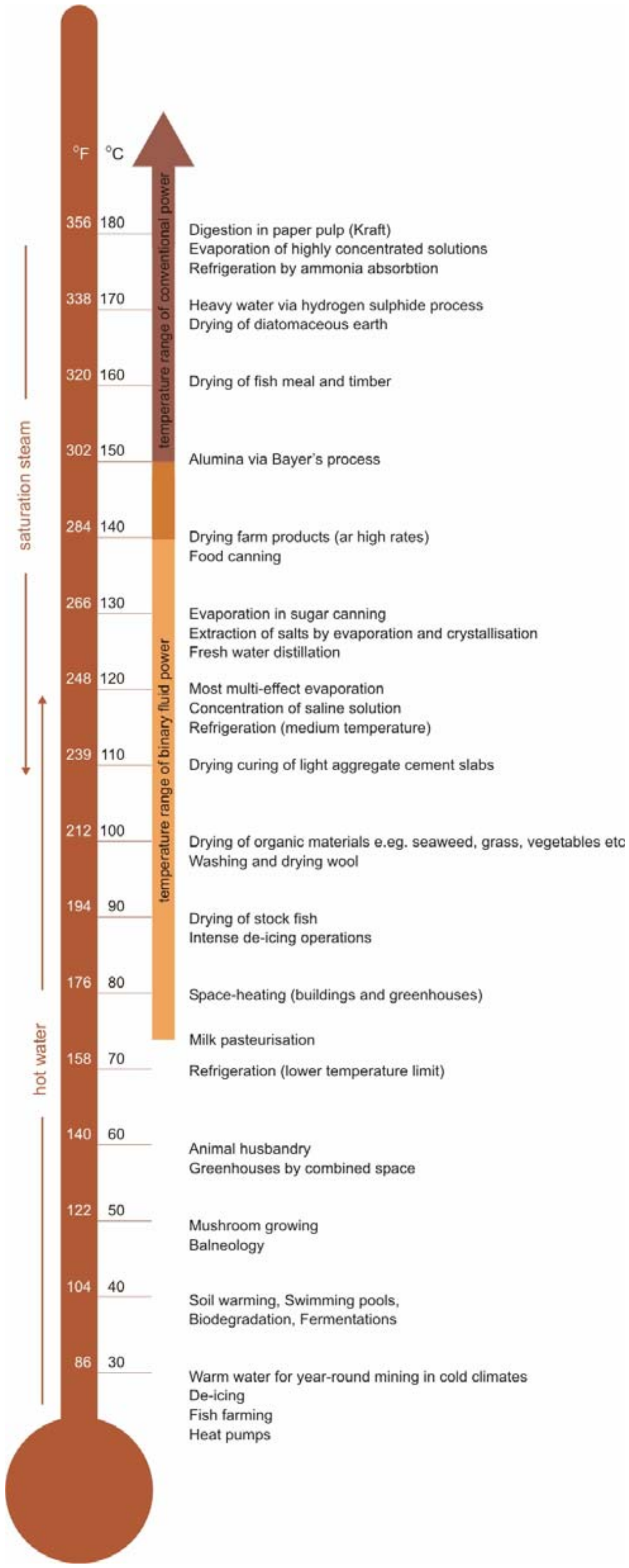

Figure 4. The revised Lindal diagram showing applications for geothermal resources.

Apart from mining heat, low temperature geothermal waters may also contain significant concentrations of chemical components such carbon dioxide, methane, helium, iodine, bromine and others, which may be extracted for commercial purposes. In New Zealand mineral waters from Bonithon-1 in New Plymouth, for example, are being commercially bottled. Specific thermal springs with temperatures of 50°C – 80°C yield bacteria used in biotechnology.

Currently, the main worldwide direct uses for low temperature geothermal resources are domestic heat pumps, bathing, space heating, greenhouse heating, aquaculture, industrial processing, and agricultural drying (Figure 5). Other applications include snow melting, fog dispersion, de-icing, textile dying, animal farming, desalination, methane extraction, spirulina production and milk pasteurisation.

Most processes requiring the input of heat can successfully use low temperature geothermal resources instead of, or as a supplement to, electricity, fuel-oil, or natural gas. If the temperature of the geothermal water is not sufficiently high for the desired purpose it may be heated to that temperature by other conventional means (such as electricity, coal or fuel oil), thus saving part of the cost of raising it from cold to the required temperature. This process is commonly used for domestic hot water heating where geothermal energy typically heats the water to 40°C, leaving electricity or natural gas to raise the temperature to the final 55°C.

Cost savings can be achieved by adopting integrated systems that, for example combine space-heating and cooling, or cascade systems where the applications are connected in series, each utilizing waste water from the preceding plant, for example electricity generation → greenhouse heating → animal husbandry.

With allowances for the nature of hot water and steam standard equipment, suitable for geothermal direct use projects, is readily available (see section 5).

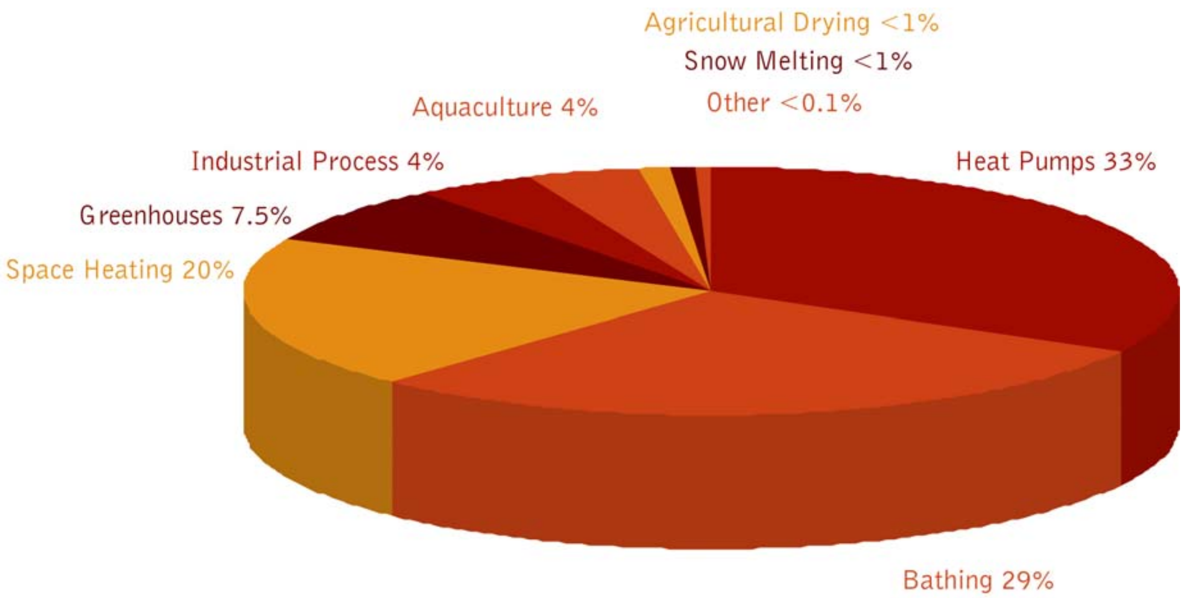

Figure 5. Worldwide uses of low temperature geothermal resources (data from Lund et al., 2005).

3.1 GEOTHERMAL SPACE HEATING AND COOLING

Many countries exploit geothermal resources for heating, and in doing so significantly reduce consumption of fossil fuels. In Iceland, for example, 86% of space heating is provided by geothermal energy saving the country up to $141 million/yr in imported oil (Ragnarsson, 1999). Iceland, Turkey, China and France are the world leaders in district heating, where geothermal fluid is supplied to multiple buildings for space heating and to provide hot water for domestic use. Geothermal heating may also be provided to individual users such as schools, prisons, hospitals and individual dwellings. This type of system is common in Australia, Russia, Japan and the USA.

High purity geothermal water can be piped directly to the users and through household radiators. However it is more common for heat exchangers to be installed to extract thermal energy from the geothermal waters. Radiant panel heating (pipes embedded in the floor) can use water at temperatures as low as 35°C – 40°C. Warm air heating systems use geothermal water-to-air heat exchangers.

3.1.1 Geothermal Heat Pump Technology

Heat flows naturally from higher to a lower temperature. Heat pumps, however, force the heat flow in the opposite direction, using a relatively small amount of electrical energy. Thus heat pumps transfer heat from low-grade energy, from natural sources in the environment, to useful higher-grade energy, which can be used for space heating or cooling, or to provide hot water.

Most installed heat pumps are air-sourced in which heat, drawn from the atmosphere outside the building, is transferred indoors. Although such systems have high efficiency (up to 5 times the heat generated from the electricity used), the efficiency decreases as the outside air temperature varies with the seasons. More efficient are Geothermal or Ground Source Heat Pumps (GSHP) which can be used anywhere because they do not need to access a source of geothermal energy.

Instead this system takes advantage of the fact that the ground below a depth of several metres, and natural water sources, remain at a near constant temperature. So in mid-winter ground and water temperatures are warmer than the air, and in mid-summer, they are cooler. In winter, heat is extracted from the earth and delivered to the home or workplace as warm air, through a ducted central heating system, or by delivering water to radiators or an underfloor heating system. In summer, heat is removed from the building and delivered for storage into the earth or water source.

Geothermal heat pump installations and energy use have increased markedly in the last 5 years, rising from about 14% of low temperature geothermal energy use in 2000 to 33% in 2005 (Lund et al., 2005). Extensive use is being made with these energy efficient systems in Europe and North America.

Heat pumps consume less primary energy than conventional heating systems, and thus are an important technology for reducing gas emissions that harm the environment, such as carbon dioxide, sulphur dioxide, ammonia and methane. Heat pumps driven by electricity generated from hydropower, geothermal or other renewable energy sources reduce emissions more significantly than if the electricity is generated by coal or natural gas.

3.1.1.1 Types of Heat Pump Systems

Closed Loop Ground Source Heat Pumps

The closed loop GSHP system relies on the soil, rock, groundwater, or surface water to provide or accept heat. A closed network of thermally-fused plastic tubing is buried in the ground and the heat is collected (or dissipated) by water or antifreeze circulated through the tubing by a small electric pump (Figure 6). No water enters the system from the ground.

The typical external closed-loop ground source system consists of polyethylene pipe, which is placed horizontally in a trench or vertically in a borehole (Figure 6). This thin walled pipe acts as a heat exchanger, which transfers heat from the ground to the heat pump working fluid via the unit's evaporator. The rate of heat transfer (conductivity) between the external loop pipe and the surrounding ground is determined by the thermal conductivity of the ground. This conductivity value is used in equations to determine the length of pipe required to achieve an adequate quantity of heat transfer for providing the required heat load.

The thermal behaviour of soils is primarily controlled by soil composition, soil moisture, vegetation and local climate. Soils can be divided into two main types: coarse-grained soils and fine-grained soils. Coarse-grained soils such as sand can be good conductors if there is ample moisture present. Dry coarse-grained soil is not a good conductor. The best types of soil tend to be sandy loams, sandy clay loam and loam. Moist soils conduct heat much better than dry soils. The heat extraction rate varies from 10 - 40 W/m^2 of ground surface depending on the following ground characteristics:

Favourable ground conditions:
Sandy ground, water saturated with high solar radiation; specific heat extraction rate 35 – 40 W/m^2

Normal ground conditions:
Humid, silty-sandy ground with average solar radiation exposure; specific heat extraction rate 20 – 30 W/m^2

Poor ground conditions:
Pumice soils, stony ground, dry ground and areas shaded from solar radiation; specific heat extraction rate 8 – 12 W/m^2

At between 1 – 1.5 m depths, the ground in New Zealand can be expected to have a year-round average temperature of 12 – 15°C.

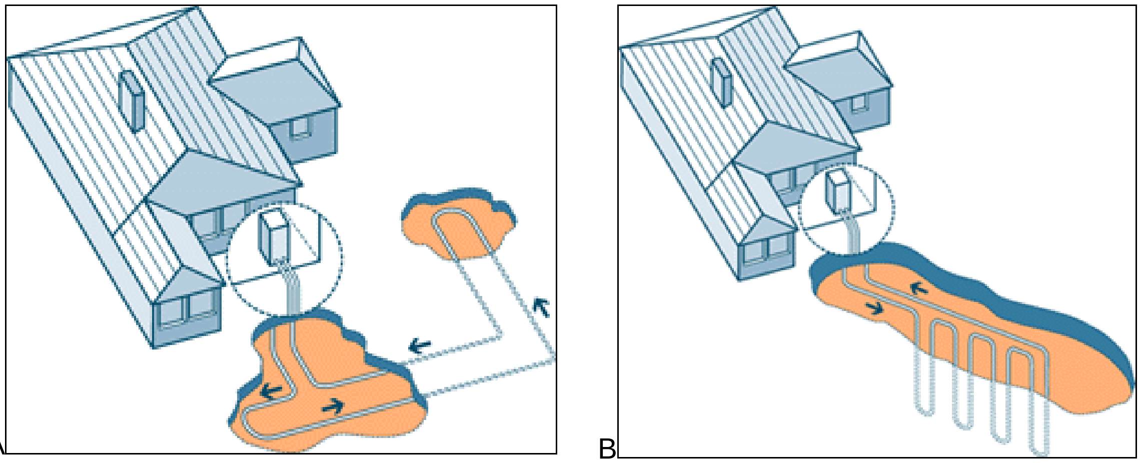

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Figure 6. Schematic diagrams of (A) closed loop and (B) earth-coupled Ground Source Heat Pumps. Images courtesy of Natural Resources Canada.

Open Loop Groundwater Heat Pump Systems

Open GSHP systems (also known as groundwater heat pump systems - GWHP) depend on having a ground water source available to accept or supply heat. Water-coupled systems can be either closed loop (in which the lake or groundwater is not taken and the heat is transferred using a confined liquid similar to an earth-source system) or open loop (in which the water is taken and returned to the lake or aquifer).

Open loop systems do not confine fluid to a loop of pipes. They use a pump to move water through the heat pump from a suitable water source (Figure 7). A river or lake water source could be used, but weed or debris pose system operational problems by blocking the water intake screen. For this reason, most open loop heat pump systems are best applied in situations where a house is served by its own water well. In such cases the water will be of good quality. A slightly larger well pump will be required to provide for water required by the heat pump. A disadvantage of using an open water system is the possibility of chemical scaling and heat transfer impairment from chemicals contained in the water. If the water source is hard then water softening treatment may be necessary.

A general rule is that for every kW of heating, a flow of 3.5 litres/minute (L/min) is required. Therefore a 6 kW system will require a flow of 21 L/min. Assuming that the heat pump operates for a maximum of 12 hours per day then the maximum water flow required to operate the 6 kW system will be around 15 tonnes/day. In New Zealand many Regional Councils will permit water to be taken in this order of magnitude without the need for a resource consent.

For open systems, a major consideration is the disposal of the water after it has passed through the heat pump. This could be to a surface disposal source such as to a river, pond or lake, but generally a separate well is used to re-inject the water back into the aquifer. The return well must be adequately isolated to allow the discharge water to reach the ambient temperature of the aquifer before being withdrawn again.

Assuming a house is to be served by its own pumped water well, the additional cost to enable this resource to be used as a heat pump source would be the cost of drilling a suitable re-injection well and the possible cost of a larger submersible pump. The same well can be used for both the take and return of the water, with the take and return points separated by a suitable vertical distance. This is referred to as the “standing well” method.

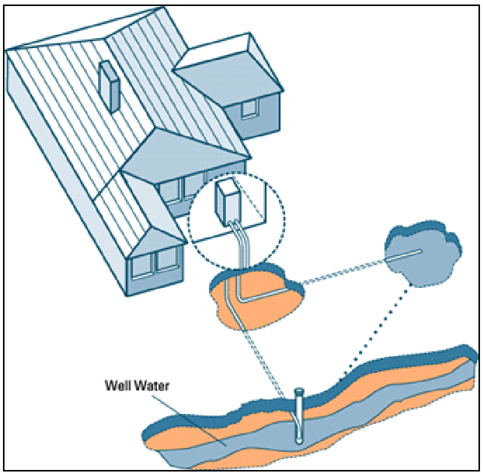


Figure 7. Example of an open loop, water-coupled Ground Source Heat Pump. Image courtesy of Natural Resources Canada.

3.1.1.2 Type and Length of Loop Pipe

Polyethylene is the only type of pipe recommended for external ground loops. This material is flexible, very resistant to weathering and has reasonable heat transfer characteristics. The life of the pipe for in ground installations is guaranteed for at least 30 years. The pipe can be easily jointed using heat fusion, which creates a very strong connection.

The length of subsurface pipe depends on several factors including the method of laying up pipe, energy load to be supplied, climate, location of the loop and ground thermal conductivity. Methods of laying up pipe in the ground include single layer, double layer and slinky coil. The various types of installation including trench details for a 6 kW heat pump installation can be found in Section 7.1.

From overseas experience the length per kW of heat load for a 25 mm diametre polyethylene pipe installed into "normal ground conditions" are:

- Single layer 36 m per kW
- Double layer 55 m per kW
- Slinky of 1 m diametre coils, 70 m per kW

Where there is no danger of pond, lake or river waterways freezing in the winter then laying a polyethylene pipe in the water source would form a very effective closed loop heat pump system. The minimum pond size for a 6 kW heat pump would be around 2 – 2.5 m deep and have a surface area of around 2000 m^2. The length of the loop pipe required for a 6 kW installation would be around 200 m.

3.1.2 Domestic Heat Pump Design

A heat pump can provide space heating by two methods.

1. By ducting warm or chilled air to various areas of the house that are to have their living space environment controlled.
2. By delivering warm water into an underfloor heating system. The underfloor heating system consists of a labyrinth of polyethylene pipes embedded in the concrete floor of the house. The embedded pipes are sectioned so that various areas of the house can be temperature controlled independently to suit the heating needs of the occupants. Domestic water pre-heating, up to around 40°C, can also be provided.

For living space comfort the under floor method is far better at providing space heating. However, this method cannot be used to provide space cooling. This is because if chilled water is circulated through the pipes, the concrete floor would be cooled below the moisture dew point and moisture in the air would condense out on the floor. This situation is not suitable for a domestic dwelling.

The design of the underfloor water heating system is common for any type of water heating system used whether for electric, natural gas or oil. The only difference with a GSHP system is that the pitch of the pipes embedded in the concrete may have to be slightly closer due to the system operating on water at 40°C instead of 50°C.

The great majority of heat pumps work on the principle of the "vapour compression cycle".

The main components in such a heat pump are the compressor, an expansion valve and two heat exchangers referred to as the evaporator and condenser. These components are connected to form a closed circuit as shown in Figure 8. A volatile fluid known as the working fluid (refrigerant) circulates through the four components. The working fluid is a liquid, which has a very low temperature of vaporisation.

In the evaporator the temperature of the liquid working fluid is kept lower than the temperature of the heat source, causing heat to flow from the heat source to the working liquid causing it to evaporate. The vapour from the evaporator is then compressed to a higher pressure causing its temperature to increase. The hot vapour then enters the condenser where it condenses and gives off useful heat. Finally, the high-pressure working fluid is expanded to the evaporator pressure and temperature in the expansion valve. The working fluid is returned to its original state and once again enters the evaporator to recommence the cycle.

Note:
The working fluid used in heat pumps is refrigerant R-22, which has an ozone depletion value (ODZ) of 0.5. This is 5% of the value of the most ozone damaging refrigerants R-11 and R-12. The R-22 refrigerant is not scheduled for phase out until 2030.

3.1.3 Advantages of Using Heat Pumps

Ground Source Heat Pumps have several advantages over air-sourced heat pumps in that they:

- consume less electricity
- have a stable energy source
- use less refrigerant
- have a simpler design
- have a lower environmental impact
- have lower annual operating costs

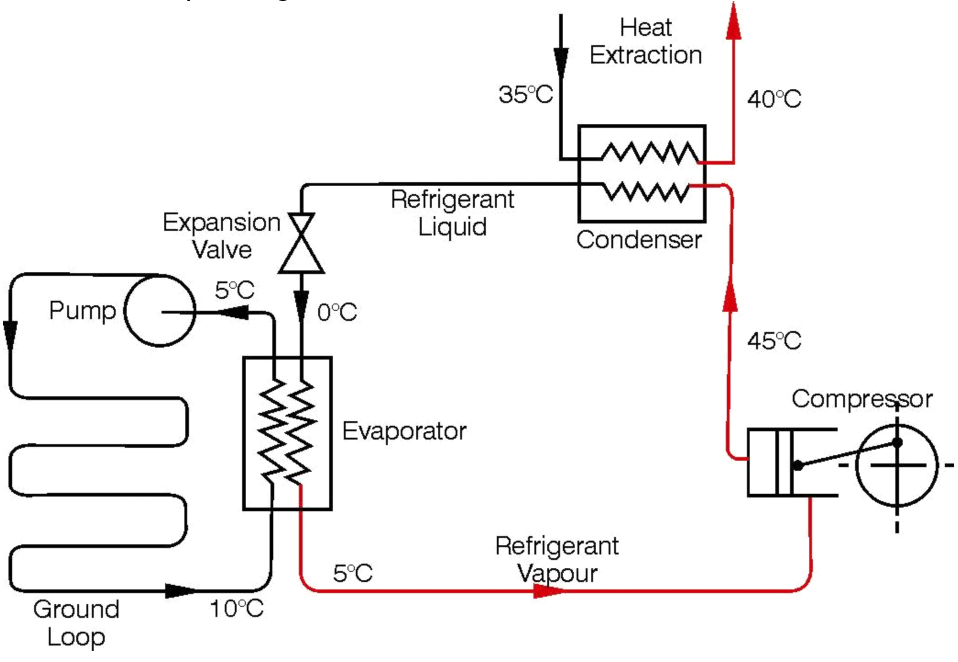


Figure 8. Schematic diagram showing main components of a heat pump.

In some places it may be possible to obtain a subsidy because of the reduced environmental impact. The main disadvantage is higher initial capital cost due to the need to bury the heat exchanger part of the system in the ground or drill a shallow well. If there is insufficient ground space for laying the horizontal configuration then either the tubing can be installed vertically or placed underneath the building before construction starts.

The most cost effective locations for geothermal heat pumps are:

- New construction
- Climates with high daily temperature variations, or where winters are cold and/or summers hot
- Areas where electricity costs are over $0.12/kWh
- Areas where natural gas is unavailable

Another advantage of ground-source heat pumps is that they require less floor space than conventional heating and cooling systems. The exterior system (the ground coil) is underground, so there are no space requirements for cooling towers or air-cooled condensers. In addition, the ground-coupling system does not necessarily limit future use of the land area over the ground loop. Interior space requirements are also reduced. There are no floor space requirements for boilers or furnaces, just the unitary systems and circulation pumps (Figure 9). Furthermore, many distributed ground-source heat pump systems are designed to fit in ceiling plenums, reducing the floor space requirement of central mechanical rooms. Compared with air-source heat pumps that use outdoor air coils, ground-source heat pumps do not require defrost cycles or crankcase heaters and there is virtually no concern for coil freezing. Cooling tower systems require electric resistance heaters to prevent freezing in the tower basin, also not necessary with ground-source heat pumps.

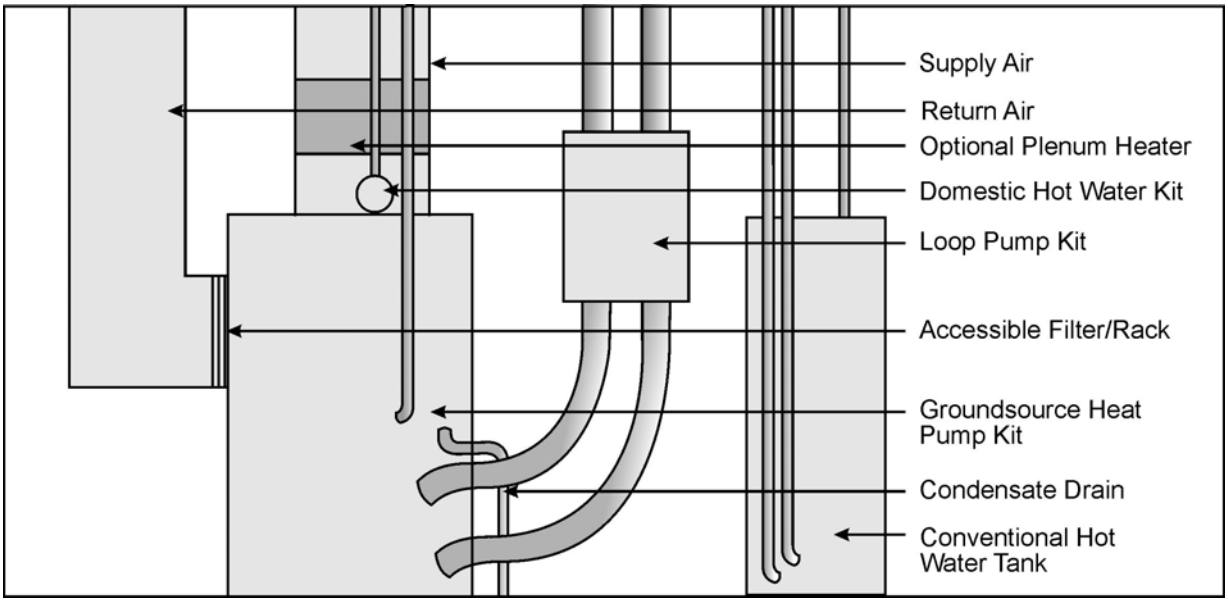


Figure 9. Installation of a domestic Ground Source Heat Pump.

3.1.4 Costs of Domestic Heat Pumps

3.1.4.1 House Heat Load

As an example, the heating needs for a typical new house built to the approved Energy Efficiency Building Code (NZS 4218:1996), and having a living space of 60 m^2 is considered. The maximum heat input needed to maintain the conditioned space at the desired comfort level during the coldest weather is given as 1 kW per 10 m^2 of floor space. Therefore the maximum heat load to be satisfied is 6 kW.

3.1.4.2 Capital Cost

As a rough order estimate a 6 kW geothermal heat pump, designed for heating duty only, will cost between $6,000 and $7,500, the ground loop installation, if installed in easily worked sandy soil, around $2,300, and the underfloor/domestic hot water (DHW) heating around $2,500, making a total installation cost of about $12,000. The installation of a similar capacity natural gas fired system is estimated to be $5,800.

3.1.4.3 Operating Costs

The savings made for the 60 m^2 house by using heat pumps instead of natural gas would be $797/yr. The present worth of this annual cost saving over 20 years at a discount rate of 8% is $7,825. See Section 7.2.3 for these calculations.

3.1.4.4 Heat Pump Efficiency

A measure of the energy performance of a GSHP system in heating mode is its Coefficient of Performance (COP). This is the amount of thermal energy delivered by the heat pump divided by the amount of electricity required to operate the heat pump (Equation 1). If a heat pump delivers 6 kW of thermal energy and requires 1.5 kW of electrical energy to operate the system then this unit would have a COP of 4.

$$\text{COP} = \text{Heating Capacity (kW)/ Electric power input (kW)} \qquad \text{Equation 1}$$

The performance of a GSHP system depends on the efficiency of the heat and circulating pumps, the effectiveness of temperature transfer in the ground, and the characteristics of the groundwater. The coefficient of performance for a geothermal heat pump increases as the ground temperature increases. The efficiency of the GSHP systems as compared to other heating systems is shown in Figure 10.

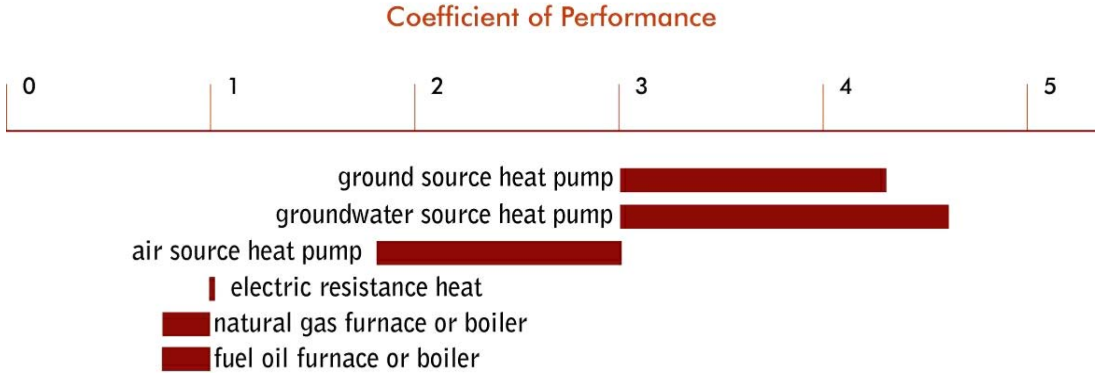


Figure 10. Efficiency of various types of domestic heating systems.

Table 1. Heating and cooling "degree day" data for Blenheim from 1991-2000 (NIWA).

Heating Degree Days													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Min	17	7	37	131	202	235	291	257	203	136	84	34	1901
Max	92	85	119	228	320	360	388	340	290	216	178	117	2248
1991/00 Ave	**46**	**42**	**83**	**159**	**237**	**308**	**343**	**307**	**235**	**171**	**134**	**70**	**2091**
Cooling Degree Days													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Min	8	4	0	0	0	0	0	0	0	0	0	0	66
Max	88	92	41	6	0	0	0	0	0	1	17	52	241
1991/00 Ave	**32**	**29**	**12**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**21**	**108**

The heat pump is the largest single energy consumer in the system and, in putting together an efficient system, this must have the greatest possible efficiency. It is difficult to compensate for a low efficiency heat pump by increasing the size or efficiency of other parts of the system. In hot, humid climates where the prime use of the GSHP is for air-conditioning, it is recommended that a heat exchanger be added to the high side of the refrigerant loop (to capture waste compressor heat) for heating domestic hot water.

3.1.4.5 Heat Pump Duty Requirements

The need for an additional cooling function for the pump can be assessed by studying how much heating or cooling is required in that particular geographical location using heating and cooling “degree day” data. In New Zealand this data can be obtained from NIWA for a small cost.

Degree-days are the difference between the daily mean temperature and 18^{o}C, the designated optimum temperature for comfort when no additional heating or cooling is required. If the daily mean temperature is greater than 18^{o}C, the difference is expressed as “**Cooling Degree Day**”; and if the mean daily temperature is less than 18^{o}C the difference is expressed as “**Heating Degree Day**”.

Table 1 shows the 10 year average “degree day” heating and cooling data for the Blenheim area for 1991 to 2000. It also shows that the cumulative temperatures below 18^{o}C (heating degree days) for each month of the year are higher than cooling degree days from 1991-2000 in Blenheim. Thus installing a reversible unit to provide for space cooling is not really necessary.

3.1.5 Commercial Heat Pump Applications

The following are examples of larger commercial ground source heat pump applications in the world.

Heat Loop Piles

At the new Geneva Airport terminal building (completed 1998) the structure required sinking approximately 130 piles about 25 m into the ground. Incorporated into each of these piles was a portion of a large heat pump ground loop. These loops were connected in parallel acting as the ground heat exchanger for a heat pump capable of providing all of the space heating needs for the new terminal building. Not all the loops fitted to the 130 foundation piles were used on the initial installation. Some were kept to provide increased future uses and some as spare loops in case of a loop failure. The size of the heat pump installation is not known but anticipated to be around 2 MWt.

Small Scale Central Heat Distribution Systems

In some European new housing schemes the developer provides a large heat pump installation capable of providing a supply of hot water at 40°C to each house for under floor heating and partial domestic hot water supply. The supply of hot water to each house is metreed and charged for at a suitable profitable rate by the developer. The size of heat pump installation is 100 to 300 kWt

Commercial High Rise Building

In Nottingham, United Kingdom a 12 story commercial office block has been fitted with a dual heat pump system coupled to a 6 x 5 array of 30 bores with an average separation distance of 8 m and to a depth of 15 m in the car parking area. The two heat pumps are interlinked so that when one unit is providing heat input to the shaded side of the building, the other unit can be providing cooling to the sunny side. The system allows the heat energy removed, from the offices being cooled, to be used in the heat pump providing heating to the shaded offices. The size of the heat pumps is not known.

Schools

In the USA heat pumps are being widely used to provide space heating and cooling in schools. These facilities lend themselves to back fitting such a heating system as they usually have large playing field areas into which the ground loop can be installed.

3.2 BATHING AND DOMESTIC USE OF HOT WATER

Thermal waters have temperatures at least 5°C higher than the average ambient temperature. This means that the lower range of temperatures of thermal waters varies widely with the climate. In most cultures of the world, thermal waters have traditionally been used for bathing, cooking, and therapeutic and medicinal purposes with specific springs kept sacred for spiritual ceremonies.

Nowadays spas and swimming pool complexes, with hot waters from hot springs and/or boreholes, are centres for healing, relaxation and tourism in more than 50 countries, including Japan, New Zealand, China, Indonesia, the Philippines, the USA, Canada, Iceland, Ecuador, Mexico, England, Russia, Italy, Germany and the Czech Republic. There are often undeveloped natural hot springs frequented only by trampers, and used for bathing, in remote places of these countries.

Geothermal district heating systems in countries like Iceland also provide geothermal hot water for domestic use and bathing complexes.

3.3 AQUACULTURE

The aim of geothermal aquaculture is to heat water to the optimum temperature for aquatic animal and plant growth. Species typically raised include carp, catfish, bass, tilapia, mullet, eels, salmon, sturgeon, shrimp, lobster, crayfish, crabs, oysters, clams, scallops, mussels and abalone. In addition, there is a rising interest in aquaculture crops such as water hyacinth, duckweed, algae species, kelp and spirulina.

A total of 16 countries have aquaculture installations and below are some examples.

- Wairakei (New Zealand) - Malaysian Freshwater Prawns (*macrobrachium rosenbergii*) are farmed at 24°C to produce about 16 tonnes of prawns per year. Water for the ponds comes from two sources: a plate heat exchanger (55°C) that takes wastewater from the Wairakei Geothermal Power Plant and Waikato River water (10°C).

- Hagerman, Idaho (USA) – catfish and tilapia, native to Africa, are bred in tanks using 32°C water from eight geothermal wells, approximately 300 m deep.
- Klamath Falls, Oregon (USA) – more than 100 different varieties of high-value freshwater tropical fish are raised in ponds heated to 27°C by geothermal water from a 50 m deep well.
- Slovakia – wild eels are caught and raised in circular tanks heated to 25°C by geothermal water from a well 220 m deep.

3.4 TIMBER DRYING

Natural air-drying of timber is slow, and expensive. For plantation grown Radiata pine in New Zealand the natural drying process results in uneven and unpredictable product quality. This wood is characterised by high moisture content, low density and strength, and proneness to fungal and insect attack.

Kiln drying is the quickest and simplest way to add value to this timber. A timber-drying kiln is a large oven in which the enclosed heated air is circulated to draw moisture from the timber and then exhaust it to the atmosphere. The heat energy is generally supplied by hot water at high pressure and temperature to heat exchangers in the kilns. Where available geothermal steam, usually half the cost of other fuel sources, can be used as the heating source.

A timber drying kiln is a proprietary item of equipment and the kiln supplier will design the kiln to suit the drying schedule the kiln will operate on and size the kilns heating elements to suit the heat energy source to be used. Figure 11 shows a typical end view of a timber-drying kiln.

In general it takes around 570 kW of thermal energy to dry one cubic metre of Radiata pine lumber and the rate of applying this energy to the timber dictates the drying schedule, type of kiln utilized, and quality of lumber produced. Heat energy is supplied to the kiln through aluminium finned steel core heating tubes through which high temperature water is circulated. Motor driven fans circulate hot air over the heating elements at velocities of 5 - 8 m/sec and heat the air to the required drying schedule temperature (usually 80°C - 140°C). As the circulating air picks up moisture from the wood, a portion of the air is vented and replaced with dry outside air.

3.4.1 Timber Drying Schedules

Indicative geothermal fluid flow rates required to service the following drying schedules can be found in Section 7.3.

3.4.1.1 High Temperature Schedule

The High Temperature (HT) drying takes between 15 to 24 hours for 50 mm thick lumber, requiring an initial maximum thermal heat energy input of 3 MW and an average heat input over the whole drying cycle, of around 1.9 MW for a kiln having a drying chamber capacity of 55 m^3. Heating the drying air to 120°C requires geothermal water to be supplied to the kiln heating elements at a temperature of at least 140°C, to exit the heater at around 90°C.

HT drying does not adversely affect the wood properties of Radiata pine. However, degradation, such as internal checking, kiln brown stain, and residual stress, detracts from its use for appearance lumber, which will be subsequently re-machined. All HT dried lumber must receive final saturated steam conditioning to reduce moisture content variation and relieve any high level drying stress associated with the HT drying process. Steam saturation is achieved within the drying chamber by generating steam in a water bath, via hot pipes boiling off the water.

3.4.1.2 Accelerated Conventional Temperature Schedule

For drying appearance grade lumber the Accelerated Conventional Temperature (ACT) drying schedule of 90/60°C (dry/wet bulb) is the preferred method, resulting in a dried product that can be further machined without warping. The ACT drying schedule takes 48 to 60 hours for 50 mm thick lumber and requires a maximum heat input of around 1.2 MWt for a kiln having a drying chamber capacity of 55 m^3. The average energy required over the whole drying cycle is around 0.75 MWt. To heat the drying air to 90°C will require at least 110°C geothermal water being supplied to the kiln heating elements and this will exit the heater at a temperature of 70°C. ACT dried lumber has also to receive final steam conditioning to reduce moisture content variation and relieve any drying stresses.

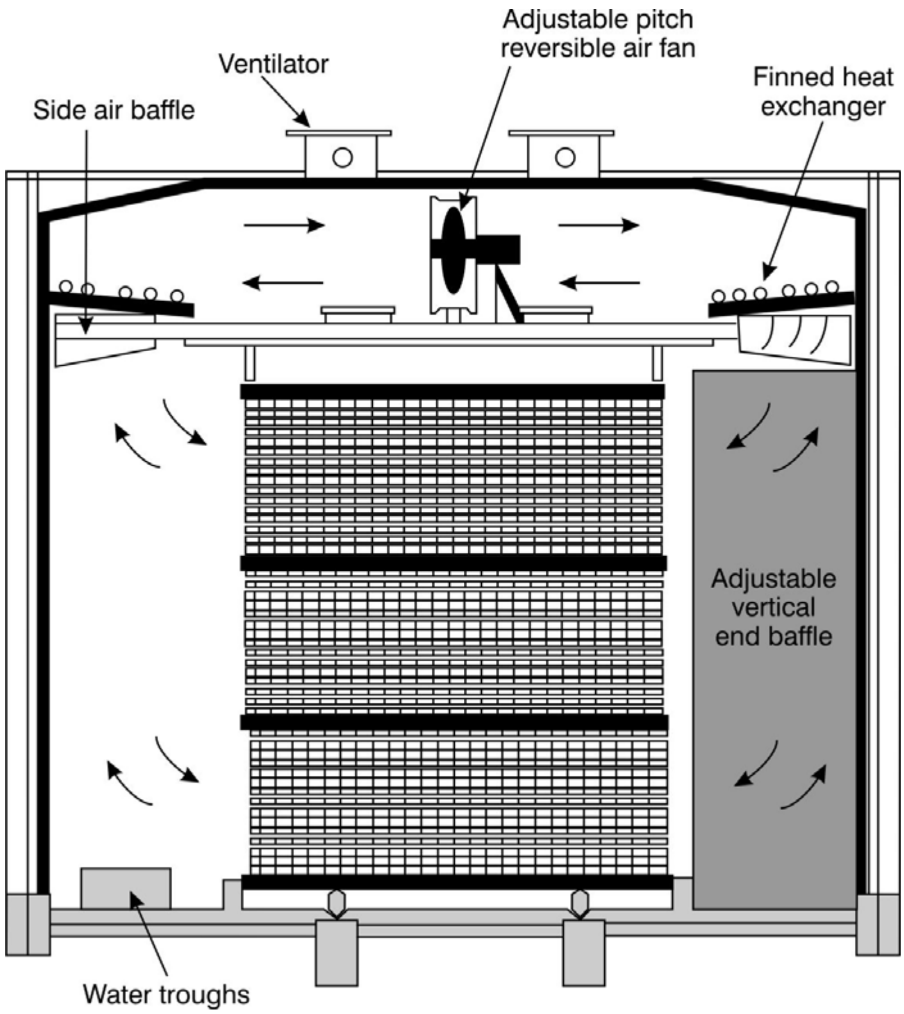
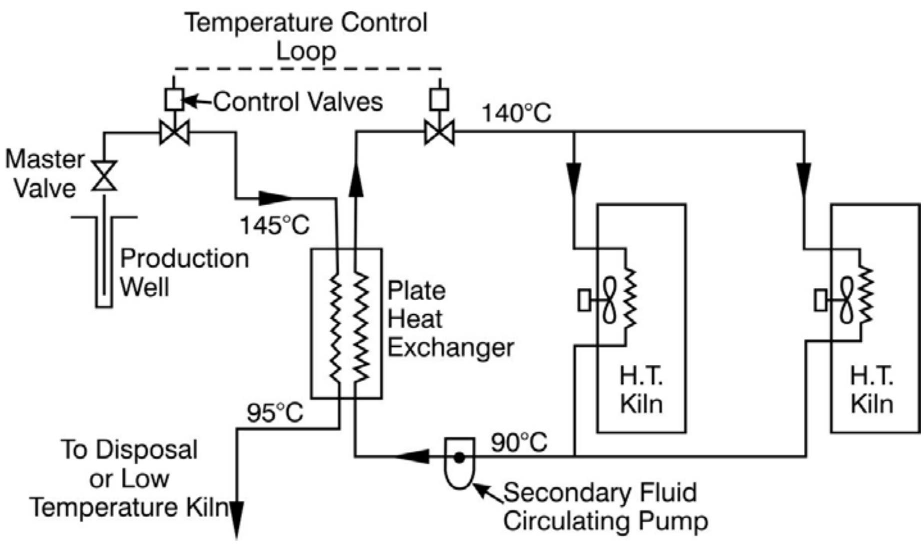


Figure 11. End view of a typical timber-drying kiln.

3.4.1.3 Low Temperature Schedule

The Low Temperature (LT) drying schedule is best suited for drying large section lumber such as 100 mm squares or large cross sectional structural beams. Kilns operating on this schedule can therefore serve a niche market for these types of lumber products. The LT schedule drying time is around 15 days. Drying is carried out at 70°C dry bulb and 50°C wet bulb temperatures. A kiln with a drying capacity of 55 m^3 requires a maximum heat input of 0.5 MWt. Heating the drying air to 70°C will require at least 90°C geothermal water being supplied to the kiln heating elements, to exit the heater at a temperature of 60°C.



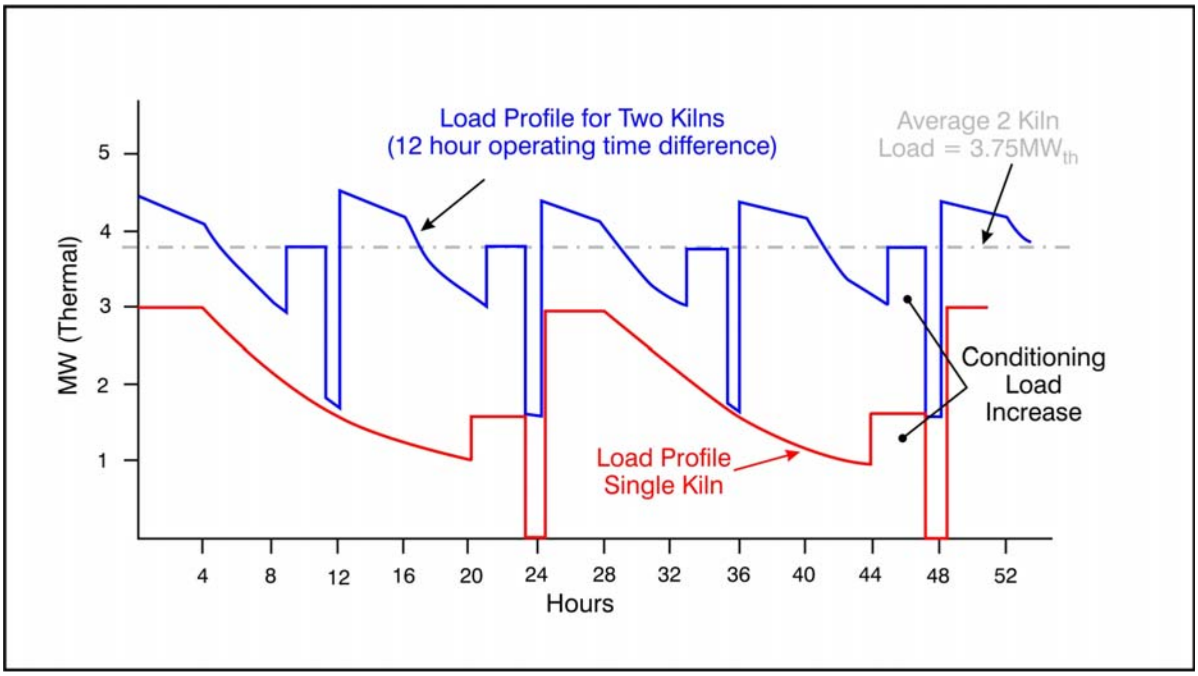


Figure 12. Schematic diagram of thermal load profile for a double High Temperature drying kiln installation.

3.4.1.4 Multiple Kiln and Cascade Kiln Operation

If a sizable geothermal resource is available a more even well loading can be achieved by operating multiple drying kilns in parallel but on a staggered operational cycle. Figure 12 shows a double HT drying kiln installation and the resulting energy load curve. Residual useful energy available in the geothermal fluid after providing energy to the HT kiln heat exchanger could be used to supply the energy requirements for LT kilns.

3.4.2 Costs of Timber Drying

3.4.2.1 Capital Costs

A budget cost for the procurement and installation of a single 55 m^3 HT drying kiln is $800,000 and for a similar sized ACT kiln the cost would be around $610,000.

Budget cost for geothermal production/re-injection wells and pipe work could be of the order of $600,000 for both HT and ACT kiln systems.

3.4.2.2 Operating Costs

A cost estimate of drying timber using geothermal energy is $518k and $375k per year for HT and ACT kilns, respectively (see Section 7.3 for details). If a suitable cascade geothermal fluid source is obtainable from a power plant then the geothermal energy supply cost would be significantly reduced.

3.4.2.3 Carbon Tax Savings

The New Zealand Government decided not to implement the carbon tax in 2005. However the calculation of carbon tax savings by using renewable sources of energy such as geothermal, for timber drying, are shown in Section 7.3.3.

3.5 GREENHOUSE HEATING

Geothermal fluids can be used to heat, irrigate or sterilize soil in open-field agriculture or, more commonly, to create a microclimate in a greenhouse for the cultivation of mushrooms, vegetables or flowers, out of season or in an unnatural climate. Heating can be accomplished by forced circulation of warm air and/or hot water circulating in pipes or ducts located in or on the floor or in the soil. In virtually all operating systems, the geothermal fluid is used in a hot water heating system to meet both the maximum and annual heating requirements of the structure.

3.5.1 Greenhouse Heating Systems

The greenhouse heating system is mainly dictated by the type of crop being grown. Tomatoes and peppers require heat to be supplied around the plant canopy, thus the heating pipe should be above the ground. In contrast, root crops like calla lilies require heated ground and in this case, the heating pipes should be buried in the ground.

To heat a greenhouse, temperatures of geothermal water should be between 60°C and 80°C. The quantity of hot water required will depend upon the optimum growing temperature for the selected crop (Table 2), size of the greenhouse, and the lowest outside temperature expected in the area. However, more often than not, the choice of heating system is not dictated by engineering considerations, such as maximum use of the available geothermal resource or even the most economical means, but by grower preference.

Table 2 Growing temperatures for typical greenhouse crops. Data obtained from Geothermal Direct Use Engineering Design Guidebook published by Geo-Heat Centre, Oregon Institute of Technology.

Produce	**Day Time Temperature (°C)**	**Night Time Temperature (°C)**
Peppers	20 - 30	16 - 20
Tomatoes	21 - 25	17 - 20
Cucumber	25 - 28	21
Lettuce	25	20
Poinsettias	21 - 27	19 - 22
Carnations	25	10
Geraniums	21 - 27	18

There are four basic methods of providing and distributing heat into a greenhouse. They are bare pipe, finned pipe, fan coil air heater for space heating and buried pipe for soil heating.

Bare Pipes

Bare pipe is just that: exposed pipe circulating water heated by geothermal energy. Figure 13 shows the heating input arrangement for a greenhouse growing tomatoes and capsicum. The bare tubes are 50 mm diameter and flow and return pipes are mounted close to the ground. The heating pipes in this system also act as rails for a powered harvest trolley.

Figure 13. Greenhouse heating system using bare 50 mm diameter steel tube.

Finned pipe

For large heat load duties in which close control of the process is required the conventional approach is to use a fan and heat the air by cross-flowing the air through a bank of finned tubes. The most commonly used finned tubing for air-heating service is bimetallic tubing with high length aluminium fins bonded onto a carbon steel pipe. Geothermal fluid or clean process fluid heated by geothermal energy in a plate heat exchanger is passed through the steel pipe and transfers its heat energy through to the aluminium fins, which transfers to the air being forced past the tube by the fan. The main difference between finned pipe and bare pipe is in the heat transfer coefficient per unit length of pipe.

Fan coil air heating

Fan heaters consist of aluminium finned heating coils through which hot water at around 100°C is passed, and an electric fan directs air though the outer finned surface of the coil. These are pre-designed units and can be obtained in either vertical or horizontal discharge configuration and are generally hung from the greenhouse structure at roof level. The warmed air is discharged directly into the greenhouse or into an array of perforated plastic distribution tubes. Forced air distribution systems can also be used to facilitate the distribution of carbon dioxide (CO_2) into the greenhouse to enhance the growing environment.

Soil heating
Tubes, through which warm water is circulated, are buried in the floor of the greenhouse to heat the soil. Heat from the warm water is transferred through the tube to the soil and, eventually to the air in the greenhouse. In the past, the buried tube material was generally copper, but because of cost, polybutylene is now the preferred material as this material can withstand temperatures up to 75°C.

A soil heating system is preferred by many growers because it results in very even temperature distribution from floor to ceiling and does not obstruct floor space. However, its ability to supply 100% of the heating requirements of a greenhouse necessitates a rather mild climate and a low inside design temperature. In order to increase the inside air temperature the temperature of the soil has to be increased and this can cause problems with overheating the plant root system. As a result, this system is generally employed in conjunction with an air space heating system such as a fan coil heater.

For greenhouse heating it is common to use finned tube, bare steel or plastic pipes placed on the ground or fitted under growing benches to provide for space heating needs. For undersoil heating, plastic pipe is generally used.

3.5.1.1 Heating Control Systems

As daytime temperatures increase due to seasonal and/or daily temperature changes then the flow of geothermal water to the greenhouse heat exchangers would be cut back. Heat load requirements would be automatically adjusted using signals from temperature sensing instrumentation.

Regulating the heat input into the greenhouse in a hot water heating system is achieved by bypassing a portion of the return cool fluid into the input leg of the heating system. A 3-way auto control valve, using input data from temperature sensing instrumentation located inside and external to the enclosure, controls the amount of fluid by-passed and thus the temperature of the water circulating through the heating pipes (Figure 14).

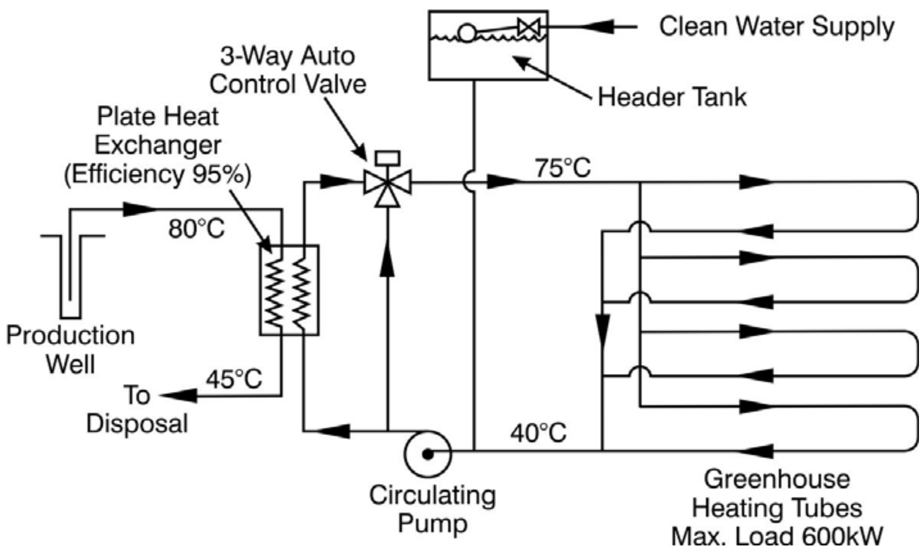


Figure 14. Schematic diagram of greenhouse heating system.

3.5.2 Determining Greenhouse Heating Requirements

To select a heating system and the load requirements for a greenhouse there are a number of calculations required (see Section 7.4). The maximum heat load should be designed to meet the structure's heating needs on all but 20 to 25 hours of the year, as the cost of designing a heating system to meet the most severe climatic conditions would become uneconomic.

Calculating the maximum heat load and seasonal heat loads (Figure 15) for the structure requires access to long term average daily temperature minima and maxima for the specific area.

For example, for a greenhouse (28 m x 90 m) with a growing surface area of 2520 m^2 (~0.25 hectare), an internal volume of 8,911 m^3 and a total surface area exposed to outside air temperature of 3,466 m^2, with a growing temperature maintained at 28°C and a minimum outside temperature of 4°C, the maximum heat load to maintain growing at the desired temperature during the coldest weather is 595 kW.

For a geothermal fluid input temperature of 80°C, with an exit temperature of 45°C, a pinch temperature of 5°C and 95% heat transfer efficiency of the plate heat exchanger:

- The geothermal fluid flow rate and secondary water flow in the greenhouse heating circuit required to satisfy this maximum thermal load are 4.4 kg/sec and 4.2 kg/sec respectively.
- The length of 25 mm aluminium finned pipe would be 1982 m, at a cost of $34,000.

See Section 7.4 for all of these calculations.

3.6 OTHER EXAMPLES OF DIRECT USE APPLICATIONS

There is a wide variety of other direct uses of low temperature geothermal resources, some of which are detailed below.

Agricultural crop drying
Apart from timber, discussed above, a variety of plant crops are dried in 10 countries using geothermal energy. Crops include garlic, onion, chilli, rice, wheat, fruit, alfalfa, seaweed, and coconut.

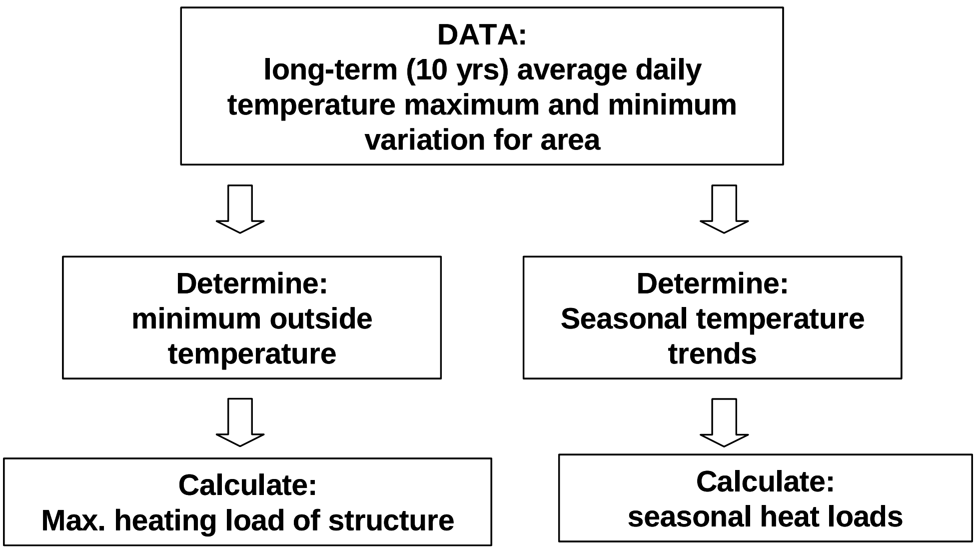


Figure 15. Determining heat load requirements.

Snow melting (USA)
A glycol solution (54°C), heated by geothermal water, is circulated through piping installed on bridges, approaches and footpaths to keep them ice and snow free.

Water desalination (Greece)
The use of low temperature geothermal resources (52-76°C) for thermal distillation desalination schemes to solve fresh water supply problems is currently being investigated.

Biotechnology (USA)
The bacteria *Thermus Aquaticus*, originally found in certain 50-80°C thermal springs in the USA, provides an enzyme that is widely used in medical diagnosis and forensics.

Industrial processing
Nineteen countries utilize geothermal heat and fluids for a wide range of industrial processes such as concrete curing, oil recovery, paper and pulp processing, processing of leather, bottling of water and carbonated drinks, salt extraction, diatomaceous earth drying, laundry use, animal husbandry and the extraction of chemicals. Some examples are shown below:

- Wool processing (China) – Geothermal water from a deep well is used to heat water (50°C) to wash wool, and air (70-90°C) to dry the wool. Waste water from the driers is then used to heat greenhouses and fish ponds.
- Milk pasteurisation (USA) – Geothermal fluid supplies a heat exchanger which heats milk (78°C) for the pasteurisation process, and also heats the building in winter months.
- Digestion of sewerage sludge (USA) – The sewerage treatment scheme uses geothermal heat to dry digested sludge (58°C).
- Cloth dyeing (Japan) – Geothermal energy is used as a heat source and geothermal water as a mordant (a chemical that fixes with the dye on a substance by combining with the dye to form an insoluble compound). Hydrogen sulphide, the main active ingredient in the steam, has a de-colouration effect for dyed fabrics. Control of these factors, as well as the mixing ratio of dyes, create uniquely beautiful patterns.
- Carbon dioxide recovery (Turkey) – Approximately 90% of Turkey's carbon dioxide (CO_2) for carbonated soft drinks is obtained from waste fluids at Kizildere field. CO_2 can also be used to promote plant growth in greenhouses.
- Helium recovery (India) – 90 L/day of 97% pure helium is cryogenically extracted from geothermal waters at Bakreswar.
- Extraction of chemicals (China) – In addition to a yearly production of 10,000 tonnes of table salt, the wells yield 0.5 tonnes of iodide, 18.8 tonnes of bromine, 40 tonnes of boron, 5.8 tonnes of aluminium carbonate, and 480 tonnes of 6% ammonia water and other trace elements.

Freezing of ice (Alaska)
A novel use of geothermal energy is somehow counter intuitive but it works. Geothermal heat from a well discharging waters (75°C), powers an ammonia-based refrigeration system that cools the Ice Museum at Chena Hot Springs in Alaska, during summer. Heat extracted from geothermal waters (via a heat exchanger) is enough to run the compressor in the refrigeration unit that keeps the gigantic igloo frozen.

4.0 DIRECT USE IN NEW ZEALAND

New Zealand Maori traditionally use hot springs for bathing, cooking, food preparation, space heating, medicinal purposes and sources of traditional products, such as red ochre and clay.

Scientific studies of hot springs in the 19th to the early 20th centuries were focused on the baleonological (bath science) and therapeutic properties of the hot waters, following the short-lived dream of the New Zealand government to create a spa of the South Seas, 19,000 km from Europe. Government sanatoriums or mineral water hospitals were built around springs in Rotorua, Te Aroha and Hanmer, and health spas and bathing areas were built in 30 other springs such as Waiwera, Te Puia, Parakai, Okoroire and Maruia. During the 20th century, soda water from Te Aroha, Paeroa and Puriri were bottled.

Nowadays industrial process heating, agricultural drying and domestic space heating account for a large proportion of the energy from direct use of geothermal energy, but bathing is still the most common use for low temperature geothermal waters (Table 3).

4.1 BATHING

Thermal pools contain either town supply freshwater heated by geothermal energy, or are fed directly by geothermal water ("mineral" pools).

4.1.1 Freshwater Pools

The Aquatic Centre, Rotorua

The Aquatic Centre in Rotorua (Figure 16) is a relatively large-scale public swimming pool facility which uses geothermal energy to heat town supply water. Although the heat source in this area is from a high temperature system, it could equally have been sourced from a low temperature system. This complex has two indoor swimming pools and a larger outdoor pool. All three are geothermally heated. All of the geothermal fluid is passed through a single plate-type heat exchanger, which heats the secondary town supply water.

Geothermal energy is also used for space heating and for domestic hot water heating at the centre. Because of the high capacity of the geothermal heating system, the supply for showers and hand basins is heated on an as-required basis, avoiding the cost of installing a large storage tank. The cold mains water feed is passed through a small heat exchanger

Figure 16. The Aquatic Centre Rotorua (Anderson, 1998).

Table 3. Direct use examples of low temperature geothermal resources in New Zealand (from Mongillo and Clelland, 1984 and unpublished GNS Science studies in 2003-2006; see Appendix 1 for more applications). s= spring; d= drillhole

Location	Temperature (°C)	Flow Rate (L/s)	Use
North Island			
Ngawha[s]	40-50	2	Bathing and therapeutic use of waters and mud (commercial); mercury extraction in the past
Kamo[s]	up to 25	<1	Bathing (public); past use by sanatorium and hospital
Waiwera[s]	45-52	1	Bathing (commercial pool complex, residential), bottling of mineral water
Parakai[s,d]	up to 65	1	Bathing (commercial pool complex, several motels, an apartment complex and residential)
Te Maire (Naike) [s]	52-93	10	Bathing (public but need to inform land owners)
Hot Water Beach[s]	54-63	<1	Bathing (public, with baths at Motor Camp)
Te Aroha	59	<1	Bathing and therapeutic use of waters (commercial)
Waingaro[s]	37-54	6	Bathing (commercial pool complex)
Miranda[s,d]	56- 64	7[s]	Bathing (commercial pool complex)
Papamoa	25	<1	Raise and quarantine tropical fishes
Paengaroa	37	<1	Bathing and therapeutic use of waters
New Plymouth	29	3.1 (artesian)	Bathing and therapeutic use of waters; bottling of mineral water
Kawerau	up to 100	-	Industrial processing, greenhouse, electricity generation (binary plant), space heating
Awakeri[s,d]	49-70	1[d]	Bathing (commercial pools)
Lake Rotokawa[s,d]	45-52, 29-99		Space heating (motel, school, greenhouse)
Tikitere[s]	30-99	<1	Bathing, space heating
Rotorua[s,d]	up to 100	-	Bathing (commercial pools and residential), space heating (domestic and industrial), timber drying, soil sterilization
Waikite	up to 99	1.5-3.5[s]	Bathing (commercial pools)
Golden Springs	40-50	9-40[s]	Bathing (commercial)
Ohaaki	25-95	<20	Heating greenhouses in the past
Mokai	up to >100		Greenhouse heating
Wairakei and Poihipi	up to >100	-	Bathing, fish farming, space heating, flower growing
Taupo-Tauhara[s]	up to >100	20[s]	Bathing, greenhouses, domestic space heating
Tokaanu[s]	19-98	1-15[s]	Bathing (commercial and domestic pools), domestic heating
Morere[s]	up to 62		Bathing (commercial pool)
Te Puia[s]	59-70	2-3	Bathing (private hot pool; hospital therapy pool)
South Island			
Hanmer Springs[s,d]	32- 50	8[d]	Bathing (commercial pool complex)
Maruia Springs[s,d]	up to 60	1.5[d,s]	Bathing (commercial pools and spas)

fitted with an automatic temperature control. There is a small buffer tank in the circuit, sized to absorb variations in temperature in the hot water caused by large changes in demand.

To minimise chlorine odour, a once-through ventilation system with a relatively high air flow rate has been installed. No air is re-circulated. The incoming air is heated using geothermal energy to maintain the building's internal temperature. A heat recovery unit significantly reduces the high heat losses that would otherwise occur. The hot, moist, chlorine-laden air being extracted is passed through a heat recovery unit, which uses it to preheat the incoming air. This unit recovers about 75% of the heat in the exhaust air. The heating of fresh air is completed by a heating coil through which low temperature hot water is circulated.

The Aquatic Centre has annual maintenance costs for its geothermal system of about $15,000. If natural gas were used to provide the energy, the gas cost would be around $125,000.

4.1.2 Mineral Pools

There are more than 100 mineral springs used for bathing in the North and South Islands, including:

- Commercial complexes with swimming pools and spas, like Miranda Hot Springs in the Waikato,
- Hot pools dug at the edge of a cold stream, like Sylvia Flats in the South Island or at the tide level of Kawhia Beach on the eastern shores of the Tasman Sea, and
- Warm well bore waters fed directly to swimming pools.

Waters from source springs, some greater than 50°C, are cooled to about 35 - 42°C by adding cold water.

One of the most picturesque mineral springs in the North Island is Morere in the East Cape, located in a lush bush reserve famous for its rainforest and nikau palm groves. The unusually saline spring waters contain high concentrations of iodine and are light brown in colour. Waters from the 50 - 62°C source spring are piped directly into a large indoor 36°C pool and two private pools kept at 40°C. The outdoor pool, containing fresh cold water, was built in 1936.

The Miranda Hot Pools complex has a swimming pool with 39°C water, spa at 40°C and a 42°C sauna with induced bubbles. The pool is mainly fed by water from a borehole with 55°C water that cools naturally to 39°C from borehole to pool, and by about 6 springs bubbling at the bottom of the swimming pool. There are two other boreholes used for winter back-up. One of the three springs northwest of the swimming pool, with discharge temperature of 55°C, is used as the source for the sauna and spa, with another spring used as back-up. Water for the 39°C swimming pool in the Miranda Springs Holiday Park, adjacent to the Miranda Hot Pools, is pumped from a 100 m deep drillhole with 56 - 60°C discharge waters. No chlorine is added to the waters.

Bathers in mineral springs of New Zealand are cautioned to keep their heads above the water to avoid amoebic meningitis and to resist prolonged exposure to hot water. Pregnant women, the elderly and persons with medical conditions such as heart disease, diabetes and blood pressure problems should consult their doctors first. Certain medications that may cause extreme drowsiness should be avoided when entering hot springs. Preferably, bathe in a hot spring with a friend.

4.2 AQUACULTURE

The Prawn Farm in Wairakei, Taupo

Malaysian Freshwater Prawns (*macrobrachium rosenbergii*) are farmed in nine ponds (24°C), varying from 0.2 to 0.35 ha in area and 1.0 to 1.2 m in depth, within a 10.2 ha area. A temperature probe controls the flow of water into the ponds and an aerator is used to obtain vertical mixing of the pond water to ensure a constant temperature throughout the depth of each pond.

The life of the prawn starts in salt water inside a building (Figure 17) in breeding tanks, proceeds to nursery tanks (28°C) and ends in the freshwater ponds outside (24°C) where they are harvested after 9 months' growth, averaging 30 to 40 per kg (about 30 g each).

At present, the farm produces about 16 tonnes of prawns per year, of which 90% are sold in the adjacent restaurant. Over a recent three-year period, the restaurant has served more than 30 tonnes of prawns to more than 45,000 visitors. The farm is also a commercial tourist attraction with visitors able to have a half-hour tour of the hatchery, five times each day.

Water for the ponds comes from two sources: a plate heat exchanger (55°C) that takes wastewater from the Wairakei Geothermal Power Plant and Waikato River water (10°C). The geothermal water from the power plant cannot be used directly in the ponds due to the presence of sulphur, lithium and arsenic. Instead the geothermal water flows through a heat exchanger. Water is re-circulated throughout the pond system from a storage and settling pond, kept at 21°C. This heat requirement could be supplied by a low temperature geothermal source.

Prawn farming is labour-intensive with high overheads. Factors which have contributed to the success of the farming are the availability of cheap hot water, cheap flat land and tourism in the area.

4.3 TIMBER DRYING

The New Zealand forestry industry is based on plantation grown pine (*Pinus radiata*). Compared to many other timber species, pine has very high moisture content (up to 130% by weight) and must be dried to set the sap and prevent warping. The sap usually sets at 57 -

A B C

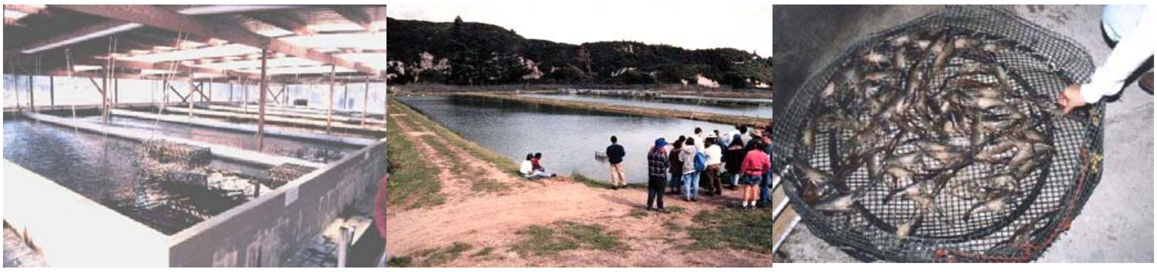


Figure 17. Views of the (A) breeding tanks, (B) outdoor freshwater tanks and (C) harvested prawns from the prawn farm in Wairakei, Taupo (Lund and Klein, 1998).

60°C, and warping is prevented by establishing uniform moisture content through the thickness of the wood, best achieved in a kiln. The use of geothermal steam as a heat source for the kilns, in the Taupo Volcanic Zone, to dry lumber adds value to this resource and makes good business sense.

Timber Drying, Kawerau

Plantation grown pine (*Pinus radiata*) is dried in a geothermal drying kiln associated with the Pulp and Paper Plant at Kawerau (Figure 18). This kiln uses an inlet steam temperature of 180°C, which produces a temperature of 150°C in the kiln.

Batches of 80 - 100 m^3 of sawn timber, each piece separated by about 2 cm using spacers, are moved into the kiln on three rail-mounted tracks. Fans (2 m diameter) produce an air flow velocity of 9 m/sec across pipe heat exchangers, and the circulation direction is automatically reversed by computer every 1.5 hours. Once moisture is reduced to 10% after about 20 hours, the timber is put through a cool-down period for 2 hours, and finally reconditioned for 6 - 8 hours at 90 - 100°C which increases the moisture content to 20%. This creates uniform moisture content throughout each piece of timber. The typical dimensions of timber dried in kilns is 60 x 120 cm. Wider planks require a lower drying temperature of 120°C and longer time. The dried product is stained by sap on the surface, which is removed in the finish planing operation. The entire procedure is monitored and controlled by computer. The final product sells in New Zealand for $250 - 350 per m^3 thus adding 50 - 100% to the price. Kiln drying costs about US$35 per m^3 of which geothermal energy is about 5 - 10% of this cost.

4.4 GREENHOUSE CULTIVATION

Tomatoes and Capsicums, Mokai

Tomatoes and capsicums are grown in greenhouses by Gourmet Mokai Ltd on the Mokai Geothermal Field (Figure 19). They are grown in a 5.5 ha climate-controlled glasshouse for New Zealand and export markets. Gourmet Mokai Ltd is the result of a joint venture between Tuaropaki Trust and Gourmet Paprika Ltd. Gourmet Paprika had an international market demand to meet year round and was also looking for ways to reduce costs such as heating and CO_2. Tuaropaki (who own the Mokai Geothermal Field resource) were looking for ways of commercialising its resources (Te Puni Kokiri).

The glasshouse complex at Mokai consists of two 25000 m^2 compartments with a dividing wall between, half dedicated to capsicum and half to vine tomato production. Each half is split further into eight compartments of 6250 m^2. Ventilation for the system is achieved through vents in the roof. The crop is grown using a hydroponics type method where each plant is individually fed with water and fertiliser (Nederhoff, 2003).

Figure 18. Geothermal timber drying at Kawerau (Scott and Lund, 1998).

The heat for the glasshouse is from geothermal fluids obtained from Tuaropaki well MK-2. The heat is extracted with the aid of a heat exchanger and a heat storage tank (buffer). At the well, the steam comes out of the ground at 170°C and is transported to the glasshouse site through an insulated steel pipe. The heat exchanger transfers the heat from steam to water in a closed circuit, which then heats up the water in the heat storage tank. An open buffer system allows the system to retrieve heat at any time of day or, in contrast, to add heat to the buffer at any time of day. This allows a constant temperature within the greenhouse to be maintained. Pipe rail heating is used in every path of the greenhouse, which acts as rails for a trolley. The tomato greenhouse has additional smaller pipes that can be elevated to the height of the plant heads (Nederhoff, 2003).

Currently Gourmet Mokai is investigating options for CO_2 enrichment in the greenhouse. Increased levels of CO_2 enhance the growth of the produce, and currently this enrichment is supplied by bulk CO_2 stored in a tank being distributed through the system. The off-gases from the power station contain high levels of CO_2, which could potentially be used as an enrichment source. However, the CO_2 is mixed with other gases, including H_2S, which are toxic to the plants. GNS Science is working on technology to separate CO_2 from other gases, so it can be used to enhance plant growth.

Orchids, Wairakei

Tropical orchids (*Phalaenopsis*) are grown in greenhouses by Geotherm Exports on the Poihipi Geothermal Field (Figure 20). In nature, these plants live on the surface of trees (epiphytes) and their stems hang downward, with the leaves arranged in a spiral fashion. However, under cultivated conditions the flower stems are tied vertically and grow upward. They are shade-loving plants, requiring a light intensity of only 10% of full sunlight (10,700 lux).

The orchids are grown for cut-flower production in artificial monsoon conditions, similar to their natural habitat in the rainforests of Southeast Asia. This enables production at any time of the year to meet market demands in Japan and elsewhere. The company has approximately 250,000 plants in its greenhouses, laboratory and quarantine area. Of these, 30,000 are mature plants. Each plant produces, on average, two stems of blooms each year upon reaching maturity (two years old) and these blooms are specially packed to produce the best possible return from overseas markets. An individual plant-performance recording system enables the company to breed selectively. In addition to good breeding, parent plants must also have good colour, shape of bloom, and be prolific in their bloom production per stem, to qualify as breeding stock.


Figure 19. Eight week old capsicums (left) growing inside 5 hectares of geothermally heated greenhouses (right) (Photos used with permission of Nederhoff, 2003).

The greenhouses cover an area of 0.8 ha and are kept at temperatures of 26°C during the day and 21°C at night. The greenhouses are heated using a small amount of steam from three wells which supply the nearby Poihipi power plant. The heating is computer-controlled and supplied to the greenhouse by large hot water heaters (using fans and finned heat extractors) or by steam radiators and fans. The peak energy supplied to the greenhouses is about 55 kW. This heat requirement could be wholly or partly supplied by a low temperature geothermal source.

Fertiliser is applied daily through a series of computer-controlled electric solenoids so that each plant can take both water and fertiliser up through the capillary watering system used on the growing tables. This enables the plants to be fed and watered without water lying in the leaf joints, which would cause plant rot and subsequent death. The lighting system produces light in an oblong pattern, so that light is not wasted on the pathways. The amount of light applied is measured by comparing light received by an exterior light sensor and light sensors in each growing area. The computer turns on the lighting system, until the amount of light applied reaches the required level for maximum growth.

Air samples are collected at 15 minute intervals and passed through a gas analyser to assess the level of CO_2 in each greenhouse, compared with pre-set levels in the computer, and if additional CO_2 is required, this is applied to each orchid table though micro tubes.

5.0 INSTALLING A DIRECT USE SYSTEM

With allowances for the nature of hot water and steam, standard and readily available equipment are suitable for geothermal direct use projects.

The major components of a direct use system are:

- Downhole and circulation pumps
- Transmission and distribution pipelines
- Peaking and backup plants
- Various heat exchange mechanisms

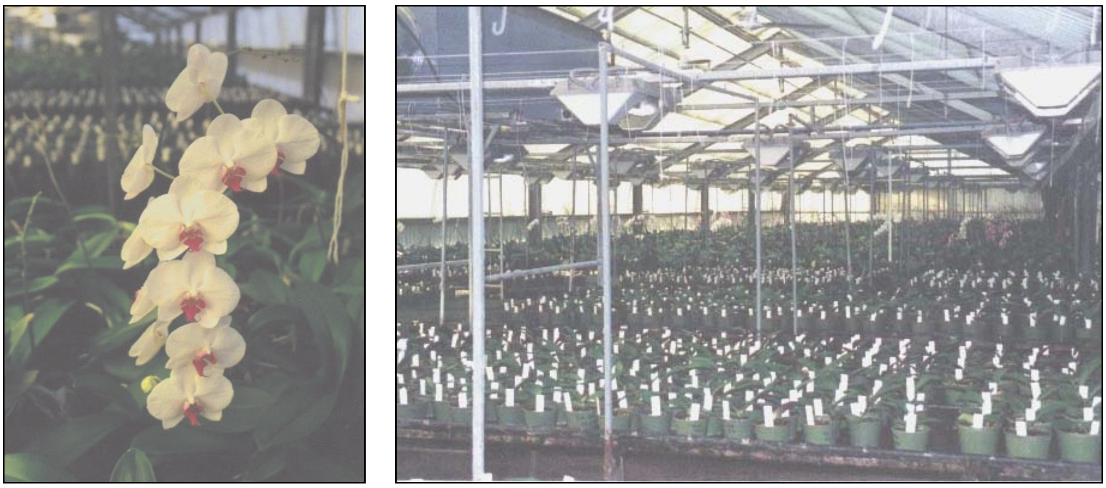


Figure 20. Orchid Phalaenopsis (left) grown in a geothermally heated greenhouse (right) (McLachlan, 1998).

5.1 DRILLING AND WELL CONSTRUCTION

5.1.1 Well Design Considerations

Well design involves specifying well depth, casing diameters and materials to be used in the construction of the well. The depth is determined by that required to obtain sufficient flow and/or temperature of fluid for the intended use.

The controlling factors are depth to aquifer, thickness of the aquifer, transmissivity or permeability of the aquifer and flow requirements. In a developed reservoir much of the information relating to depth, thickness etc, of the aquifer will be fully documented and one need only follow local practice. However, if aquifer conditions are not known then it will be prudent to engage a qualified geologist to thoroughly review the available geological information before undertaking the well design.

5.1.2 Well Drilling

Well drilling is a major cost of any direct use geothermal project. Tapping a shallow reservoir is carried out using a rotary drilling rig and normally proceeds in stages. The casing and wellhead differ for pressurised aquifers and non-pressurised aquifers.

There are several versions of rotary drilling rigs but in all cases, the fundamental principle is the same. A drill bit is rotated by a hollow drill string driven by a hydraulically rotated turntable located on the drill rig operating platform. As the drill penetrates the ground additional sections of drill pipe are added until desired drill depth is reached. During the drilling operation, fluid is circulated down the drill pipe and through the drill bit where it serves to clean cuttings from beneath the bit, cools the bit, and then carries cuttings to the surface.

5.1.2.1 Pressurised Aquifers

If a pressurised aquifer is being tapped, a surface casing followed by a slightly smaller diameter anchor casing is cemented into the ground. This forms the pressure containment portion of the well. Next the production section is drilled and the steel production liner inserted and cement grouted into position to prevent cold groundwater or subsurface water from invading the hot fluid production zone. The last part of the well to be drilled penetrates the hot fluid production zone. This section, depending on geological conditions, may be left as an open hole or fitted with a slotted liner, which acts as a coarse filter to prevent debris from entering the well. Figure 21 shows typical casing details for a pressurised geothermal well.

The cost of a deep 100 mm diameter pressurised production well drilled to a depth of 400 m would be roughly NZ$150,000. The cost can vary depending on geological conditions encountered.

5.1.2.2 Non-pressurised Aquifers

If a non-pressurised aquifer is being tapped then there is no need for the well to have pressure containment casings. However, it will be necessary to fit a steel production casing and cement grout this in position, so as to prevent cold groundwater or subsurface water from invading and cooling the hot fluid. Figure 21 shows typical casing details for a non-pressurised well fitted with airlift facilities.

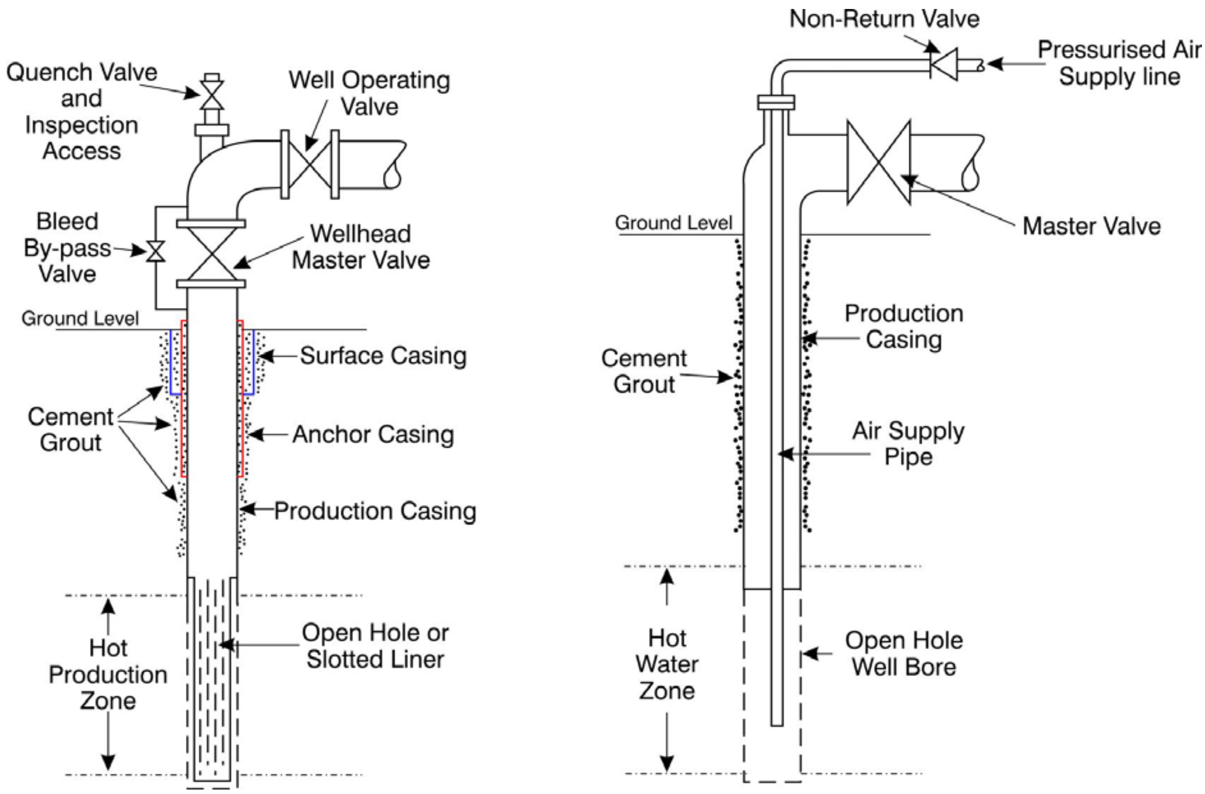


Figure 21. Casing and wellhead details of a pressurised well (left) and non-pressurised well (right).

To enable a non-pressurised well to discharge it would be necessary to install a downhole pump to bring the hot geothermal fluid to the surface where it can be utilized. Alternatively air can be injected into the base of the well to reduce the density of the fluid enabling the well to self-discharge. With these well discharge methods thermal outputs of from 1 - 4 MW can be achieved. An alternative method of tapping a non-pressurised well is to install a Down Hole Heat Exchanger (DHE). However the heat output is much less, typically 200 kW maximum.

The average cost of drilling a non-pressurised well to a depth of 80 m is estimated to be around $25,000.

5.1.3 Construction Materials

5.1.3.1 Well Casings

As corrosion can be a problem in shallow wells it is advisable to use thicker gauge casings or apply a corrosion resistant coating, especially to sections located above the bore standing water level.

Typical well casing sizes for a deep production well are:

- Surface casing 250 mm diameter by 10 m length
- Anchor casing 150 mm diameter by 30 to 40 m length
- Production casing 100 mm diameter by 50 to 120 m length
- Open hole or slotted liner length approximately 5 to 10 m

5.1.3.2 Piping Materials

The source of geothermal fluids for a low temperature direct use application is often located some distance away from the end use. This requires a transmission pipeline to transport the geothermal fluid to that end use and to carry the cooled geothermal fluid to where it can be disposed of, to a re-injection well or some environmentally acceptable source.

Both metallic and non-metallic piping can be considered for geothermal applications, although care must be exercised in the use of non-metallic materials as these materials have restrictive operating temperature and pressure limitations. The advantage of non-metallic materials is that they are virtually impervious to most chemicals found in geothermal fluids.

Carbon steel is the most widely used metallic material and has an acceptable service life, if properly applied, and can be used for all temperature and pressure conditions likely to be encountered in any geothermal low temperature application.

Fibreglass (RTRP) commonly referred to as Reinforced Thermosetting Resin Pipe can only be obtained in pipe sizes 50 mm and above. The two materials used in the manufacture of this pipe are epoxy resin and polyester resin. Both epoxy resin and polyester resin materials can be compounded to be serviceable up to temperatures of 150°C. Regardless of type of fibreglass material used, care must be taken to maintain operating pressure high enough to prevent flashing of hot fluids. RTRP systems are susceptible to damage when water flashes to steam. The forces associated with the flashing may spall the fibres at the interior of the pipe surface and thus reduce its mechanical strength.

Polyvinyl Chloride (PVC) is a low temperature rigid thermoplastic material with a maximum service temperature of 60°C. It is manufactured in 12 to 300 mm diameter and is a very commonly available piping material. Most likely use would be for carrying cooled geothermal fluid to the reinjection well or approved disposal site.

Polyethylene (PE) is in the same chemical family as polybutylene and both materials have similar physical characteristics. It comes in pipe sizes from 12 to 1000 mm diameter. The material has a maximum operating temperature of 70°C.

Cross-linked Polyethylene (PEX) is a high-density polyethylene material in which the individual molecules are “cross-linked” during production of the material. The effect of cross linking imparts physical qualities to piping which allow it to meet higher temperature/pressure applications. PEX piping carries a nominal rating of 6.5 bar at 80°C.

5.2 HEAT EXCHANGERS

Heat exchangers transfer heat from the geothermal fluid to a closed process fluid loop. Most geothermal fluids, because of their elevated temperatures, contain a variety of dissolved chemicals. These chemicals are frequently corrosive towards standard materials of construction. As a result, it is advisable in most cases to isolate the geothermal fluid from the process to which the heat is being transferred.

There are a number of different types of heat exchangers. The transfer of heat can be carried out using a plate heat exchanger or a shell and tube heat exchanger. The main advantage of the plate heat exchanger over the shell and tube system is their superior thermal transfer performance and smaller space requirements. However, they are generally more expensive than a simple shell and tube exchanger.

Table 4. Comparison between exchangers.

Plate Heat Exchanger	Shell and Tube Heat Exchanger
Maximum design ratings 150°C and 20 bar	Operate at much higher temperature and pressure
Flow rates 2 – 1500 tonnes/h	Flow rates 2 – 1500 tonnes/h
Excellent thermal energy transfer characteristics; 3000 - 4000 $W/m^2/°C$	Lower thermal energy transfer characteristics; 1000 - 1500 $W/m^2/°C$
Lower surface heat transfer area – smaller unit size – lower capital costs	Larger surface heat transfer area – larger space requirements – higher capital costs
High pressure drop across exchanger – larger pump size and pressure head – higher operating costs	Low pressure drop across exchanger – smaller pump size and pressure head – lower operating costs

For smaller systems downhole heat exchangers (DHE) provide a unique means of heat extraction. The DHE eliminates the requirement for the physical removal of fluid from the geothermal resource. For this reason, DHE-based systems avoid entirely the environmental and practical problems of geothermal fluid disposal.

Heat exchangers, regardless of type, are selected to transfer a specific quantity of heat under a specific set of conditions. The key parameter in this selection process is the heat transfer area required to accomplish the task. An example calculation for determining the heat transfer area of a plate heat exchanger can be found in Section 7.5.

5.2.1 Plate Heat Exchanger

The plate heat exchanger is basically a series of individual plates form-pressed with a series of continuous indentations, such that when the plates are assembled together and pressed tightly between two heavy end covers by tie bolts, these indentations form an extensive flow path for the circulating fluid. Gaskets placed between the individual plates deliver hot geothermal fluid and clean fluid to be heated into alternating plate flow paths. The unit can be easily dismantled to facilitate cleaning of the individual plates. The nature of flow through a plate heat exchanger is shown in Figure 22.

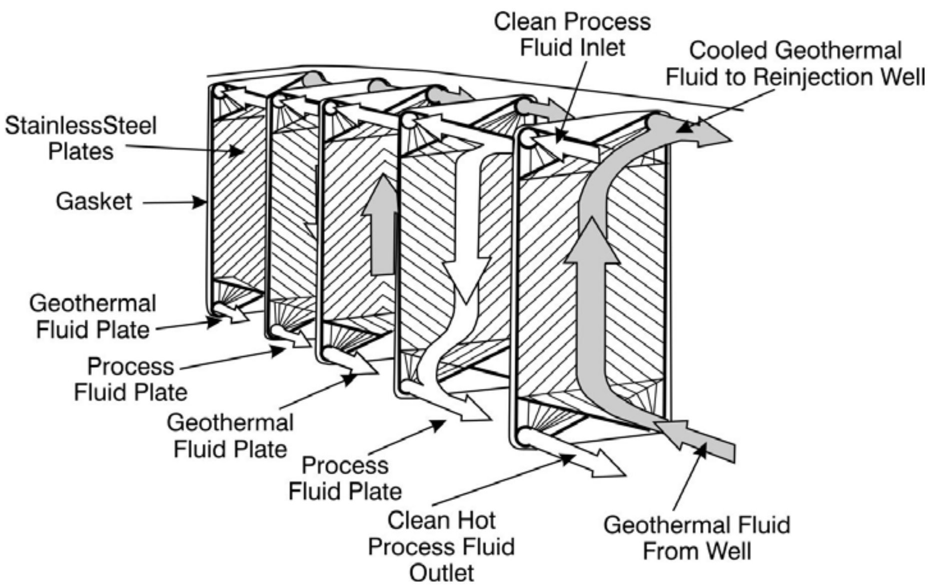


Figure 22. Nature of fluid flow through a plate heat exchanger.

Figure 23. Wairakei Prawn Farm heat exchangers.

In order to facilitate cleaning of the plates it is normal practice to install two 100% duty plate heat exchangers. This enables one unit to be taken out of service for cleaning, while the second unit takes up the full service load. Figure 23 shows the dual plate heat exchanger plant arrangement at the Wairakei Prawn Farm.

5.2.1.1 Advantages and Limitations

Plate heat exchangers are relatively low-pressure low temperature devices and current maximum design ratings are temperature 150°C and 20 bar. The temperature is limited by the gasket material used and a good performing material for geothermal applications is fluorocarbon (common name “viton”). The largest units are capable of handling flows up to 1,500 tonnes/h and the smallest flows of around 2 tonnes/h.

For direct use geothermal applications, the choice of plate material is generally between; 304 stainless, 316 stainless, and titanium. Titanium is only required when the temperature and chloride requirements are in excess of the capabilities of 316 stainless.

Plate heat exchangers have excellent thermal energy transfer characteristics. Typical estimates of heat transfer coefficients (U-value) for a plate heat exchanger operating with geothermal fluid and clean water are 3000 - 4000 W/m^2/°C. This high thermal transfer performance enables the equipment to operate with very small approach temperature differences e.g. 2 to 3°C difference between the temperature of the geothermal fluid entering the heat exchanger and the temperature of the heated clean fluid leaving the unit. This high thermal transfer performance does come at the expense of having a higher pressure drop across the plate heat exchanger compared with the shell and tube unit.

If geothermal steam is being used then partial condensation will likely occur within the tube bank or between the plates of the heat exchanger. As the geothermal steam will contain a small fraction of gas, mainly carbon dioxide and a small amount of hydrogen sulphide, it will be necessary to provide a flow path to remove these non-condensable gases. If these gases are not removed they will accumulate within the heat exchanger and blanket the heat transfer surface and severely affect the performance of the equipment.

5.2.1.2 Selection

The selection of a plate heat exchanger is a trade off between the heat transfer coefficient (U-value), which dictates the surface heat transfer area of the unit and hence the capital cost, and pressure drop, which influences pump size and its pressure head and hence operating costs.

Selection of a plate heat exchanger is normally left to the company providing the unit as they have proprietary selection data pertaining to their equipment. The purchaser has to provide details of the duty the heat exchanger has to perform and details of the quantity and temperature of geothermal fluid available. However there are some general formulae, which the purchaser can apply to refine flows and temperatures prior to seeking a formal quotation for the equipment.

5.2.2 Shell and Tube Heat Exchanger

Standard shell and tube heat exchangers consist of a cylindrical shell with multiple tubes running inside the shell. Figure 24 shows the typical components of a shell and tube heat exchanger. One fluid passes through the tubes and then exits the heat exchanger; the other fluid circulates on the outside of the tubes within the cylindrical shell. Heat is transferred from one fluid to the other through the walls of the tubes. The flow path of the fluid within the cylindrical shell is directed through the vessel by means of baffles, which has the effect of increasing the flow path and thus contact time of the fluid heat transfer interchange.

Shell and tube heat exchangers can operate at far greater pressure and temperature conditions than a plate heat exchanger although, as already noted, they do not possess such good heat transfer characteristics as the plate heat exchanger.

5.2.2.1 Advantages and Limitations

Shell and tube heat exchangers are generally constructed from carbon steel when operating with a closed secondary process loop fluid. For open secondary services, such as a swimming pool, heating 316 stainless steel should be used. Because of the risk of chemical scaling on the geothermal fluid side, this fluid should flow through the tubes, as easy access for their cleaning can be obtained by removing the heat exchanger end heads. Heat transfer coefficient (U-value) for shell and tube heat exchangers working with geothermal fluid and clean water are generally between 1000 to 1500 W/m^2/°C, i.e., less than half that of a plate heat exchanger. However, the pressure drop is much less.

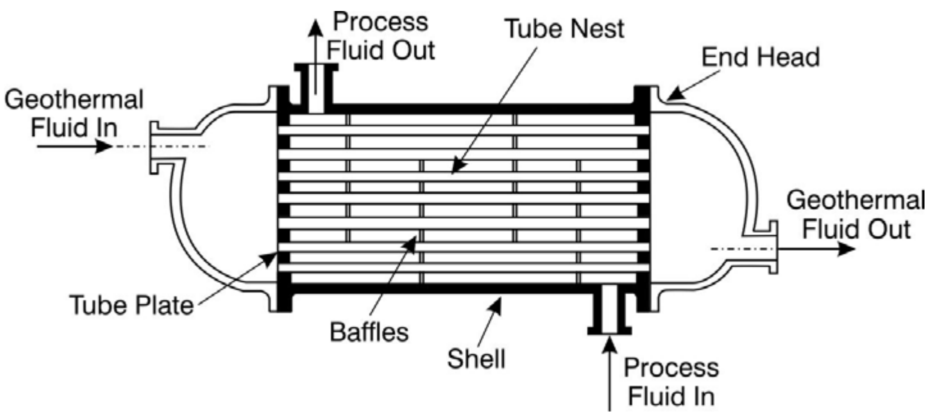


Figure 24. Typical shell and tube heat exchanger.

5.2.3 Down Hole Heat Exchanger

The down-hole heat exchanger (DHE) eliminates the problem of disposal of geothermal fluid, since only heat energy is taken from the well. The simplest and most commonly used downhole heat exchanger consists of a pair of tubes connected at one end by a “U” bend through which clean secondary water is pumped (Figure 25). The tubes are suspended from the well casing surface flange and project deep into the water level of the geothermal reservoir.

In order to promote maximum output, the well should be designed to have an open annulus between the wellbore and casing, and perforations through the casing wall located above and below the U tube heat exchange surface. This arrangement of casing design is termed a “promoter casing” as it promotes natural circulation of the hot geothermal fluid up the well annulus through the upper perforated section of the casing and down the inside of the casing. This allows the hot geothermal fluid to sweep the U-tube heater legs thus transferring heat to the clean fluid being circulated through the tubes. The cooler geothermal fluid then exits the casing via the lower perforated section.

In New Zealand the DHE has generally been used for small domestic installations serving a few households or an industrial application requiring a thermal output of around 100 to 150 kWt. Overseas DHE installations are credited with outputs of several MWt. DHE have been installed in wells of up to 200 m depth. However, because of the low output from these devices it is generally economic to operate DHE only in wells of less than 100 m. Figure 25 shows a typical downhole heat exchanger system fitted with a promoter casing.

The diameter of a DHE well is dictated by the diameter of the U-tube pipes. If these are 50 mm then the U-tube would have to be installed in a casing having an internal diameter of 150 mm, and to provide an annulus between the well bore and casing would necessitate drilling the well at least 200 mm diameter. The well is drilled to penetrate the hot geothermal aquifer. Any cool subsurface flows are packed off to prevent their invasion of the hot productive zone. The casing concrete is grouted for several metres up to surface level to secure the casing and prevent surface water penetration.

The U-tube assembly is suspended from the casing surface flange. Generally carbon steel piping is used for its construction with the section lengths joined together using malleable couplings rather than cast iron. Other suitable materials are copper or stainless steel, and if temperatures are less than 140°C, fibreglass or polybutylene piping has been used very successfully. The return U-bend should have a short section of pipe welded on the bottom to act as a trap for debris that may fill the U-bend preventing free circulation of the secondary fluid.

Considering life replacement costs, materials should be selected to provide economical protection from corrosion. In this respect, attention must be given to the galvanic cell action between ground water and well casing since the casing is an expensive replacement. Past experience with the operation of DHE indicates that general corrosion is most severe at the air-water interface at the static water level and that stray electrical currents can cause extreme localised corrosion. For this reason DHE piping should be electrically isolated at the wellhead from stray electric currents, which may be present in the building and city water supply pipes. To prevent pipe corrosion above the static water level up to the underside of the casing flange the pipes should be wrapped with a proprietary protective corrosion inhibiting covering such as “densotape”.

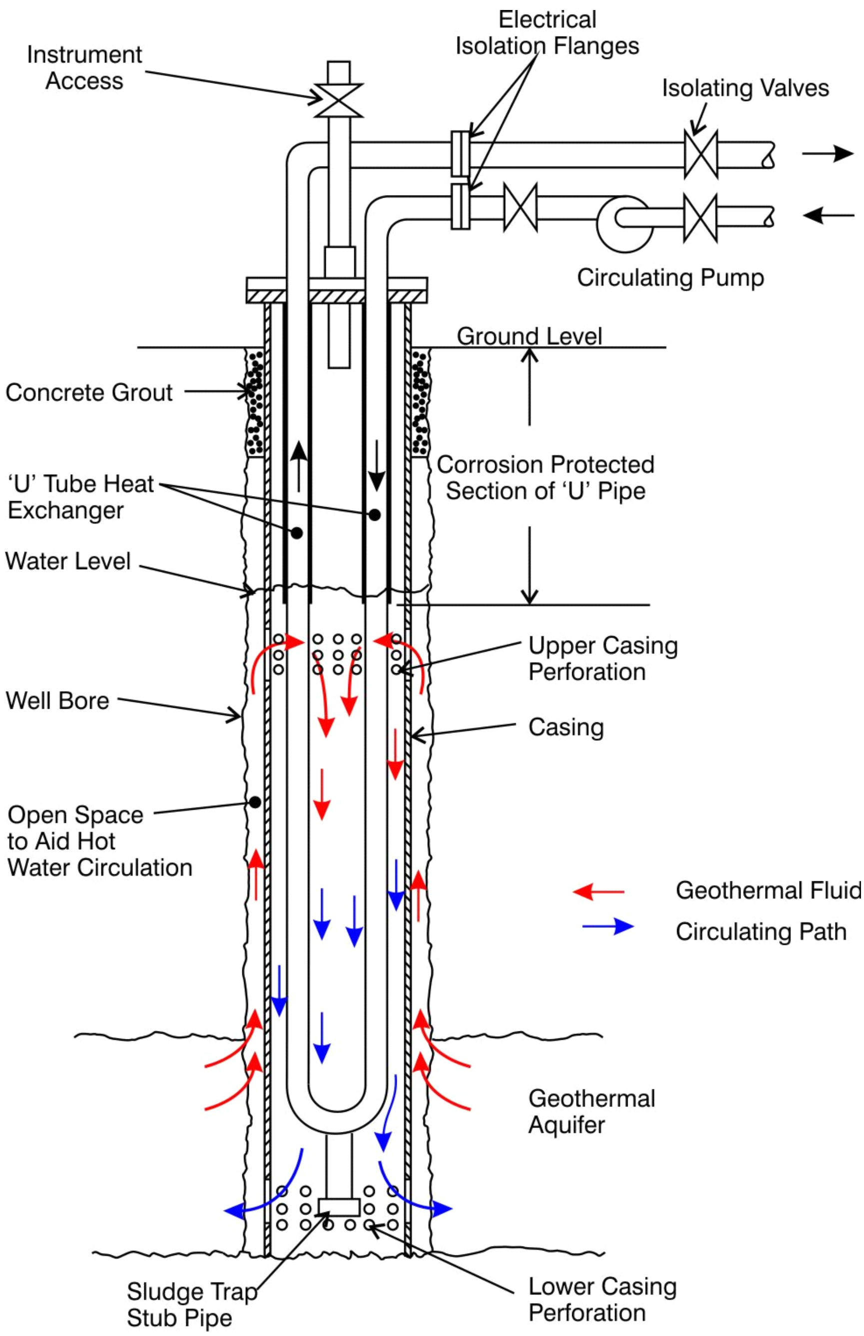


Figure 25. Typical down-hole heat exchanger with promoter tube casing.

The performance of a DHE is dependent on the strength of the convective cell established between the casing/well bore annulus and down the inside of the casing. The driving force is the density difference between the water surrounding the DHE and the water in the annulus. The more heat extracted, the higher the velocity of water flowing past the heat pick up section of the DHE. Velocities of up to 0.6 m/sec have been measured resulting in very high heat extraction rates. However, in general, the velocities are between 0.01 and 0.1 m/sec.

5.2.3.1 Operation

Down hole heat exchangers extract heat from the water flowing through the aquifer and heat stored in the rocks surrounding the well. Once the DHE is extracting heat and a convection cell established, a portion of the convective water is new water entering the well and a similar quantity of cooled water leaves the well and sinks, due to its now higher density, to near the bottom of the aquifer. The ratio of convective water to new water is the well mixing ratio (Equation 2).

$$RM = 1 - \frac{MF_1}{MF_2} \qquad \text{Equation 2}$$

Where:
RM = mixing ratio
MF_1 = mass flow of new water added
MF_2 = mass flow of total convective water in well

Mixing ratios vary widely and depend essentially on the aquifer permeability. The theoretical maximum steady-state amount of heat that could be extracted from the aquifer would be when the mixing ratio (RM) equals zero. That is, when all the water makes a single pass through the convection cell and out the bottom of the well to be replaced by an equal amount of new hot recharge fluid entering cell. Mixing usually range from about 0.5 to 0.94 indicating little mixing. Ratios lower than 0.5 have never been measured. The theoretical maximum steady state can be estimated if the hydraulic conductivity and the hydraulic gradient are known assuming some temperature drop of the water.

Before developing a DHE system it is recommended that geologists and well drilling experts, with a sound knowledge of the geothermal aquifer being tapped, be consulted to establish depth, temperature, permeability, water cross flow conditions, chemical conditions of fluid and geological conditions likely to be encountered. Experience of other DHE installations in the area should also be sought.

6.0 NEW ZEALAND’S REGULATORY REQUIREMENTS

6.1 RESOURCE CONSENT

The principal environmental legislation in New Zealand is the Resource Management Act (RMA). http://www.mfe.govt.nz/issues/resource/. The purpose of this Act is to promote the sustainable management of natural resources and physical resources.

Usually, a Resource Consent must be approved by your Regional Council for the use of geothermal resources. Resource Consents are permits that allow you to use or take water, land or coastal resources, and/or to discharge water or wastes into air, water or onto land. Consented activities are monitored to make sure that the conditions are being met. Refer to the Regional Council websites for more information and regional plan and policies for geothermal activities.

All fluids removed from a geothermal aquifer should be disposed off in an environmentally acceptable manner. This generally requires the fluid to be reinjected back into the subsurface unless resource consents are obtained which permit soak hole or discharge to a natural surface water way.

6.2 MATERIAL STANDARDS

Production casings and slotted liners can be selected to conform to either British Standard BS 1387 or BS 3601 or American API Spec 5CT or 5L.

6.3 NEW ZEALAND REGULATIONS AND STANDARDS

A **Ministry of Commerce “Details for Work Notice”** has to be approved by the Ministry of Commerce prior to commencing any geothermal drilling work.

In addition, geothermal drilling and well construction work must be carried out in compliance with New Zealand Standards and Guidelines. Reinjection wells are constructed in a similar manner to production wells and must comply with the relevant design standard or guideline pertaining to the temperature and pressure conditions the well may encounter during its normal operation.

NZS 2403: 1991 “Code of Practise for Deep Geothermal Wells”

- Geothermal production wells drilled to a depth greater than 250 m and have steam or water at a temperature exceeding the boiling point of water must be constructed to comply with NZS 2403:1991 “Code of Practice for Deep Geothermal Wells”.
- Wells drilled to a depth range of 150 m to 250 m may also require to be constructed in accordance with NZS 2403 depending on the temperature and pressure of the fluid being tapped.

Ministry of Commerce “Guidelines for Shallow Geothermal Wells”
Geothermal wells that are drilled to a depth of less than 150 m and tap an aquifer with water temperature over 70°C are required to be constructed so as to comply with the Ministry of Commerce “Guidelines for Shallow Geothermal Wells”.

These guidelines may also be applicable for wells drilled to a depth of up to 250 m where the subsurface temperatures are 20°C or more below boiling point for depth and the wellhead pressure is less than 5 bars (ambient pressure is 1 bar).

7.0 INSTALLATION AND CALCULATIONS

7.1 TYPES OF INSTALLATION FOR A 6 KW HEAT PUMP INSTALLATION

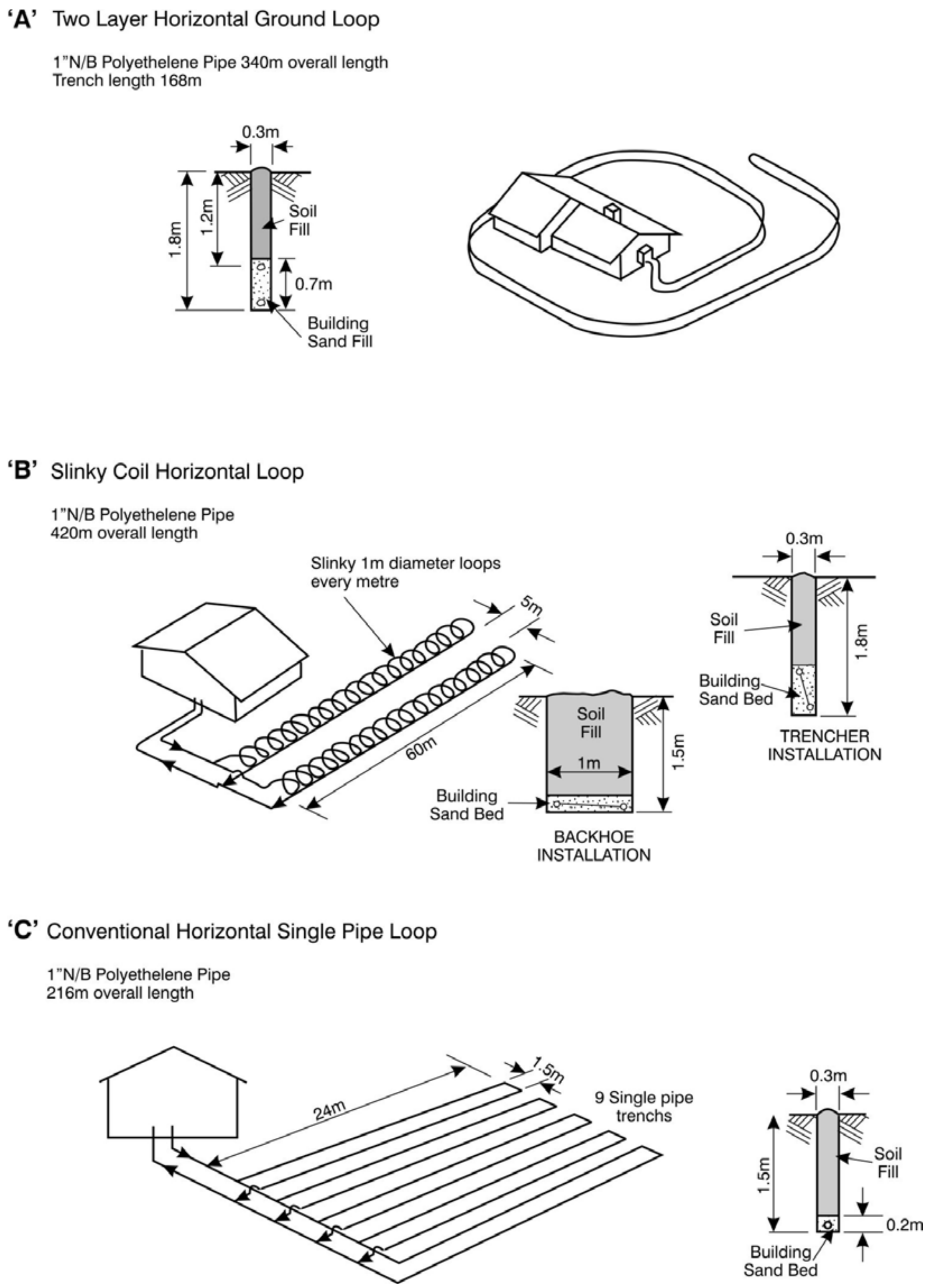


Figure 26. Ground loop systems and installation details for a 6 kW system.

7.2 CALCULATING COSTS FOR DOMESTIC HEAT PUMPS

The following calculations are taken from the Geo-Heat Centre, Geothermal Direct Use Engineering Design Guidebook.

House heat load
As an example, the heating needs for a typical new house built to the approved Energy Efficiency Building Code (NZS 4218: 1996), and having a living space of 60 m^2 is considered. The maximum heat input needed to maintain the conditioned space at the desired comfort level during the coldest weather is given as 1 kW per 10 m^2 of floor space. Therefore the maximum heat load to be satisfied is 6 kWt.

Capital cost
As a rough order estimate a 6 kW geothermal heat pump designed for heating duty only will cost between $6000 and $7,500, the ground loop installation, if installed in easily worked sandy soil, around $2,300, and the underfloor/DHW heating around $2,500, making a total installation cost of $12,000. The installation of a similar capacity natural gas fired system is estimated to be $5,800.

Space heating
The annual operating cost, assuming the heat pump operates with a COP of 4, runs for 800 hours per year on space heating duty, and with a cost of electricity at $0.12 kWh.

$$\$_{space} = h \times \frac{Q_{\max}}{COP} \times \$_{unit} \qquad \text{Equation 3}$$

Where:
$\$_{space}$ = cost of space heating
h = number of hours operated per year
COP = coefficient of performance
Q_{max} = maximum heat load (kW)
$\$_{unit}$ = unit cost of electricity

$\$_{space}$ = 800 x 6/4 x $0.12 = $144/yr

Domestic hot water (DHW)
The average family DHW usage is 340 litres/day, at a temperature of 55°C. A heat pump is able to provide DHW up to a temperature of 40°C.

7.2.1 Costs for Heating Water using Heat Pump

The cost for heating hot water is the cost of using the heat pump to get the water to 40°C plus the cost of electricity to heat the water the extra 15°C to 55°C.

Geothermal energy supplied by heat pump:

$$E_{geothermal} = \frac{V \times (H_{T1} - H_{T2})}{3600} \qquad \text{Equation 4}$$

Where:

$E_{geothermal}$ = geothermal energy supplied (kWh/day)
V = volume of water required (L)
H_{T1} = enthalpy for high temperature (kJ/kg)
H_{T2} = enthalpy for low temperature (kJ/kg)

$$E_{geothermal} = \frac{340 \times (\text{Enthalpy } 40°C - \text{Enthalpy } 12°C)}{3600}$$

$$= \frac{340 \times (167.6—50.4) \text{ kJ/kg}}{3600} = 11 \text{ kWh/day}$$

Annual cost of running heat pump for hot water

$$\$_{heatpump} = \frac{E_{geothermal} \times P_{electric} \times \$_{unit} \times d}{Q_{\max}} \qquad \text{Equation 5}$$

Where:

$\$_{heat\ pump}$ = annual cost of running heat pump
$\$_{unit}$ = unit cost of electricity
$E_{geothermal}$ = geothermal energy supplied (kWh/day)
d = number of days
Q_{max} = maximum heat load (kW)
$P_{electric}$ = electric power input for pump (kW)

$$\$_{heatpump} = \frac{11 \times 1.5 \times 0.12 \times 365}{6} = \$120/\text{yr}$$

Cost of DHW electric top up - similarly, using the equations above:

$$E_{electricity} = \frac{340 \times (\text{Enthalpy } 55°C - \text{Enthalpy } 40°C)}{3600}$$

$$= \frac{340 \times (230.2 - 167.6)}{3600} = 5.9 \text{ kWh/day}$$

$$\$_{electricity} = 5.9 \times 0.12 \times 365 = \$259/\text{yr}$$

Estimated total annual operating cost of geothermal heat pump to provide space heating and DHW for an average New Zealand family home = **$523/yr**.

7.2.2 Costs for Natural Gas Energy

If this heating is provided by natural gas costing $0.12/kWh the cost is estimated to be:

Space heating

$$\$_{space} = 800 \times 6 \times \$0.12 = \$576/\text{yr}$$

Domestic Hot Water

$$E_{electricity} = \frac{340 \times (\text{Enthalpy } 55°C - \text{Enthalpy } 12°C)}{3600}$$

$$= \frac{340 \times (230.2 - 50.4)}{3600} = 17 \text{ kWh/day}$$

$\$_{electricity}$ = 17 x 0.12 x 365 = $744/yr

Cost of natural gas space and DHW heating = **$1320/yr**

7.2.3 Savings Due to Geothermal Energy Use

Geothermal heat pump annual cost saving = $1321 - $522 = **$797/yr**

The present worth of this annual cost saving over 20 years at a
discount rate of 8%= $797 x 9.818 (Uniform Series Present Worth Factor) = **$7,825**

7.3 CALCULATING TIMBER DRYING HEATING REQUIREMENTS

7.3.1 Calculating Geothermal Fluid Flow

To assist in assessing the potential of a low temperature geothermal resource's suitability for timber drying service the following estimates are made of the quantity (flow tonnes/h) of geothermal fluid required to supply energy needs for a 55 m^3 drying kiln operating on the most commonly used drying schedules. These estimates should be used as a guide only. More accurate estimates of geothermal fluid flows must be made in conjunction with the kiln supplier.

$$F_{geothermal} = \frac{Q_{kiln}}{(H_{T1} - H_{T2})} \qquad \text{Equation 6}$$

Where:

$F_{geothermal}$ = flow rate of geothermal fluid (kg/sec)
H_{kiln} = heating needs of kiln (kW)
H_{T1} = enthalpy for high temperature (kJ/kg)
H_{T2} = enthalpy for low temperature (kJ/kg)

HT Schedule, where geothermal fluid is supplied at 140°C and exits the kiln at 90°C calculated for maximum heating (3000 kW) and average heating needs (1900 kW).

$$F_{geothermal} = \frac{3000}{(589 - 376.9)} = 14.1 \text{ kg/sec}$$

$$F_{geothermal} = \frac{1900}{(589 - 376.9)} = 8.95 \text{ kg/sec}$$

ACT Schedule, where geothermal fluid is supplied at 110°C and exits the kiln at 70°C; for maximum heating (1200 kW) and average heating needs (750 kW).

$$F_{geothermal} = \frac{1200}{(461.3 - 292.9)} = 7.1 \text{ kg/sec}$$

$$F_{geothermal} = \frac{750}{(461.3 - 292.9)} = 4.5 \text{ kg/sec}$$

LT Schedule, where geothermal fluid is supplied at 90°C and exits the kiln at 60°C; for maximum heating (500 kW).

$$F_{geothermal} = \frac{500}{(376.9 - 251.1)} = 4 \text{ kg/sec}$$

7.3.2 Calculating Cost of Timber Drying

A budget cost for the procurement and installation of a single 55 m^3 HT drying kiln is \$800,000. For a similar sized ACT kiln the cost would be around \$610,000.

Table 5. Estimated costs of using geothermal energy for timber drying. Note: If a suitable cascade geothermal fluid source is obtainable from a power plant then the geothermal energy supply cost would be significantly reduced.

Costs	HT Kiln	ACT Kiln
Kiln capital repayment, plant life 15 years, 12% financial interest rate, CRF = 0.147	$= \frac{\$800k \times 0.147}{15{,}400 \text{ m}^3/\text{yr}}$ = \$7.65/ m^3	$= \frac{\$610k \times 0.147}{7{,}700 \text{ m}^3/\text{yr}}$ = \$11.65/ m^3
Geothermal supply, well life 15 years, 12% financial interest rate, CRF =0.147	$= \frac{\$600k \times 0.147}{15{,}400 \text{ m}^3/\text{yr}}$ = \$5.73/ m^3	$= \frac{\$600k \times 0.147}{7{,}700 \text{ m}^3/\text{yr}}$ = \$11.45/ m^3
Filleting contract cost	= \$12/ m^3	= \$12/ m^3
Electricity costs	= \$4/ m^3	= \$5/ m^3
Labour costs	= \$4/ m^3	= \$8/ m^3
Maintenance	= \$0.3/ m^3	= \$0.6/ m^3
Budget drying cost/cubic metre	= \$33.68/ m^3	= \$48.70/ m^3
Capacity	15,400 m^3	7,700 m^3
Annual cost	\$518,672	\$374,990

Budget cost for geothermal production/reinjection wells and pipe work could be of the order of \$600,000, for both HT and ACT kiln systems.

The annual timber drying capacity of these kilns are 15,400 and 7,700 m^3, based on kilns operating 7,000 h/yr and cycle turn round times of 25 h for the HT kiln and 50 h for the ACT kiln. Average thermal loads are: HT kiln 1.9 MWt and the ACT kiln 0.75 MWt.

A budget estimate of cost of drying timber using geothermal energy is outlined in Table 5. This is a rough financial estimate and should only be used for indicative purposes.

7.3.3 Estimate of Carbon Tax

The New Zealand Government decided not to implement the carbon tax in late 2005. To meet its commitments to cut greenhouse gases the Government is encouraging generation of renewable energy sources such as geothermal, and planting trees to soak up CO_2. The following calculations show how much money can be saved when renewable rather than fossil-fuel energy sources are used. Geothermal energy, when used directly, releases very little greenhouse gas. As the Government has classed such resources as renewable no carbon tax will be incurred. Consequently by using geothermal resources businesses could potentially save money which would otherwise be spent on carbon tax (Equation 7).

Natural gas releases around 185 grams of CO_2 per kWh of thermal energy used. For example, the annual energy use for a 55 m^3HT kiln, if operating for 7000 h/yr on 1900 kW natural gas is 13,300,000 kWh/yr.

$$\$_{Ctax} = \frac{E_{annual} \times m_{CO_2} \times \$_C}{1000} \qquad \text{Equation 7}$$

Where:

$\$_{Ctax}$ = total annual carbon tax
E_{annual} = average annual energy use (kWh)
m_{CO2} = amount of CO_2 released by natural gas heating (kg/kWh)
$\$_C$ = carbon tax (\$/tonne)

If a carbon tax is $15 per tonne of CO_2 released to the environment, then the annual carbon tax charged for a natural gas fired 55 m^3HT kiln would be:

$\$_{Ctax =}$ = 13,300,000 x 0.185 x $15 /1000 = $36,907/yr

This would add an additional $2.40 to the cost of drying a cubic metre of lumber.

In the absence of carbon taxes, the Government is considering ways in which NZ can meet its Kyoto Protocol commitments. A possibility being investigated is putting incentives on renewable energy projects, which geothermal resources are.

7.4 CALCULATING GREENHOUSE HEATING REQUIREMENTS

The following calculations are taken from the Geo-Heat Centre, Geothermal Direct Use Engineering Design Guidebook.

7.4.1 Calculating Maximum Heat Load

To evaluate the heat load, heat losses must be determined. The heat loss for the greenhouse structure is composed of two components:

1. Heat transmission losses through the walls and roof, and
2. Ventilation losses caused by heating of cold air to replace warmed air vented from the greenhouse.

For this example, a growing temperature of 28°C and a minimum outside air temperature of 4°C are assumed, so the maximum temperature difference (T_{diff}) is 24°C (Equation 1).

$$T_{diff} = T_{grow} - T_{\min} \qquad \text{Equation 8}$$

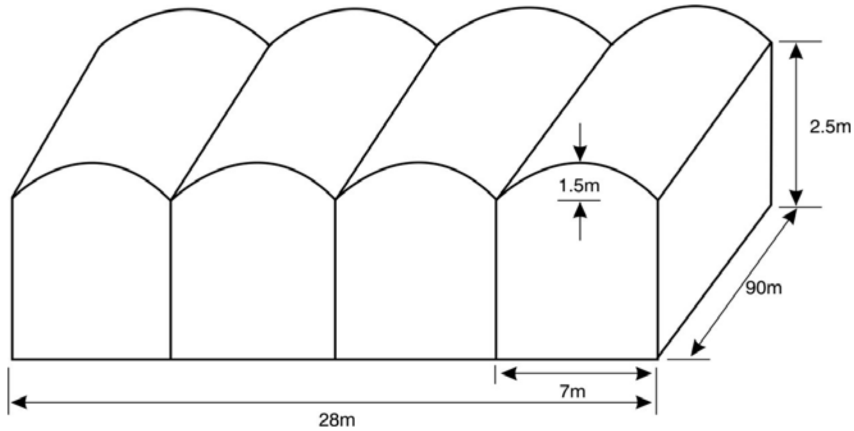


Figure 27. Example dimensions for a four bay, single polyethylene greenhouse.

Where:
T_{diff} = maximum temperature difference (°C)
T_{grow} = growing temperature (°C)
T_{min} = minimum outside air temperature (°C)

Heat loss through transmission
The first step is to calculate the total surface area exposed to outside air temperature.

For example consider a four-bay 7 m wide by 90 m long, single polythene greenhouse, having 2.5 m high sides and 1.5 m high-curved roof (Figure 27). This structure would have a growing surface area of 2520 m^2 (~0.25 hectare), an internal volume of 8,911 m^3 and a total surface area exposed to outside the air temperature of 3,466 m^2.

The heat transmission loss through the covering material can be calculated according to Equation 9. The heat loss value for selected glazing materials and wind speeds are listed in Table 5.

Table 6. Glazing material heat loss values. *Data obtained from: Geothermal Direct Use Engineering Design Guidebook; Published by Geo-Heat Centre, Oregon Institute of Technology.*

Material	Heat Loss	Heat loss
Average wind speed	25 km/h	50 km/h
Glass	20.43 kJ/m^2/°C	21.91 kJ/ m^2/°C
Single polythene	23.5 kJ/ m^2/°C	25.13 kJ/ m^2/°C
Double Polythene	14.3 kJ/ m^2/°C	15.03 kJ/ m^2/°C

$$Q_1 = \frac{A \times T_{diff} \times Q_{mat}}{3600} \qquad \text{Equation 9}$$

Where:
Q_1 = heat loss due to transmission (kW)
A = surface area exposed to outside air (m^2)
T_{diff} = maximum temperature difference (°C)
Q_{mat} = Heat loss due to material for given conditions (kJ/m^2/°C)

For our example:

$$Q_1 = \frac{3{,}466 \times 24 \times 23.5}{3600} = 543 \text{ kW}$$

Heat loss through ventilation

The heat loss through ventilation is calculated using Equation 10, assuming one complete air change per hour and an air heat transfer coefficient of 1.207 kJ/h/m^2/°C:

$$Q_2 = \frac{V \times T_{diff} \times U_{air}}{3600} \qquad \text{Equation 10}$$

Where:

Q_2 = heat loss due to ventilation (kW)
V = internal volume of greenhouse (m^3)
T_{diff} = maximum temperature difference (°C)
U_{air} = air heat transfer coefficient (kJ/h/m^2/°C)

For our example:

$$Q_2 = \frac{6480 \times 24 \times 1.207}{3600} = 52 \text{ kW}$$

Maximum heat load

The maximum heat load to maintain growing space at the desired temperature during the coldest weather for this example is 543 + 52 = 595 kW (Equation 11).

$$Q_{\max} = Q_1 + Q_2 \qquad \text{Equation 11}$$

Where:

Q_{max} = total heat load required (kW)
Q_1 = heat loss due to transmission (kW)
Q_2 = heat loss due to ventilation (kW)

7.4.2 Calculating Flow Rates

Equations 12 and 13 can be used to calculate the flow rates of geothermal fluid (Equation 12) and the secondary water flow in a greenhouse heating circuit (Equation 13) required to satisfy the maximum thermal load of the example greenhouse above.

This example greenhouse is set up according to the schematic diagram in Figure 27, with a 95% heat transfer efficiency of the plate heat exchanger, a geothermal fluid temperature of 80°C, and a geothermal fluid exit temperature of 45°C. The plate heat exchanger operates with a “pinch temperature” of 5°C. The “pinch temperature” is the difference between the geothermal fluid temperature and the temperature of the secondary fluid providing the heat energy to the greenhouse.

$$F_{geothermal} = \frac{Q_{\max}}{0.95 \times \left(H_{80} - H_{45}\right)} \qquad \text{Equation 12}$$

$$F_{\sec ondary} = \frac{Q_{\max}}{\left(H_{75} - H_{40}\right)}$$ Equation 13

Where:
$F_{geothermal}$ = flow rate of geothermal fluid (kg/sec)
$F_{secondary}$ = flow rate of secondary geothermal fluid (kg/sec)
H_{80} = enthalpy at 80°C (334.8 kJ/kg)
H_{75} = enthalpy at 75°C (313.8 kJ/kg)
H_{45} = enthalpy at 45°C (188.3 kJ/kg)
H_{40} = enthalpy at 40°C (167.6 kJ/kg)
Q_{max} = total heat load required (kW)

For this example:

$$F_{geothermal} = \frac{595}{0.95 \times (334.8–188.3)} = 4.3 \text{ kg/sec}$$

$$F_{secondary} = \frac{595}{(313.8 – 167.4)} = 4.1 \text{ kg/sec}$$

7.4.3 Calculating Length of Piping

The length of finned 25 mm pipe required to provide the 595 kW heating load can be calculated. The heat transfer coefficient of 25 mm diameter steel pipe fitted with aluminium fins is 0.0121 kW/m^2/°C.

$$l_{pipe} = \frac{Q_{\max}}{U_{pipe} \times LMTD}$$ Equation 14

Where:
l_{pipe} = length of pipe (m)
Q_{max} = total heat load required (kW)
U_{pipe} = heat transfer coefficient of pipe (kW/m^2/°C)
LMTD = natural log mean temperature difference (°C); see Equation 15.

$$LMTD = \frac{\left(GTTD - LTTD\right)}{Ln\frac{GTTD}{LTTD}}$$ Equation 15

Where:
LMTD = Log mean temperature difference (°C)
GTTD = Greatest temperature terminal difference (°C); see Equation 16.
LTTD = Least temperature terminal difference (°C); see Equation 17.

$$GTTD = T_{GHWT} - T_{grow}$$ Equation 16

$$LTTD = T_{LHWT} - T_{grow}$$ Equation 17

Where:
T_{GHWT} = Greatest heating water temperature (°C)
T_{LHWT} = Least heating water temperature (°C)
T_{grow} = Growing temperature (°C)

For this example:

GTTD = 75°C - 28°C = 47°C

LTTD = 40°C – 28°C = 12°C

$$LMTD = \frac{47°C - 12°C}{\ln(47/12)} = 25.6°C$$

$$l_{pipe} = \frac{595}{0.0121 \times 25.6} = 1921 \text{ m}$$

The budget cost of a 25 mm aluminium finned heating pipe is $17.00/m. Thus the total cost of heating pipe is1,985 m x $17.0 = $33,745.

If the lowest water heating temperature increased to 50°C then the LMTD temperature would be increased to 32.9°C and the length of finned pipe would then be reduced to 1543 m and the cost of heating pipe to $26,231.

7.4.4 Calculating Seasonal Heating Loads

The seasonal heat load variation can be calculated using Equation 11 and the average monthly temperature for the specific region of interest. An example of a greenhouse in Reporoa is shown in Figure 28. Approximate annual energy use can be obtained by summing the monthly energy figures. For the example greenhouse annual energy use is estimated to be 4,996 MWh (thermal). A more accurate estimate of energy use can be made if daily temperature data is averaged on a weekly instead of monthly basis.

7.4.5 Estimate of Carbon Tax

No carbon tax would be incurred by renewable energy resources such as geothermal if carbon taxes are introduced in the future. The annual energy used will be the same irrespective of the form of energy used, so by using geothermal energy money would be saved from carbon taxes (Equation 18).

$$\$_{Ctax} = E_{annual} \times m_{CO_2} \times \$_C \qquad \text{Equation 18}$$

Where:
$\$_{Ctax}$ = total annual carbon tax
E_{annual} = average annual energy use (kWh)
m_{CO2} = amount of CO_2 released by natural gas heating (kg/kWh)
$\$_C$ = carbon tax ($/tonne)

For this example the annual savings would be:

$\$_{Ctax} =$ = (4,996,000 x 0.185 x $15/tonne)/1000 = $13,864/yr

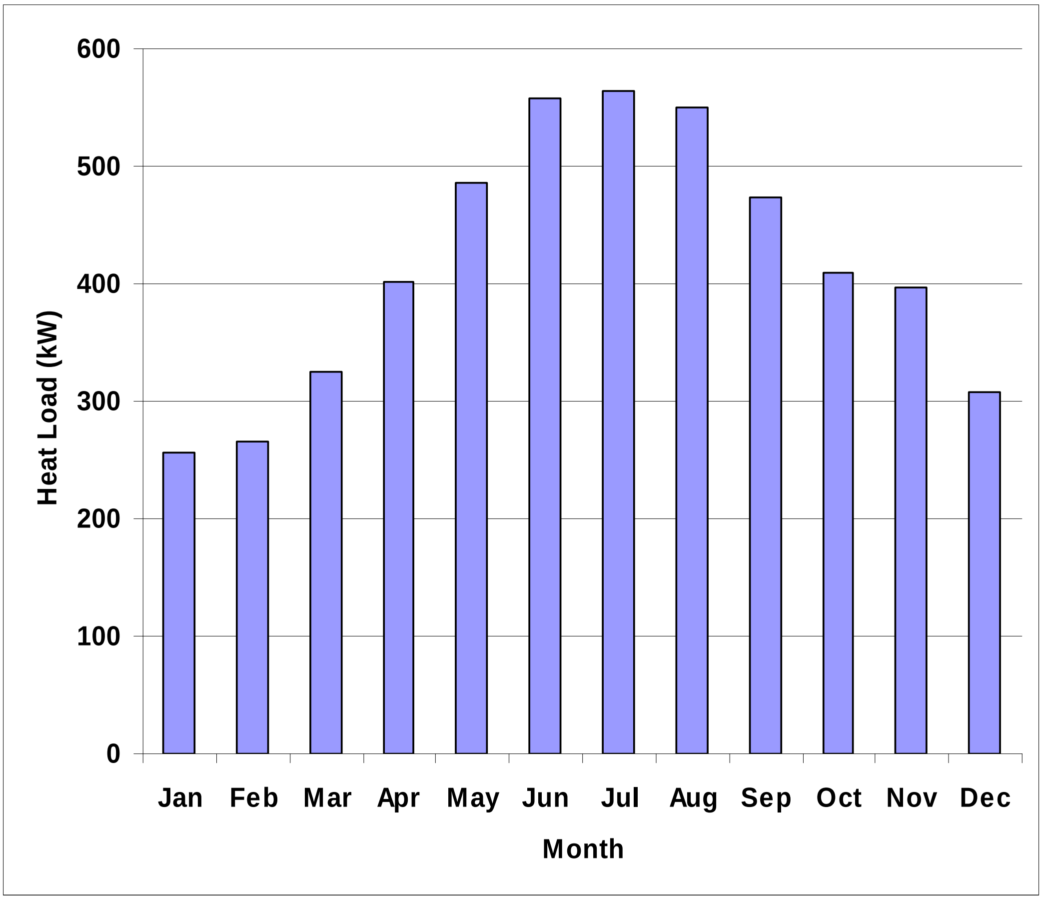


Figure 28. Average monthly heat loads for example greenhouse situated in Reporoa.

7.5 EXAMPLE FOR SIZING A PLATE HEAT EXCHANGER

Heat exchangers, regardless of type, are selected to transfer a specific quantity of heat under a specific set of conditions. The key parameter in this selection process is the heat transfer area required to accomplish the task. The following formulae describe this situation:

$$Q = U \times A \times LMTD \times C_f \quad \textbf{or} \quad A = \frac{Q}{U \times LMTD \times C_f} \qquad \text{Equation 19}$$

Where:

Q = Heat load in (kJ/h)
U = Heat transfer coefficient (kJ/h/m^2/°C)
A = Surface area of the heat exchanger (m^2)
LMTD = Log mean temperature difference (°C)
Cf = LMTD correction factor (0.85 to 1.0) for most geothermal applications

The “log mean temperature difference” is calculated using the difference between the entering and leaving temperatures of the two fluids according to the following relationship:

$$LMTD = \frac{\Delta_{Ta} - \Delta_{Tb}}{Ln\left(\Delta_{Ta} - \Delta_{Tb}\right)} \qquad \text{Equation 20}$$

Where:
Geothermal fluid 90°C in; 60°C out
Process fluid 70°C out; 45°C in
Δ_{Ta} = Temperature of inlet geothermal fluid– Temperature of outlet process fluid = 20°C
ΔTb = Temperature of outlet geothermal fluid – Temperature of inlet process fluid = 15°C

$$\text{So LMTD} = \frac{20 - 15}{\text{Ln}(20/15)} = \frac{5}{0.2877} = 17.4°\text{C}$$

A heat exchanger having a coefficient of heat transfer (U) = 3000 $W/m^2/°C$, and required to provide a heat load Q = 300 kW at the above fluid inlet and outlet temperatures would need a surface area of:

$$A = \frac{300 \text{ kW}}{3 \text{ kW/m}^2\text{/°C} \times 17.4 \times 0.85} = 6.8 \text{ m}^2$$

8.0 GLOSSARY

Annulus	A circular or ring-shaped opening, structure or object.
Asthenosphere	The hot (1400^{o}C) and ductile region of the earth's upper mantle, about 200 km thick, over which the tectonic plates move.
Aquifer	An **aquifer** is an underground layer of fluid-bearing permeable rock, or permeable mixtures of unconsolidated materials. Aquifers can be **confined** or **unconfined**. If a confined aquifer follows a downward grade from a recharge zone, groundwater can become **pressurised** as it flows. This can create artesian wells that flow freely without the need of a pump. The top of the upper unconfined aquifer is called the water table or phreatic surface, where water pressure is equal to atmospheric pressure. Unconfined aquifers are **non-pressurised**.
Crust	Uppermost layer of the earth varying in thickness from 5 to 65 km.
Desalination	**Desalination** is the process of removing soluble salts from water to render it suitable for drinking, irrigation, or industrial uses.
Diatomaceous earth	**Diatomaceous earth**, also known as diatomite, is a soft sedimentary rock mineral. It is primarily made of silica and consists of fossilised remains of diatoms, a hard-shelled algae. It is often used as a filtration aid, as a mild abrasive, as an insecticide and as an absorbent.
Galvanic Cell	Unwanted **galvanic cells** are formed whenever two dissimilar metals are in contact in the presence of an electrolyte, such as salt water, resulting in the galvanic corrosion of the more active metal (Figure 29). Galvanic action is the electrochemical oxidation of metal. A galvanic cell = an electrochemical cell.

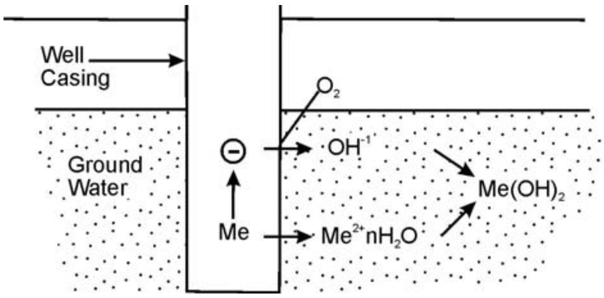


Figure 29. The corrosion of well casing due to the galvanic action of ground water.

Geothermal reservoir	Permeable and porous rocks where rising hot water and steam heated by hot rock are trapped under a layer of impermeable rock.
Hard water	Water with a high mineral content is known as **hard water**. This usually contains high levels of metal ions, mainly calcium and magnesium in the form of carbonates, but may include several other metals as well as bicarbonates and sulfates. Some hard water chemicals, particularly silicates and calcium carbonate are also effective corrosion inhibitors.

J	A <u>joule</u> is a unit for measuring energy. For example, the amount of heat energy required to raise the temperature of one kilogram of liquid water one degree Celsius is 4186 Joules or 4.186 kilojoules (kJ). A terajoule (TJ) corresponds to 10^{12} joules, PJ to 10^{15} joules
kWh	**Kilowatt hour**. A kilowatt hour is the expenditure of one kilowatt (kW=1000 watts) of power for one hour. The kilowatt-hour is commonly used for electrical energy. A toaster running for an hour will use about this much energy.
Lithosphere	The lithosphere consists of the crust and the rigid upper layer of the mantle and extends to about 80 km deep.
MWe	**Megawatt electricity**. The watt electricity (We) is a term that refers to power produced as electricity. The productive capacity of electrical generators is often measured in MWe.
MWt	**Megawatt thermal.** The watt thermal (Wt) refers to thermal power produced. To convert MWt to MWe an efficiency conversion factor of 10-15% is used. This is because power generation using steam is very inefficient that only about 10-15% is converted to electricity.
Permeability	In geology, **permeability** is the ability of a material to transmit fluids through it. The usual unit is the darcy, or more commonly the milliDarcy or mD (1 darcy $\approx$ $10^{-12}m^2$).
Plenum	In a building, the **plenum** is the space between the real ceiling and the dropped ceiling, which is often used as an air duct for heating and air conditioning.
Porosity	The **porosity** is proportion of non-solid volume to the total volume of material in a porous medium (such as rock or sediment). It is defined by the ratio: $$\varphi = \frac{V_p}{V_m}$$ Where V_p is the non-solid volume (pores and liquid) and V_m is the total volume of material, including the solid and non-solid parts. Porosity is a fraction between 0 and 1, typically ranging from less that 0.01 for solid granite to more than 0.5 for peat and clay, although it may also be represented in percent terms by multiplying the fraction by 100%.
Tectonics	The study of the earth's structural features and how these are deformed by forces such as compression, extension and shearing.
Transmissivity	The **transmissivity**, *T*, is a measure of how much water an aquifer can transmit horizontally.
Volcanism	The phenomena associated with volcanic activity
W	A **watt** is a unit for measuring energy over a time span (e.g. joules per second). A megawatt (MW) corresponds to one million (10^6) watts.

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10.0 FURTHER READING

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www.chenahotsprings.com

APPENDIX 1 – DIRECT HEAT UTILIZATION OF HOT SPRING AND WELL DISCHARGES IN NEW ZEALAND

*****1994 and earlier reports. Present state of springs from 2000-2006 fieldnotes of Reyes A.G., Faure K., Leonard G., Jongens R., some South Island springs from Jackson (2006)

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
AUCKLAND						
Clevedon area, Auckland	not reported	Whitford wells had max. T of 55^oC at 80-100m		31.5 at 160 m	domestic boreholes	Whitford area
Franklin area, Auckland	not reported			31.5 at 165 m	domestic boreholes	Whitford area
Helensville, Parakai Hot springs	3 swimming pool complexes, 4 motels with hot pools, 5 private pools/baths	65	12	65	Swimming pool in Aquatic Park Parakai, pools/baths in 4 motels, domestic use; new tourist complex being built plans to use warm waters; about 7-8 wells still in use	Exploitation in the last 30-40 years has lowered water level and caused some seawater incursion
Omaha	not reported			19	gone	Decommissioned old well in golf course still discharged slightly warm gassy waters in 2005 but was cemented in 2006. Strong seawater incursion
Waiwera (Riverhaven)	not reported			49.5	domestic use	
Waiwera	public, commercial and private hot swimming pools and space heating	40 (old spring); 52 from boreholes		51	Commercial swimming pool (Waiwera Resort), domestic heating and baths; commercial bottling of thermal waters	no springs since 1978; overproduction from wells caused lowering of water level and some seawater incursion reported. Well flow: 8-10 L/s. There are several houses using hot water from wells in their properties. New commercial complex plan to harness more of the hot water
Great Barrier Island, Kaitoke Hot Springs	bathing	up to 85.5			bathing, with well-maintained DOC constructions	
Great Barrier Island, North Peach Tree Springs	bathing	61		62	bathing	
Great Barrier Island, South Peach Tree Springs	bathing	50		62	bathing, largely undeveloped	

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
Owhiti (Waiheke Island) hot spring	no trace of springs				gone	hot water well in west side of island reported by Ian Brown
BAY OF PLENTY						
Matata	none	no natural manifestations				Delineated by geophysical methods. hot spring existence known to local Maori in the past but finding springs impeded by landslides in last 2 years
Paengaroa	none	warm		36.6	warm well waters used for therapeutic swimming pool and domestic use of motel	
Papamoa	none	warm		24.8 from 233 m well	raise and quarantine tropical fishes (Highway Fisheries) using warm water from well	spring could not be located
Sapphire, Katikati	swimming pool	spring: 36; well: 39 at 61 m		31-40	swimming pools	3 wells about 50 m deep
Tauranga Geothermal System	private and public swimming pools	springs: 22-39; wells: 20-54	wells: 2-127			Several wells are being used to provide hot water to commercial swimming pools and motels
TGS1					spring, inactive	
TGS2					spring, inactive	
TGS3					spring, inactive	
TGS4					spring, inactive	
TGS52					spring, inactive	
TGS53					spring, inactive	spring (Woodland spring)
TGS54					spring, inactive	
TGW5					well (not used?)	
TGW6					well	within Sapphire
TGW7					well (not used?)	
TGW8					well (not used?)	
TGW9					well (not used?)	
TGW10					well	within Omokoroa
TGW11					well	within Plummer’s Point

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
TGW12					well (not used?)	
TGW13					well (not used?)	
TGW14					well (not used?)	
TGW15					well (not used?)	
TGW16					well (not used?)	
TGW17					well (not used?)	
TGW18					well	within Fernland
TGW19					well (not used?)	
TGW20					well (not used?)	
TGW21					well (not used?)	
TGW22					well (not used?)	
TGW23					well (not used?)	
TGW24					well (not used?)	
TGW25					well (not used?)	
TGW26					well (Silver Birch)	
TGW27					well (not used?)	
TGW28					well (not used?)	
TGW29					well	within Maunganui Pools
TGW30					well	used by Wainui Motel
TGW31					well (not used?)	
TGW32					well (Welcome Bay)	
TGW33					well (not used?)	
TGW34					well (not used?)	
TGW35					well (not used?)	
TGW36					well (not used?)	
TGW37					well (not used?)	
TGW38					well (not used?)	
TGW39					well (not used?)	
TGW40					well (not used?)	
TGW41					well	used in Little Waihi
TGW42					well (not used?)	
TGW43					well (not used?)	

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
TGW44					well (not used?)	
TGW45					well (not used?)	
TGW46					well (not used?)	
TGW47					well (not used?)	
TGW48					well (not used?)	
TGW49					well	within Sanctuary Point
TGW50					well (not used?)	
TGW51					well	within Maketu
Athenree Hot Springs and Holiday Park	not reported			39	swimming pool fed by well drilled to 244 m in 1999 (temperature is boosted during cold days)	
Bennett's Tauranga Motor Inn					bathing	
Cameron Road Motel					bathing	
Dave Hume Swimming Complex				41	public swimming pool	2 swimming pools and 2 hot spas
Fernland				38.5	swimming pool	pool fed by 2 wells
Katikati (Woodlands) hot springs	none	38				inactive
Little Waihi (Bledisloe Park), Tauranga	undeveloped			29	small bathing pool for children, domestic use, new owner of park wants to make more use of well (flow <0.5 L/s)	
Maketu Hot Springs/wells	not known	springs: 44-49; wells: up to 42	1	41	private pool, heat exchanger, domestic use	2 wells about 38 m deep but the older one (> 20 years old) has clogged-up. New one is about 8 years old. Springs are gone
Mt Maunganui Hot Salt Water Pools	public swimming baths			46	swimming pool complex	
Omokoroa	not reported			40	well, swimming pool, thermal resort	well
Oropi Spa Pools				56.3	bathing, domestic use	well is 500 m deep with pump, drilled in 2000
Plummer's Point caravan park and Mineral pools					bathing	
Sanctuary Point hot mineral spa and pool	not reported			39	mineral spa and pool	

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
Silver Birch Thermal Holiday Park					bathing	
Tauranga harbour Tidal Flat hot spring				warm	not used	
Wainui Thermal Pool (TGW30)	not reported			39.4	swimming pool	old DSIR borehole
Welcome Bay Hot pools and holiday park	Swimming pool				bathing	
18TH Avenue Motel					bathing	
Whale Island	none	98-100.8	5		not used	
White Island	sulfur and gypsum mining	fumaroles: up to 350			tourism	
COROMANDEL						
Hot water Beach (Orua) springs	bathing; may produce up to 6 MWe	50-63	0.06-2	60	bathing	intertidal springs
Hot Water Beach Bore		up to 50	5-7	56.2	bathing, largely unused	
Taputapu Hot Springs	none	49			none	spring reportedly issued from sandy bed of Taputapu stream but could not find in 2005
Whitianga borehole			126	48	New well for use in tourist resort being built	(well drilled 20 years ago down to 625 m had T= 48^oC, flow= 126 L/s; well drilled in 2005 is 635 m with reported maximum T=50^oC although there is strong cold water incursion)
Wigmore (Hahei) borehole	bathing	27		28	1 borehole mostly left unused, some water apparently used for domestic greenhouse	
EASTLAND						
Morere	bathing, heat exchangers	up to 62		50.2	bathing	
Te Puia	bathing	52-70		69	bathing, therapeutic pool for hospital, cultivation of special plants	
HAWKES BAY						
Mangatainoka (Mohaka) hot sp	bathing	58.5	0.4	56	DOC-created baths	
Mangatutu Spring (Puketitiri)	bathing	52	1	50	DOC-made baths	
Maungaharuru Springs		no temperature measured, probably cold				travertine deposits at spring site reported

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
Ohane spring				45	undeveloped; bathing	beware of ongaonga along the way
Pukehinau (Waikokopu) hot springs	none	warm		45	undeveloped, bathing	
Tarawera Hot Springs	bathing	up to 49		48	DOC-made baths	not maintained
Waipiropiro Spring	none			40	bathing, small pool dug out	permission for access from owners required
NORTHLAND						
Kamo	several sites; bathing, private pools; used in the past by Whangarei hospital	25	0.23 to large flow	25	bathing	Kamo spring with largest flow, located in Kamo Christian College grounds, is fenced off and feeds a pool at the Kamo Springs Holiday Park. Flow about 13 L/s. CO_2 is high and fills pit where spring flows
Kopenui East Spring 1	none	23	low	20	undeveloped	gassy
Kopenui East Spring 2	none				undeveloped	
Kopenui West Spring	none			cold	undeveloped	gassy
Lake Omapere	none	30-43	3.5-28	28	not used	man made pool
Neilson's Soda spring	none	26-29	1			
Ngawha springs	mercury mining, bathing, power generation	springs: up to 76; wells up to 301	springs: 2	50 (springs)	bathing, therapeutic pools	includes Tiger, Velvet, Jubilee, Favorite baths, Waiariki, Ginn's
Taita Warm Spring		23				
TARANAKI						
Arawhata Warm Springs	none	29				Could not find springs in sand dunes. The spring surrounded by concrete cylinder had dried up during drought in 2003
Bonithon-1, New Plymouth				29	swimming pools, therapeutic spas, mineral water production	abandoned oil and gas well drilled in 1906; artesian, flow of 3.1 L/s. First used as baths in 1916 then became Tarawhata hot mineral spring baths that was closed. Taranaki Mineral Pools opened in 2000. Temperature is boosted to 38 to 40^oC

Spring/Hot Water Discharges	Past Use*	Measured T (°C)*	Flow (L/s)*	Present T (°C)	Present Use	Notes
TAUPO - ROTORUA						
Atiamuri	swimming pool	springs: 59-63; well: 165 (550-590m)		98		
Awakeri	swimming pools	springs: 58-69; wells: up to 70	wells: 50	69	swimming pools, domestic use	3 wells extant
Golden Springs	rare ferns associated with warm waters	40-50	up to 40	>50	bathing	
Haparangi	none					
Hipaua-Waihi	domestic and recreational use					
Horomatangi Reef	none			44 at a depth of 184 m	none	springs under eastern Lake Taupo explored by submarine in 1998
Horohoro	none	springs: 50-81.5; well: 86.6	1		exploration for possible power generation	
Kawerau	power generation, space heating, industrial heat processing	springs: up to 100; wells: up to 310	large		power generation, industrial process heat	
Ketetahi Geothermal Area	warm springs and pools used by trampers	74-91; fumaroles up to 138				
L. Okataina	none	30-36				
L. Rotoiti	none	39 to >130				
L. Rotokawa	space heating, glasshouse, swimming pool	springs: 45-52; wells: >99				
Manaohau Hot Spring	none	warm				
Mangakino	none	100				
Mangakotukutuku Sp	none					
Mokai		springs: up to 59; wells: up to 324			power generation, greenhouse, space heating	
Motuoapa Hot Spring	none	warm				
Ngakuru	none	no natural manifestations				
Ngatamariki		springs: up to 88	4.5-8.5			

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
Ohaaki-Broadlands	power generation, greenhouse, lucerne drying	springs: up to 95; wells: up to 308	20-22		power generation	hot springs and fumaroles
Ongaroto		no natural manifestations				
Orakeikorako	tourist facility, may support 150 MWe	springs: up to 100; wells: up to 265			bathing, tourism	
L. Ohakuri				35-50	bathing	
Pakaraka Hot Springs						
Reporoa	scenic attraction; may support 65 MWe	springs: up to 97; well: 240 (950 m)				
Rotokawa Geothermal Field	sulfur mining	wells: up to 335			power generation	
Rotoma	mineral water; power potential	springs: up to 50; fumaroles up to 97; wells: up to 120 (30 m)	11.3-53.1		bathing	
Waitangi Soda spring				49	bathing	
Otei hot spring	not reported					does not exist anymore although still plotted in 260-U16 map
Rotomahana	sulfur mining, tourism, domestic and commercial heating, hot water supplies, swimming pools, hot house horticulture, soil sterilisation, timber drying, air conditioning of hotel	wells: up to about 194 (250 maximum)		99	bathing/swimming pools, spas, domestic use, space heating, hot house gardening, heat pump	
Te Puia		37-90		80	tourism	
Kuirau-Ohinemutu				98.1	tourism	
Mokoia Island (Hinemoa's pool)	none			54	bathing	
Ruapehu Crater Lake						
Taheke Area	bathing, sulfur mining	springs: 57-97, fumaroles: 99; natural heat flow: 12.8 MW	up to 18			

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
Tarawera	bathing	springs: 37-90, fumaroles: 55-70	100	49.1		
Humphreys Bay Hot Spring	none	warm			bathing	
Te Rata Bay Hot springs	bathing			38	bathing	
Tauhara-Taupo	space heating, domestic use	springs: 40-98, wells: up to 279	springs: 20		power generation, space heating	
AC Baths	bathing				bathing	
Otumuheke				at least 65	bathing	
Tapuaeharuru Bay				65	bathing	
de Bretts	bathing			62	bathing	
Waitetoko Hot springs	none	SE shore of L. Taupo but exact location unknown				
Te Kopia	sulfur mining, mushroom growing, space heating, tourism	wells: up to 241				
Tikitere					tourism	
Hellsgate				99	tourism	
Manupirua Springs				39	bathing	
Waiaute Springs	none	up to 23				
Waikite	swimming pool	springs: up to 99	up to 3.5	40	bathing	
Waimangu-Rotomahana	tourism	up to 81	120			
Waiotapu	tourism	springs: up to 100; wells: up to 295			tourism, bathing	
Wairakei	power production, space heating	fumaroles: 100; wells: up to 270	3		power production, prawn farming, greenhouse, tourism	
Te Kiri io Hinekai				40	bathing, tourism	
Wairoa Stream				38	bathing	
Whakamaru Hot Springs	none					
Whangairorohea Hot Spring	none	42-56				
WAIKATO						
Gravesons Rd (Waiteariki)	none	34	good	32.8	undeveloped (0.5 L/s)	

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
Hamilton Warm Water wells	heat pump for space heating/cooling; domestic use	27 at 135 m	11.3		decommissioned	Several wells drilled in the 1950's discharged 19-32^o C waters at depths <200 m. Thermal gradient relatively high as measured in wells
Horotiu Hot Springs	registered as hot spring					Gassy wells with warm waters (up to 32^{o}C) drilled intermittently from 1915 to about 1966
Kawhia (Te Puia), Hamilton	public bathing	53		54	bathing	Occurs in hand-dug pools in beach. Intertidal springs usable within ± 2 hours of low tide
Kerepehi Springs	used in early times for flax washing	55				covered up or drained since about 1955
Kerepehi wells		57 at 50 m		29.3	domestic; owner wants to use well discharge	This well has low flow. There are about 4 other wells in area within 200 m radius but these have been blocked save 1. Some other wells drilled by Ravensdown Fertiliser Co-op Ltd but data not available to the public
Lake Waikare Hot Springs	none	springs: 35; well: 70	none			still being used by duck hunters
Manawaru springs	none	43-57.5		44-47	undeveloped	springs under river water
Matamata Centennial Pool	swimming pools				bathing	
Mayor Island, North West Bay Spring	none	warm		warm	springs at tide level used for bathing	intertidal springs
Mayor Island, Orongatea Bay Spring	none	warm		warm	none	intertidal springs
Miranda Hot Pools	swimming pool	springs: 56; wells: 64	>7	55	Swimming pool, spa, sauna	Swimming pool has 6 springs in bottom. There are 3 other springs and 5 boreholes
Miranda Springs Holiday Park				54.1	Swimming pool fed by 100 m deep borehole	
Ngatea wells					decommissioned	Several wells drilled in the past with discharge temperatures of 27 to 31^{o}C, used for council swimming pool (31^{o}C)., a private 80 m^2 greenhouse to

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
						grow orchids about 30 years ago. Wells show relatively high thermal gradient in Ngatea
Ohinewai Hot Spring	none	23		16		Spring is gone.
Ohinewai wells		35-47 at 115-285 m			domestic use	Household wells found in 2004 discharge cold waters with distinct smell of H_2S. Old wells had warm waters and indicate relatively high thermal gradient
Okauia (Matamata) Hot Springs	swimming pools	40-47	1		swimming pool	
Crystal or Okahukura	swimming pool	spring: 47; 1 well: 39		40	heat exchanger; hot water used domestically	swimming pool in disrepair, unused
Ramaroa or Opal	swimming pool	spring: 40; 1 well: 40	spring: 1.45	38.6	swimming pools	
Okoroire North 1	bathing facility	38-43	56.3	40.5	bathing facility	
Okoroire South 1	none	35.5		38.9	undeveloped	
Okoroire South 2				38.9	undeveloped	
Orini hot springs					unknown	gassy wells with T= 22^oC drilled in 1966
Paeroa Soda Spring	cold spring of interest				not in use	Water contaminated; covered by concrete bunker
Puriri Soda Springs	cold spring of interest			18	2 major springs, mineral water production planned	
Scherers Rd (Waharoa or Walton)	private pool	32	2	31	not in use	pool has been covered by vegetation; warm waters still trickle through. Low flow
Sheenan	none	23	100			could not locate
Taihoa South Road Hot Spring	private swimming bath	44			not used	
Te Aroha Springs Group	swimming pools	springs: up to 59; wells: up to 85	wells: 0.9	springs: 40-50; well: 82	swimming pools, therapeutic baths	
Te Aroha (Mokena Geyser)	tourism			82.4		
Te Maire (Naike)	swimming pool	53-93	10	64	bathing, undeveloped	
Waikorea	none	54	0.04	48	undeveloped; bathing; domestic use	
Waingaro	swimming pools	37-54	5.7	55	swimming pool	1 well being pumped

Spring/Hot Water Discharges	Past Use*	Measured T (^{o}C)*	Flow (L/s)*	Present T (^{o}C)	Present Use	Notes
Waitoa springs	none	55	2	52	undeveloped	used as bathing pool about 25 to 30 years ago
Waitoa Well-1				50	bathing, domestic	
Waitoa Well-2				50	not used	
WANGANUI						
Jerusalem Hot Spring	none			25	cultivation of special plants (<1 L/s)	
Pipiriki (Waiora) hot spring		23	5	18	not used	trickle of warm water
Upokongaro seepages				20.4	not used	
Upokongaro bore				21	potable water	artesian
SOUTH ISLAND						
Anchorage Cove Spring	none		58-61		not known	
Banks Peninsula, Cass Bay Spring	bathing, watering plants in glasshouse, used as potable water	up to 30				
Banks, Cass Bay: (2 concrete pipes) under road	none			29.8	none	in the past 2 years flow has halved
Ferrymeade	hothouse	20	1.8			no water in cairn in 2003
Heathcote Valley Spring	none	24				could not find in 2003
Lyttelton Tunnell	none				gone	
Motukarara swamp	domestic use for well	24.5 (well)	1 (well)	26 (springs)	undeveloped	warm springs in swamp
Mt Pleasant	none	24	low			did not find in 2003
Purau Bay	none reported	18	up to 4	19	domestic use	
Rapaki Bay	none			28	bathing, undeveloped	intertidal springs
Hanmer springs						
Hanmer well	bathing, spa, heat exchanger	springs: 32-43; wells: 50	8	52	swimming pools, heat exchanger	1 well producing but several wells have been drilled
Barrier River Spring		warmer than stream	trickles			
Copland River	bathing	Up to 57	3.7	56	bathing, hut nearby	
Cow Stream Springs	none	52				
Cox River Spring	none	hot				
Deception R. spring	none			38	bathing, undeveloped	
Fox River warm spring	none	29.5	0.05	34	not being used, adjacent	

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
					to road	
Franz Josef Spring	none	44	0.6		covered by river gravel	smell of H_2S still present
Franz Josef track	none					smell of H_2S
Grantham River Spring		warm				
Haupiri River	none	49		46	bathing, undeveloped	
Havelock Creek Springs	none					reported as a hot spring but is cold with FeOOH deposits
Henry Burn Spring	none	warm			none	
Hope River Lower Spring	none	28		50	bathing, undeveloped	
Hope River Upper Spring	none	50		54	bathing, undeveloped	
Hurunui River (North branch) Springs	bathing	55		39	bathing, undeveloped	
Hurunui River (South branch)Springs	none			29	none	
Irene Valley Spring	none	28.5		23	none	
Iron Gate Stream: tidal rocks just north of bridge				22.6	not used	springs along river and in intertidal area; river springs found in 2003 have been covered by river gravel in 2006
Kahutara River spring	none	34				
Kokatahi River Springs	none	71				
Kotuku bore spring				21.4	none	leakage of gassy warm waters from abandoned oil and gas well (drilled 1904). Still extant in 2003 but flow ceased in 2006
L. Christabel (Grey R.)	none					several reports of H_2S smell but springs not found
Lewis River Springs (Sylvia Flats)	bathing	44	0.02	44	bathing, undeveloped	
Maruia Spring natural spring	bathing pool	60	5	53		
Maruia Spring well				55.3	Japanese ryokan style thermal resort, swimming pools, spas	1 well, several springs along river
McKenzie Stream Spring		hot		38	bathing, undeveloped	
Mungo River Springs	none	66	0.1-0.2		bathing, undeveloped	

Spring/Hot Water Discharges	Past Use*	Measured T (^oC)*	Flow (L/s)*	Present T (^oC)	Present Use	Notes
Otehake River Spring (Lower)	none			40?	bathing, undeveloped	
Otehake River Spring (Upper)	bathing			40	bathing, undeveloped	
Otira River spring	none	31	small			strong H_2S smell along Otira road in 2005 but springs could not be located
Perth River (Scone Hut)	none			30	undeveloped (trickles)	
Perth River Lower Spring (near Nolan's Hutt)	none			38	undeveloped (trickles)	
Perth River Upper Spring	none					
Poison Bay, Fiordland						cold spring of interest
Taipo River (Fraser) Sp	bathing	82	large	70	bathing, undeveloped	flow not as large as reported in 1984
Toaroha River . (Cedar Flats) spring	bathing	71	0.1-0.2	46	bathing, undeveloped	
Transit Valley spring	none	up to 25	<0.01			
Upper Cascade Valley	bathing	20	1			
Waitaha R. Hot spring	bathing	40	1	48	bathing, undeveloped	
Wanganui R Lower Springs	bathing	wells: up to 38	0.7			springs do not exist anymore
Wanganui R Mid Springs	bathing			42	bathing, undeveloped	
Wanganui R Upper Spring (Smythe Hut)	bathing		5	40?	bathing, undeveloped	
Wanganui R., Amethyst hot springs	bathing			55.4	bathing, undeveloped	
Whataroa River (Butler Junction Hut)	bathing			38?	bathing, undeveloped	

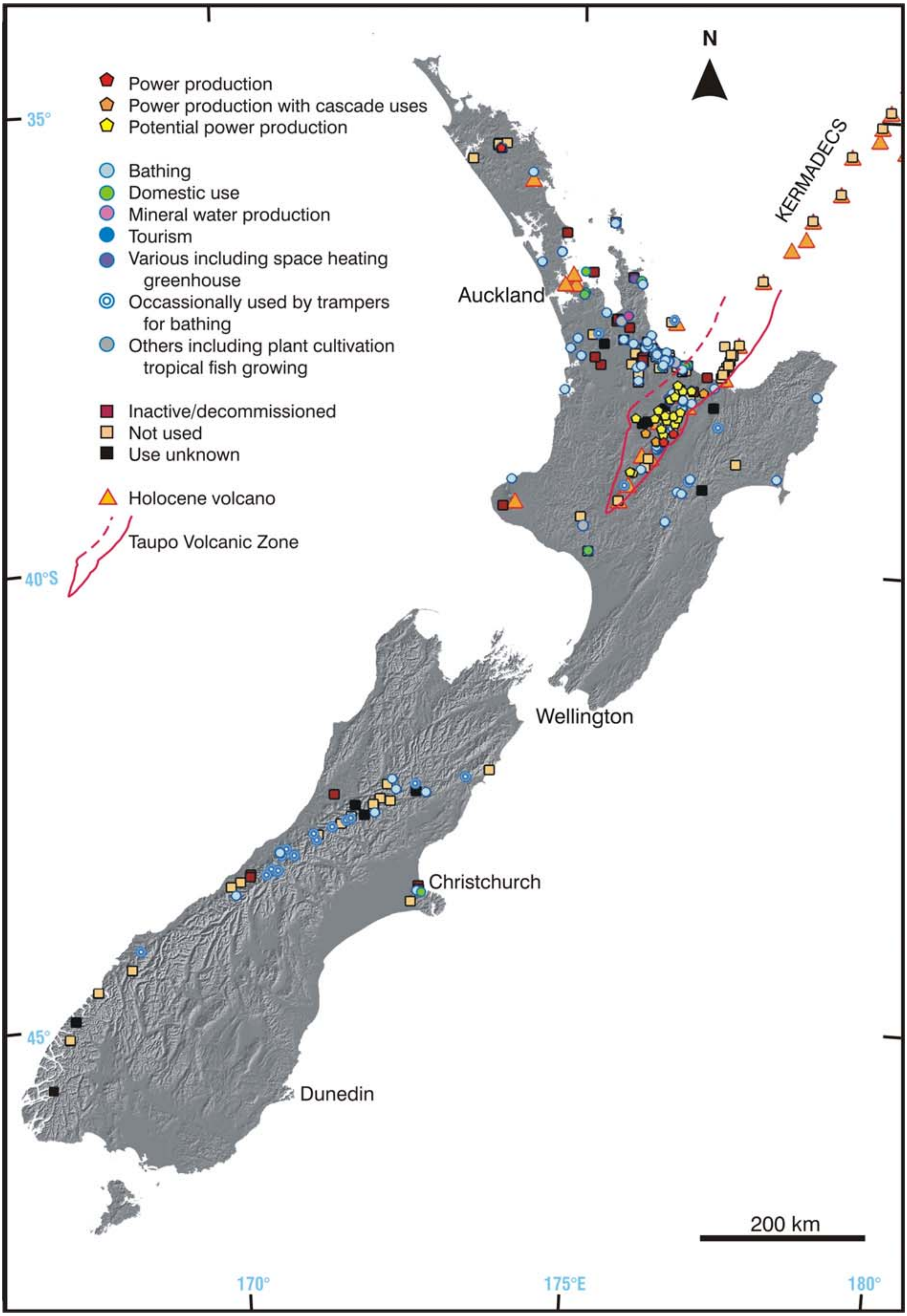

Figure 30. Map showing the main uses of geothermal fluids in New Zealand. (Reyes in prep).

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