TE WHAREWAKA, WELLINGTON – A CASE STUDY IN GEOTHERMAL HEAT PUMP APPLICATIONS BESIDE A LARGE BODY OF WATER

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ABSTRACT

One of the challenges for geothermal heat pump installations is management of resource risk. There has been recent uptake of geothermal heat pump developments for commercial buildings in Christchurch where risks associated with underlying reservoirs are now well understood, and a range of parties are working to facilitate use. Reservoir risks in many other places are less understood and this may discourage similar investment. However many towns and cities have their commercial centres located by harbours, lakes or rivers for which characteristics are readily available. These offer major sources of heat, which is one of the dominant energy requirements of commercial buildings.

Te Wharewaka o Pōneke Function Centre on Wellington's waterfront provides a case study of a commercial facility built beside one of these large water bodies taking advantage of the heat available through geothermal heat pumps.

This paper looks at the design of this facility and performance since it was opened. Some possible improvements are considered before the paper goes on to briefly discuss the wider opportunities for similar commercial developments in other centres.

We are surrounded by oceans, lakes and rivers of energy for which we have been preoccupied with generating electricity from movement rather than directly extracting the heat energy inherent in these vast reservoirs.

Figure 1: West view of Te Wharewaka over the Whai Repo lagoon. Waka are stored and displayed to the right of the building, with launching ramps in front of them.

1. PREAMBLE – CHRISTCHURCH GEOTHERMAL HEAT PUMP EXPERIENCE

Christchurch has long been a significant centre for geothermal heat pump developments, especially for commercial applications. Christchurch City Council was an early leader in this through the 1970s and 1980s. Swimming pools were heated via heat pumps extracting heat from reticulated water in the mains to give necessary warmth. A Council library and other facilities followed.

In 2010 and 2011 and periods in between and beyond, Christchurch was rocked by massive earthquakes that essentially flattened the central business district. This disaster has been met by a slow rebuilding process in which geothermal heat pumps are again playing a significant part, this time drawing from underlying aquifers.

Figure 2 shows some of the commercial buildings in Christchurch that will have geothermal heat pumps as the prime means of space conditioning.

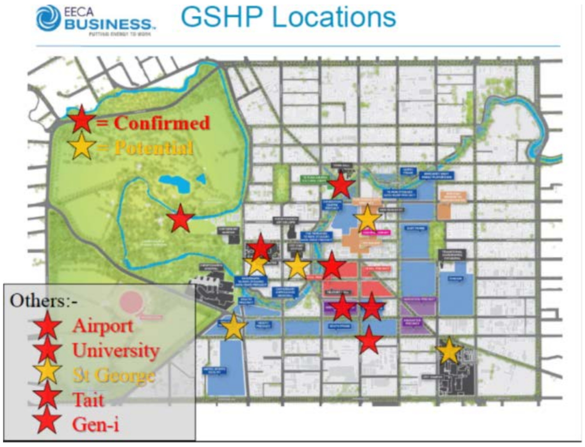

Figure 2: Some of the sites in the Christchurch rebuild now being developed using geothermal heat pump systems. Several of these may form the core of localised district heating schemes.

This development has been encouraged by (based on an initial list by Peter van Meer, EECA):

- A growing cluster of supporting consultancies
- Good information about Canterbury aquifers
- Non-notifiable consents based around zero net extraction that mean these projects can be quickly approved
- Clean slate (in terms of levelled CBD) to enable possible interlinking with other users
- Slightly higher density people/m^2 in the new buildings (now more like national average)
- EECA feasibility study assistance
- Limited renewables subsidies through Christchurch Agency for Energy (CAfE) and from EECA to demonstrate underutilised technologies

- Payback period of 5 years or less for projects over 6,000m^2
- Christchurch's clean air requirements.

Some of these conditions will not exist elsewhere, but many could. Expertise exists in a number of centres outside of Christchurch, and Christchurch consultants could offer services nationally. People density in other centres has been higher than Christchurch traditionally and this helps the heat pump economics elsewhere. EECA feasibility study funding is a national service as is their support of underutilised technologies (including heat pumps). There are growing calls for cleaner air in terms of particulate emissions, and there will be growing calls for less carbon emissions on a national basis. In any location, there will be a requirement for a development of sufficient scale and occupancy rate (or air treatment requirement e.g. library, gallery, archive) to justify investment. However very few locations exist that provide the degree of confidence possible for well performance that is available from the very forgiving Christchurch groundwater aquifers, and that could be discouraging for developers.

One action to reduce this resource risk could be programs of aquifer research in other commercial centres. However another option is to develop surface bodies of water for which temperature data could be provided by Regional Councils (this data would seem a natural fit for the National Institute of Water and Atmospheric Research (NIWA) but is not collected by them) and for which there is no doubt about the capacity that can be extracted. If Regional Councils recognised the opportunity through non-notifiable consents for zero net extraction developments as in Christchurch then conditions could be right for major uptake of this type of heat pump option across the country for the right size of development. (In practice, in many places, extraction and nearby reinjection is a permitted use, though clarification may be needed around acceptable temperature change and acceptability of biocide dosing). One precedent-setting example of such a development is Te Wharewaka o Pōneke Function Centre on Wellington's waterfront.

2. COMMERCIAL BUILDING ENERGY REQUIREMENTS

For Te Wharewaka, the principal requirement was for space heating with some water heating. For commercial buildings, space conditioning and water heating are usually significant energy loads.

The Building Research Association of New Zealand (BRANZ) has undertaken a Building Energy End-use Study (BEES) between 2007 and 2013 looking specifically at non-residential buildings to establish where and how energy and water resources are used in these buildings and what factors drive their use. From the separate Christchurch assessments by EECA, it is known that office projects with a floor area exceeding 6000m^2 are generally required for geothermal heat pump projects to be viable (it could be even smaller areas for projects such as Te Wharewaka that do not face the cost of wells). This floor area corresponds to a mid-point in the second to largest building size category in the BEES. This still corresponds to about 30% of all non-residential building floor area in New Zealand (i.e. 12.4 million m^2) though perhaps only 3% of the number of buildings. If applied to commercial office and commercial retail sites only then 15% of floor area is still in this category. Energy consumption is a strong function of floor area in any building. Amongst large commercial premises a floor area of 18,000m^2 would be an average size. Centralised HVAC systems were the most common mode of heating and cooling in large buildings.

For commercial buildings, average electricity use is about 200 kWh/m^2 y but added to this is roughly 50 kWh/m^2 y for gas use. The following graph shows how electricity is used in these buildings with strata 4 and 5 being the building size of most interest. Space conditioning accounts for about 20% of electricity consumption. However, added to this is another roughly 25% of energy supplied by gas for heating purposes. Combined, this aligns with EECA's assessment that commercial buildings use about 40% of their energy in space conditioning.

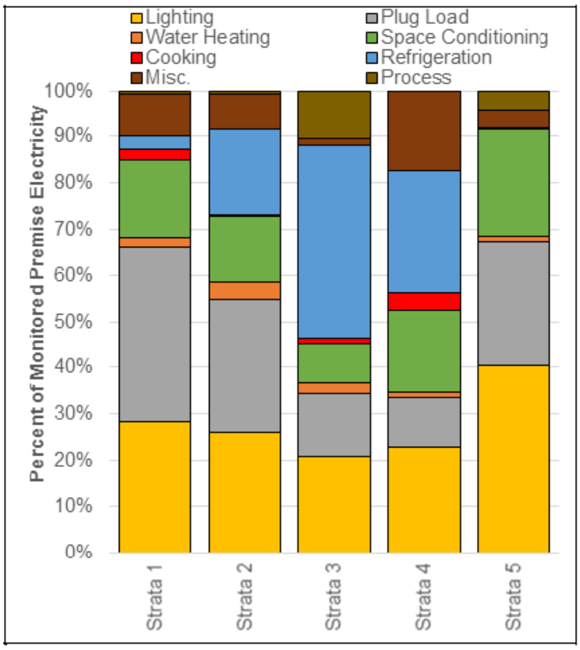

Figure 3: Electricity use in various sizes of non-residential buildings.

In total HVAC energy consumption for buildings that might be suitable for geothermal heat pump development would come to around 90kWh/m^2 y.

The analysis above is based largely on office space for which people are missing through much of the night. However, if hotels, prisons or retirement facilities are considered, there is greater need for 24/7 space conditioning making smaller premises viable to heat with geothermal heat pumps.

Conclusions from this are that:

- A significant portion of floor area for non-residential (or large high occupancy) buildings could be commercially heated by geothermal heat pumps under the right conditions.
- Since geothermal heat pumps have a coefficient of performance of around 4 (for some Australian systems, COP in cooling mode is 11 while it is 6 in heating mode averaging 7-8 for the system, average of 4 is typical of hydronic systems) (Yale Carden, personal advice), the effective energy savings (with associated emissions reductions)

through use of these predominantly for space heating (with some hot water) could be around 70kWh/m^2 y.

3. TE WHAREWAKA O PŌNEKE FUNCTION CENTRE

Te Wharewaka o Pōneke Function Centre on Wellington's waterfront provides an interesting focal point and may provide a springboard for the uptake of geothermal heat pumps in many parts of New Zealand. It is a meeting place of Maori and Pakeha design, of city and sea, of old connections and the current city. The overall design includes the form of the traditional wharenui, wharekai and wharewaka, but was always intended as a function centre able to welcome all cultures and peoples in a modern way. It brought in radical elements of architectural design and of services engineering, for which the geothermal heat pump system is the focus of this paper. Together these elements provide a remarkable function centre (with floor area less than 2000 m^2 i.e. less than a third of the normal threshold floor area for geothermal heat pumps) designed on sustainable principles with low energy consumption.

3.1 Historical Perspective

The building is located in the Te Aro suburb of Wellington, close to the site of the Te Aro pa from which the suburb draws its name. When Port Nicholson was established by the New Zealand Company in 1839 (the name changed to Wellington in 1840), there was a thriving community and pa just to the south of the present building site. Te Ātiawa together with Ngati Ruanui and Ngati Haumia people originally from Taranaki had arrived about twenty years previously and occupied the Kapiti Coast and the head of the fish of Maui (Port Nicholson/Wellington harbour was known as Pōneke in Te Reo Maori). Canoes (waka) lined the shore in the vicinity. Marae-based communities remained in this area until the 1880s, affected by the 1840s and 1850s earthquakes, then partly displaced by resettlement plans, encroaching low-cost housing, then wharf and harbour development and by the industrial centre being developed at that end of town.

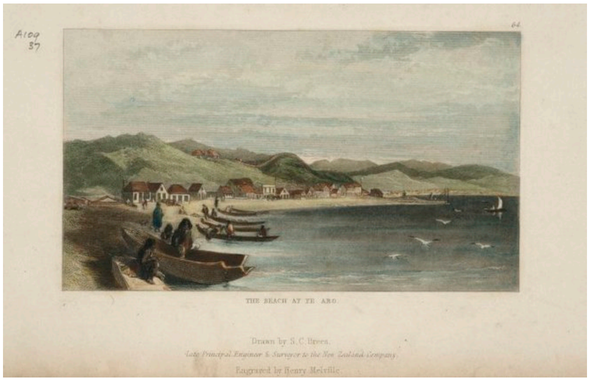

Figure 4: Waka and the beach at Te Aro about 1843 (painting by S.C. Brees).

Originally the harbour had abundant marine life. To this day dolphins visit the area, blue penguins nest in the surrounding rocks and under the wharves, while eagle rays can be seen in the recently formed lagoon now named after them (Whai Repo Lagoon) and cruising beside the wharves. The roof line of Te Wharewaka has been variously described as a cloak/korowai or as a representation of the flapping wings of an eagle ray.

From the late-1980's Wellington town planners developed concepts for a revitalised public harbour area. This saw development of Frank Kitts Park and the nearby lagoon, shifting of old rowing club buildings around the newly-formed lagoon, development of the TSB Bank arena, shifting of the Museum hotel to allow construction of Museum of New Zealand Te Papa Tongarewa, shifting the façade of another building to form the façade of the new Circa Theatre, revitalising the old Odlins timber merchants building into the headquarters for the New Zealand Stock Exchange, construction of bridges and wharf cutouts, conversion of an old store into a brewery then function centre and preparation for shifting the St John's Free Ambulance building behind its current site. In the end the St John's building was left in its original position and converted to its own function centre, and the space behind it became available for Te Wharewaka.

3.2 The Trust Background and Building Design

Responsibility for development was vested in Te Wharewaka o Pōneke Charitable Trust (TWOPCT). This Trust originally included two trustees from the Wellington City Council, two trustees from the Wellington Tenths Trust, and one trustee each from the Palmerston North Reserve Trust and the Port Nicholson Block Settlement Trust. The Wellington Tenths Trust has origins in the original purchase of land by William Wakefield for the New Zealand Company in 1839. The Palmerston North Reserve Trust is linked to the original sale and to a resettlement programme from the 1860s associated with acquisition of Lowry Bay land and is a sister trust to the Wellington Tenths Trust. The Port Nicholson Block Settlement Trust has links back to the same Taranaki whānui displaced by the establishment of Wellington but was established in 2008 to receive and manage the Treaty of Waitangi settlement package for Taranaki Whānui ki Te Upoko o Te Ika.

The original concept was for separate buildings for wharewaka and wharenui purposes but was eventually simplified into a single structure.

Figure 5: Ceremonial waka (Te Hononga and Te Rerenga Kotare) (Photo by John Patterson).

Funding for the building came from a combination of Crown payment ($7million) outside the Port Nicholson Block Trust Settlement, a $1million grant from the Wellington City Council and loans secured by the Trusts outlined above to cover the total cost of $12million.

TWOPCT commissioned architecture + as architects, with e-Cubed as building services engineers.

There were tight constraints on the building envelope to comply with the existing consents, essentially being constrained to the width of the planned relocation of the St John's building, ensuring a gap for the rowing clubs and allowing space for the karaka grove. This meant that there was no space available for outside plant. While the building was intended to house a waka ("Raukura") that had been specially commissioned for Wellington and temporarily housed at Waiwhetu in Lower Hutt, it became necessary for two new waka (Te Rerenga Kotare (a waka taua) and Te Hononga (a waka tete)) to be constructed. These were carved in various places while the hulls were carved from 1,000 year old swamp kauri and joined together in Mangonui. A third waka has recently been added.

Figure 6: While the building is not dedicated to a single ancestor, there is an oblique reference to the explorer Kupe in the sculpture located in front of what should be the marae atea. (Photo by Désirée Patterson).

The building was conceived as a low energy structure. It is a simple two storey rectangle filling the consented space. Triangular shades break the rectangle. There is extensive use of double-glazed windows with high performance low-E glass to reflect solar energy out of the building. The southwest end of the building is the glass-enclosed show room for the two (now three) ceremonial waka (see Figure 5), while the opposite end has a design based on that of a traditional wharenui (see Figure 6). The most striking feature is the aluminium-clad roof structure based around a complex arrangement of triangles, now generally considered to be the cloak/korowai of the building (see Figure 1). From many angles this roof appears to be solid, but disguises vents which form part of the building space-conditioning arrangements.

The building sits amid open spaces so needs to manage passive solar heating. Dynamic thermal models were used in the design of the building to simulate likely conditions and to set the final specifications. Walls are well-insulated while the ceilings have double the required insulation, helping with both thermal and noise insulation. "Advantage" is taken of Wellington winds in that maximum use is made of natural ventilation to minimise energy consumption. Fresh air is taken in through low level windows or the open doors of the wharekai/café and vented through hidden roof louvres. The windows and louvres operate automatically in response to signals from the Building Management System, responding to changing temperature, wind and rain and CO_2 levels, and room motion sensors and this avoids mechanical cooling (though heat management can still be an issue in mid-summer).

The heating mode is the real subject of this paper. Water at fairly constant temperature of 13-14 ^{o}C is drawn from the harbour via a screened and throttled intake pipe, then is subject to further filtering, before passing through floor-mounted pumps. Access to the seawater intake screen is located beneath the Kupe statue and associated grills forming a wharf cutout. Sea water then goes to a first floor plant room, through a titanium plate heat exchanger, then back to the harbour through another throttled outlet pipe beneath the adjacent Taranaki wharf. A secondary circuit links the heat exchanger to the heat pump. The heat pump in turn links to hot water manifolds which bring heat to individually controlled in-floor in-room heating coils (inlet temperature is limited to about 40^{o}C using return valve bypasses to avoid issues with cracked concrete) before collection in return manifolds and recirculation. Another circuit brings heat to in-duct heat exchangers which again control heat and air flow to individual spaces. Heat requirements are controlled by a combination of pre-programming of the building management system and from motion and temperature sensors within each space and outside. Various trips are built into the system to avoid out-of-design conditions. A gas boiler/calorifier system is also present to ensure adequate domestic hot water supplies in the building but gas consumption is primarily directed for cooking purposes. The building management system could be probed to assess utilisation further but is not set up for this currently. This system is energy efficient and avoids the need for any heat rejection equipment on the outside of the building.

Figure 7: Partial view of plant room with the sea water heat exchanger in the foreground (some plates are temporarily missing).

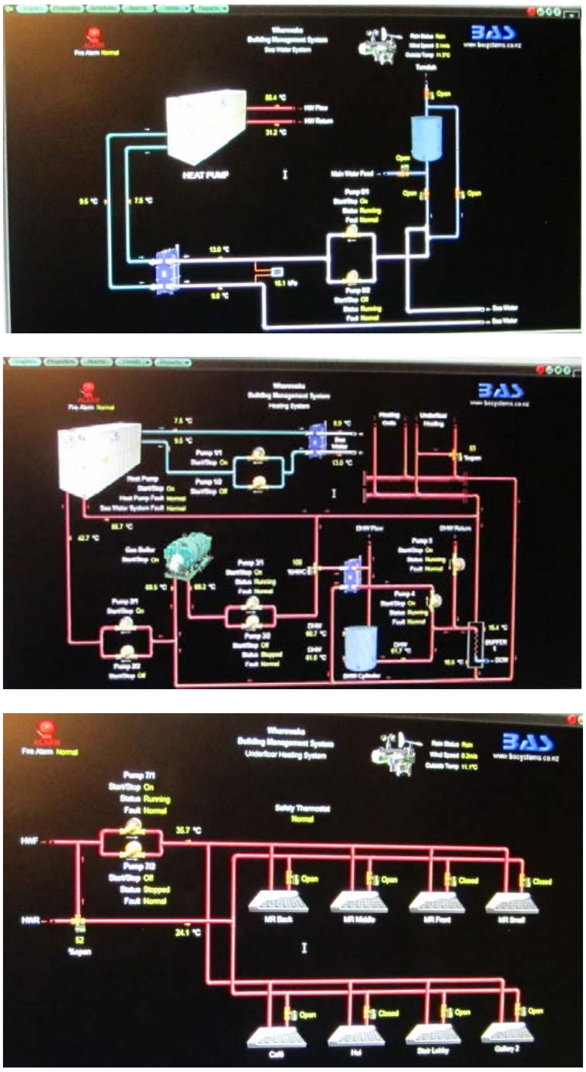

Figure 8: Process flow diagrams a) sea water system, b) general system (note the gas boiler is on a system associated with domestic hot water), c) zoned under-floor system (system includes remixing of return water to keep temperature of supply through the concrete floor below 40ºC)

3.3 Subsequent Experience

The building services were installed and maintained by Aquaheat and subsequently Cowley Services (now ENGIE Services). The project sits as a unique operation within their maintenance portfolio, so has an inconvenience factor (in terms of dealing with a marine environment, and degree of on-site management) which is tempered by their desire to work with the owners who want a low energy, renewable heating system. No significant changes have been made to the system design though some operational refinements have been made.

Corrosion management in a marine environment has been an issue.

The screen at the inlet keeps out larger organisms but requires cleaning by divers on a quarterly basis.

Filters are installed in the system and are effective for most duties. However during periods of heavy rain, surface runoff into the harbour creates a cloud of fine material which is not effectively removed via the filters. This can then start to clog the plate heat exchanger, eventually requiring disassembly and cleanout, normally on an annual basis. However the more common form of fouling in the heat exchanger is from the small muscle shellfish which grow there, a feature of the absence of any biocide dosing in the system.

The seawater pumps have now been replaced with self-priming pumps. Difficulties arose when air was entrained with sea water or air leaked through gaskets. Self-priming pumps have now been installed, gaskets have been replaced and a pump is left continually running (unless a vacuum exceeding 40 psi is achieved) so air cannot accumulate, whereas they were originally designed for more efficient automatic operation.

While it could be argued that a sump could have been constructed below the building to help avoid the problem of air entrainment, the designers weighed up this option in the design phase wanting to isolate the building from the sea as much as possible. This would have been complicated by the numerous piles below the space. They also considered placing submersible pumps in the harbour itself, but land use was essentially restricted to the leased land rather than extending into the harbour.

3.4 Lessons from other Developments

e-cubed had drawn from experience at a Wellington-based NIWA facility they designed, and has designed another sea-water heating and cooling system for the Auckland Viaduct Events Centre completed in June 2011, four months after Te Wharewaka. The Viaduct Events Centre was intended to be developed as a green building. Although duties and consent conditions are different, further evolution in design was possible. This was also an open loop system. Consents restricted sea water temperature change to 3ºC. Greater attention was paid to use of stainless steel throughout the sea water system. There is provision to temporarily close off the seawater section for closed recirculating loop biocide dosing. For the half of the events centre served by the heat pump system, all space conditioning is achieved through air conditioning rather than hydronic systems. The Italian heat pump is more complex being able to operate in heating, cooling and a heat recovery mode, which (together with language difficulties) led to longer setup time. In terms of maintenance, the owners failed to undertake maintenance for the first year, by which time there were significant issues with marine growth. Harbour dredging work in the vicinity of the Events Centre led to further problems with silt in the system. This system continues to run successfully and e-cubed continue to look for other development opportunities.

Major geothermal heat pump developments have been implemented internationally or are in the process of development. Very often these are based around district heating or cooling schemes. There are many examples in Sydney's harbour starting with the Sydney Opera House. The current largest installation in Sydney Harbour is the 80MW Barangaroo cooling system. Many of these are open system designs but a proposed 7MW Rocks Heat Exchange will be of a closed loop design. Other existing closed loop systems include Wharf Terraces (a residential system in Woolloomooloo) and the Sydney Water Police systems among others.

Open systems face high maintenance costs due to continual marine growth, changing ecology, complex facility maintenance routines and increasing environmental compliance requirements. Fouling can occur in pipes and heat exchangers. All elements have to be corrosion resistant. Often some biocide is added to control marine growth in the system.

A closed loop system can restrict these concerns to the heat exchanger immersed in the harbour, but at slightly higher capital cost. Designs for best closed loop heat exchanger arrangements are still being developed, but can be based on lattices of plastic tubes as trialled at the Rocks. The relatively poor exchange ability of the plastic pipe means that large quantities must be used to achieve the required heat exchange. Closed loop system options include polyethylene in a variety of configurations or immersed heat exchanger plates in stainless steel or titanium. The option selected depends on water quality, location and access.

Tidal movement or currents are sufficient to ensure rejected heat is dissipated and removed from the area. (Note that lakes do not have the same advantage).

Whether open or closed loop systems are employed, benefits include minimised life cycle costs, less power/water/chemicals, no legionella risk, and less rooftop clutter. If designed well, then staged development can be possible. Where district energy schemes are employed then supplied facilities need less space for services and face lower energy and water bills.

There are opportunities for designers and maintainers to network or to gain from the experience of others through membership of groups like the Geothermal Heat-pump Association of New Zealand (GHANZ) or through courses offered by the International Ground Source Heat Pump Association.

4. OPPORTUNITIES FOR REPLICATION

While circumstances around the establishment of the Te Wharewaka o Pōneke are unique and there are lessons to be learned, the example of using water as a heat source from harbours, lakes or rivers (anywhere a waka can travel) can be repeated in many towns around the country. Examples could include downtown Wellington or Auckland by their harbours; Queenstown, Taupo or Rotorua along their lake front; or Hamilton along the course of the Waikato River.

One of the provisions that enabled Christchurch development of heat pump systems was the non-notifiable consent provisions established for this form of heating by the Canterbury Regional Council. Given willingness to encourage use of renewable energy then other councils could follow suit for zero net extraction projects, based on reasonable margins of temperature change between water inlet and outlet conditions.

At this point in New Zealand's history it is easy to see a number of small incremental steps in development. However, a review of global heat pump data (Figure 9) shows exponential growth to the point where geothermal heat pump applications are now the dominant form of geothermal direct use globally. New Zealand has been slow to take up these opportunities, but:

- as confidence builds on the part of commercial developers,
- as people seek responsible sustainable developments, and
- as more people understand the economics of geothermal heat pumps in buildings of sufficient size, occupancy and design

then national development should also accelerate.

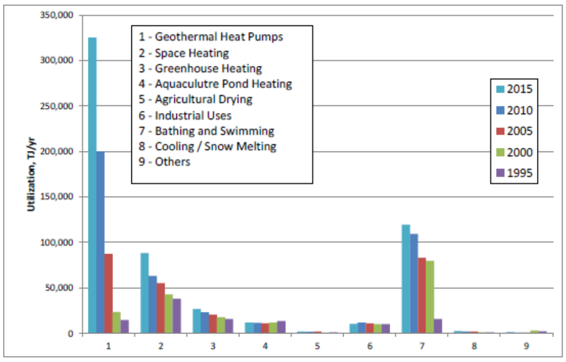

Figure 9: Left hand bars show global growth of geothermal heat pump use in comparison with other geothermal direct uses. (Lund and Boyd, 2015)

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