DIRECT GEOTHERMAL ENERGY DEMONSTRATION PROJECTS FOR VICTORIA, AUSTRALIA

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ABSTRACT

It has been estimated that there are over 3 million individual direct geothermal energy systems operating around the world providing heating and cooling for buildings. However, the various guidelines which have been developed for the determination of the length of ground loops are generally conservative so that there is little risk of these systems failing to deliver enough energy. Therefore, ground loop installations have generally been over-designed leading to systems which are neither as cost effective nor competitive as they could be.

To make direct geothermal systems more cost effective and commercially attractive, particularly in Victoria and Australia, the Department of Infrastructure Engineering at the University of Melbourne has started an extensive research project aimed at understanding the ground processes so that installation and operation costs can be reduced. Although the overall project involves a number of elements, a key component is the installation of instrumented direct geothermal systems in several buildings throughout the state to provide data on performance for a range of different conditions. The project aims to make the technology an everyday sustainable alternative to conventional systems to economically and effectively heat and cool buildings in Victoria.

1. INTRODUCTION

Outside the volcanic regions of the world where it is readily available at the ground surface, geothermal energy can be accessed in two ways. One involves heat extracted using water from boreholes drilled to several kilometres below the surface where temperatures exceed 200ºC to generate electricity. Although this source of power has enormous potential, we are still several years from producing electricity on a commercial scale. The other is the direct form, which is well established outside Australasia (Banks 2008, Brandl 2006, Preene and Powrie 2009).

Direct geothermal energy uses the ground within a few tens of metres of the surface as a heat source and sink to heat and cool buildings. It has been estimated that there are over 3 million installations in operation around the world (Lund et al, 2010), mainly in northern Europe and North America, with a rapidly growing number in Asia. The key element in direct geothermal systems is the ground source heat pump or GSHP. In winter the GSHP extracts heat from water circulating in ground loops and delivers it to a building. In summer, the reverse happens with the GSHP extracting excess heat from the building and dumping it to the ground. Figure 1 illustrates the principles of this technology.

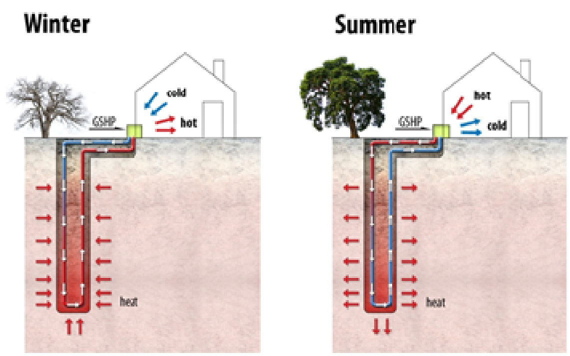

Figure 1: Principles of direct geothermal heating and cooling (borehole not to scale).

The ground loops themselves can take a variety of forms including placement in small diameter vertical boreholes drilled to an appropriate depth (typically 30m to 100m), in shallow trenches between about 1m and 2m depth provided there is adequate space beside the building to be serviced, and for larger commercial and industrial buildings, in the foundations themselves.

While direct geothermal energy is extensively used in other countries, it is rarely encountered in Australia. There are several reasons for this including our cheap sources of energy (although, regrettably, not the cleanest), and the fact that our climate is not as demanding as the much colder, heavily populated areas of the northern hemisphere.

However, it is highly likely that this is going to change dramatically as soon as carbon taxes are introduced and greenhouse gas emissions have to be seriously reduced. All forms of renewable energy, as well as the continued use of coal for several years, are likely to play a part in this transition. However, the direct geothermal alternative is likely to become a major player in this space because it is abundant and renewable as it is recharged over very large areas by the sun, it involves well established and reliable above ground technology, and, unlike most others, it is available 24/7.

Because a significant proportion of our total energy production is used for heating and cooling buildings, the introduction of direct geothermal heating and cooling to Australia on even a moderate scale would have a significant impact on power requirements with enormous economic and environmental benefits. The reason for this is that for each kilowatt of electrical energy put into a direct geothermal system, about 4 kilowatts of energy is developed for the purposes of heating and cooling. This means that outside the capital costs of the installation, about 75% of the power is free and greenhouse gas production is reduced by about the same 75%.

Although there are a large number of installations worldwide, these have been driven by the heating, ventilation and air conditioning (HVAC) industry, with little technical input from geotechnical engineers. This has led to numerous, very approximate guidelines of what should be installed in the ground to provide the energy required. Based on these guidelines, installations are generally over-designed leading to systems which are neither as cost effective nor competitive as they could be. Further, only a handful of these installations has been instrumented to check the applicability of the design and installation processes used or to provide information about balanced design for optimal performance.

In order to correct this imbalance, particularly with respect to Victorian and Australian conditions, the Department of Infrastructure Engineering in the University of Melbourne's School of Engineering has embarked on an extensive research and demonstration project involving many geothermal installations around the state. This paper provides an overview of this project.

2. CAMPUS GEOTHERMAL TEST FACILITY

The first of the field installations was constructed adjacent to the Beaurepaire Sports Centre on the main university campus in Parkville. Figure 2 shows the test facility lay-out, Figure 3 shows some of the reinforcing cages with attached ground loops ready for installation and Figure 4 shows one of these piles being constructed.

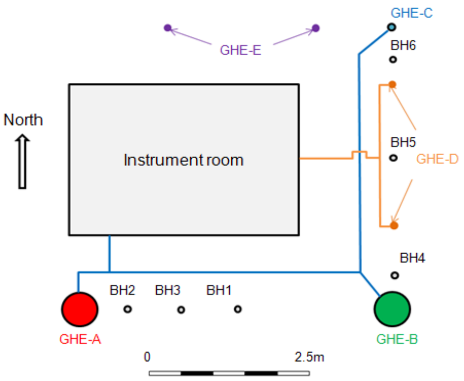

Figure 2: Campus Geothermal Test Facility lay-out.

There are 5 ground heat exchangers (GHEs) or sets of ground loops at this facility, all of which are installed to a depth of approximately 30m below the ground surface in extremely weathered Silurian mudstone. All of these have thermistors attached to monitor temperature variations during testing. Two of the GHEs (GHE-A and GHE-B) are 600mm diameter piles each containing 3 ground loops which can be operated together or singly. The HDPE pipes are 25mm outside diameter in one pile and 32mm outside diameter in the other. GHE-C is a 125mm diameter borehole in which a single HDPE ground loop has been installed using 20mm outside diameter HDPE pipe. GHE-D and GHE-E are direct exchange systems for which refrigerant, instead of water, circulates within smaller diameter copper pipes installed in the boreholes. Boreholes BH1 to BH6, installed at specific locations adjacent to the GHEs, contain arrays of thermistors to measure the variations in ground temperatures during testing.

Data derived from the test facility has a variety of forms but a typical test result indicating the variations in power deposited to the ground with time (the GSHP in cooling mode) is shown in Figure 5. This data is currently being assessed and results should be publicly available soon.

Figure 3: Pile reinforcing cages with ground loops ready for installation

Figure 4: Installation of an energy pile at the Geothermal Test Facility

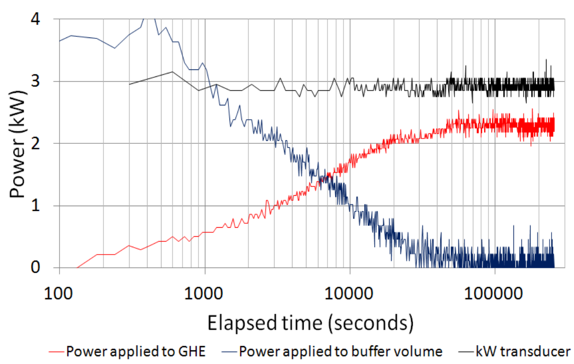

Figure 5: Typical test data from a ground loop in cooling mode

3. HORIZONTAL SYSTEM AT MAIN RIDGE

Another field installation has recently been completed in an area known as Main Ridge on the Mornington Peninsula approximately 80km from the University. The buildings were recently renovated and have a total floor area of about 700m^2. As there was considerable land available close to the buildings, it was decided to install a horizontal "slinky" system of ground loops to provide the 70kW heating load required for the buildings and its swimming pool. Figure 6 provides a view of the loop field just after completing installations but before back filling.

Figure 6: Part of the "slinky" system at Main Ridge

A summary of the installation is as follows:

- The depth of the excavation is about 2m into basaltic clays and extends over an area of about 1560m^2,
- The ground loops comprise 25mm outside diameter HDPE pipes arranged in a "slinky" formation of 900mm width with varying pitches. There are 20 lines of loops arranged at 2m centre to centre spacing. The total length of pipe is about 4.7 km.
- In addition to being able to assess the influence of pitch, each line of loops can be isolated with solenoid valves to allow an assessment of loop spacing on performance.
- Larger diameter header pipes connect the GHEs to 3 Mitsubishi GSHPs (see Figure 7).
- There are 172 thermistors on the HDPE pipes, in 15 boreholes above, below, adjacent and some distance away from the loops, on the heat pumps and in various water tanks making up the overall system. There are also 8 flow meters measuring water flow in various parts of the system. Data logging facilities are provided in a data control area (Figure 8) and data can be accessed remotely through wireless links to the university. There are over 6kms of data cable in this project.

At the time of writing this paper, the monitoring of data from Main Ridge has just commenced. However, typical output data recorded remotely can be seen in Figure 9. This shows that the heating system was turned on late on Friday 6th July when the owners arrived for the weekend. Heating continued until the morning of Monday 9th July when the owners left.

The minimum temperature reached during this period in this particular ground loop was generally a little over 10°C at entry to the loop, although there seems to have been a slight decrease in heating demand on the Sunday afternoon. The leaving temperature during this period was about 12˚C. The differential 2˚C is used and upgraded by the GSHP to satisfy the heating demand of the buildings.

Figure 7: Mitsubishi GSHPs (note header pipes at left awaiting connection)

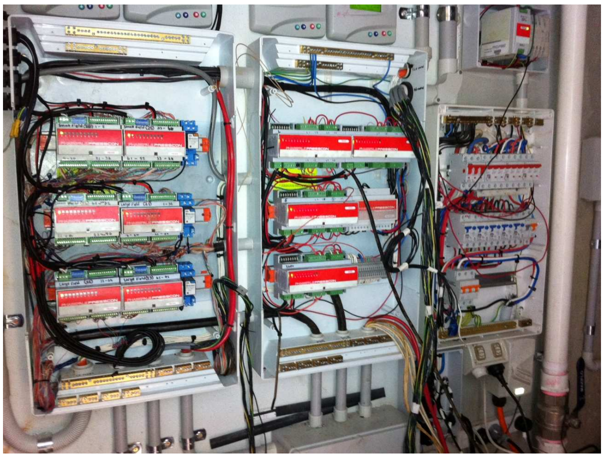

Figure 8: Data control area

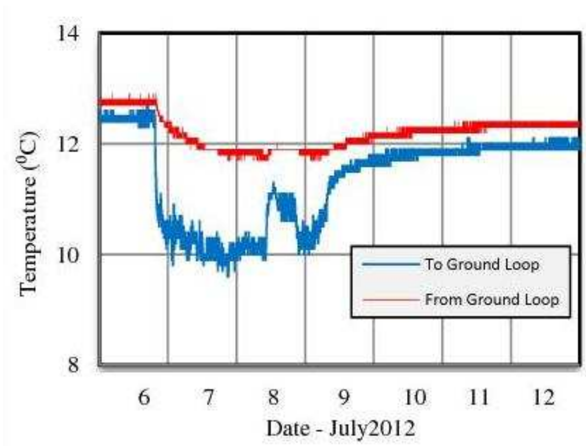

Figure 9: Temperature variations at inlet and outlet of a ground loop at Main Ridge

4. WALTER BOAS BUILDING ON UNIVERSITY CAMPUS

The Walter Boas Building on the main university campus at Parkville has recently been renovated to accommodate a number of tenants including the university's Sustainability Centre. In order to provide a living demonstration of the technology, it is currently being fitted out with a direct geothermal system. This system will include a set of double HDPE ground loops installed to 50m in vertical boreholes located in the garden immediately to the north of the building, as illustrated in Figure 10. It is intended to use a series of different grouts in the boreholes so that the influence of this important factor can be assessed. The distribution systems inside the building have now been connected to a number of highwall fan coil units from the 25kW GSHP donated by Mitsubishi Electric Australia Pty Ltd. It is planned that the ground loops will be installed in August 2012.

Figure 10: The Walter Boas Building installation

5. BIO21 SCIENCE SCHOOL

The University of Melbourne, in conjunction with University High School and Debney Park Secondary College, with funding from the Victorian Department of Education, is about to build a Science Sub-school in the grounds of the Bio21 Institute in Flemington Road. The building will be used for science teaching for year 11 and 12 students. It will comprise a floor area of about 1200m^2 over 2 floors, made up of 2 medium sized lecture theatres, an experimental area, several classrooms and some general central open access spaces. Final design is nearing completion as this paper is being prepared and it is envisaged that the project will go to tender in August 2012 with construction planned to start in November 2012 and the building ready for occupation for the 2014 school year.

The direct geothermal system will comprise 28 boreholes each containing double loops of HDPE pipe of 25mm outside diameter to a little over 50m depth. The ground loops will be arranged in 4 borefield rows of 7 and each row can be isolated with solenoid valves to allow an increase in heating and cooling loads on each loop. Header pipes from each row will be combined in a main header to the 4 GSHPs (1x 30kW, 3x 20kW) to provide the 90kW required for heating.

It should be noted that had conventional commercial design parameters been used, the peak cooling load for the building would be higher than the peak heating load. However, the Department of Education does not require cooling in schools. Therefore, cooling will be limited to the amount provided by the system designed for heating. Allowing for a number of factors, it is likely that cooling in the building will be quite effective with perhaps ideal conditions not being reached only on a few particularly hot afternoons.

The monitoring to be installed in the Bio21 building will comprise the following:

- About 372 thermistors (290 on ground loops and in adjacent monitoring boreholes, 8 at entry to borefield rows, 16 on entry and exit to GSHPs, 38 on fan coil units in the building and 20 measuring the building response).
- About 20 flow meters measuring water flows into selected ground loops, into all borefield rows, into and out of GSHPs, from circulating pumps and into selected fan coil units.
- Power meters measuring electrical power into all GSHPs and the circulating pump.
- A weather station measuring temperature, humidity, wind speed and wind direction to be located on the roof of the building.
- One borehole adequately remote from the geothermal installation to measure "far field" temperature variations with time to a depth of 50m.
- One borehole for monitoring ground water level.

The Bio21 building has an added advantage in that the science students using the building will have direct experience of the technology, and will be able to use the building as a living experiment in their studies with direct access to the data generated. Indeed, as is intended at a number of other larger sites, data derived from the geothermal monitoring will be displayed on screens to show how the systems are performing, what power is being generated to heat and cool, what temperatures are being experienced in various parts of the system and most importantly, how much is being saved, in terms of both dollars and carbon emissions, through the use of a direct geothermal system.

6. PORT MELBOURNE BUILDING RETROFIT

One of the university's partners in this overall project (Geotechnical Engineering), owns a large building comprising office accommodation and workshops in Port Melbourne (Figure 11). This location is underlain by much poorer quality geotechnical materials (in terms of load bearing capacity) than most other parts of Melbourne and was therefore considered to be appropriate to extend the range of ground characteristics investigated.

The office building has a total floor area of about 1500m^2 on 2 floors. However, an initial assessment of the site suggested that there was only enough free surface area close to the building to accommodate GHEs to provide for half of the building. Therefore, it was decided to set this particular project up with the north facing building divided into a west half and an east half. The west half, because it is the closest to the area for the GHEs, will be retrofitted with a geothermal system, and the east half will continue to use the existing conventional air source heat pump system mounted on the roof of the building. This arrangement provides an ideal framework to allow a direct comparison of performance of the two technologies.

Figure 11: The Port Melbourne Building

Although detailed designs are still to be commenced, initial planning has indicated that 40 boreholes to 50m will be required to provide the power for the dominant cooling load for half of the building. Because Geotechnical Engineering is a large piling contractor and interested in developing a capacity to design and install geothermal systems in commercial buildings making use of pipes placed in foundation piles for energy, some consideration will be given to replacing some boreholes with larger diameter energy piles. As with other projects, the ground loops, surrounding ground, GSHPs and the building will be thoroughly monitored to establish actual performance.

As indicated above, there may only be enough surface area close to the building for half the building to be provided with geothermal heating and cooling. While this arrangement could be allowed to continue after comparisons are completed, a more economic approach would be to include a distribution system for the geothermal energy into the whole building to allow it to provide base-load power to about 50% of power capacity. The balance of the power could be provided by the existing conventional system. As is discussed by Johnston (2012), this arrangement would mean that over about 80% of energy requirements would be provided by the geothermal system, thereby providing significant economic and environmental benefits.

7. VICTORIAN PROPERTIES

The five projects discussed above involve detailed monitoring in geothermal installations either in or relatively close to Melbourne. There are many other areas in Victoria (and indeed the whole of Australia) which have quite different climatic and geological conditions. There are also other significant differences relating to service availability, costs of energy and household demographics. Therefore, in order to investigate and demonstrate the use of direct geothermal energy across the whole state, a significant part of the Victorian Government funding will be used on a project known as Victorian Properties. A key partner in this overall project is Direct Energy Australia Pty Ltd.

A total of up to about 40 new and retrofit buildings will be selected to cover a range of conditions typically encountered in Victoria. While most of the buildings will be houses, it is possible that other forms of construction may be used. These will provide important data with respect to the overall physical performance of direct geothermal systems from a range of building types and the associated capital and operating costs along with the socio-economic energy demands of a range of buildings and the characteristics of their pattern of use by the occupiers. The individual property owners will be paying for the capital costs of the geothermal systems. The project funding will be paying for the instrumentation, and its design, installation and monitoring.

Although this project is just starting, at this stage there have been many individuals who have indicated their willing participation. This includes several homes, both new and retrofit, some already built (to which monitoring will be more limited but still meaningful) and to be built. These projects include both horizontal and vertical loop systems, closed water loop projects involving dams, quarries to be backfilled, and even the use of failed copper loop/refrigerant systems redesigned for water. It is envisaged that the installation of all of these systems will be completed by early 2014 and monitoring will continue for at least 2 more years.

8. EDUCATION AND TRAINING

While the derivation of design data is crucial to the project, another important part of the overall project is to educate and engage the general community about direct geothermal energy as well as provide specific training to the trades and professions so that the technology can be rolled out in Victoria. Therefore, in addition to a broad range of presentations, seminars and workshops (delivered through community groups, trades organisations, special interest groups, individual companies, technical societies, energy conferences, several media channels, a dedicated website and technical publications), it is intended that a series of detailed training courses on both design and installation will be initiated. It is intended that the highly successful training and accreditation systems developed by the Canadian GeoExchange Coalition (CGC) over the last 10 years will be adapted for Victorian conditions. Several meetings between the partners of the project, the CGC and the Australian Geothermal Energy Association (AGEA) have already taken place and it has been agreed that with some appropriate adaptations, the material developed by the CGC would readily fit the Victorian context and be ready for presentation during 2013. The examples of and the data derived from the monitored buildings will be important input for these training courses to provide essential local content.

9. CONCLUDING COMMENTS

While a large number of direct geothermal energy systems have been installed in other parts of the world, very little detailed information about system performance has been made publically available. This has led to various approximate and often conservative guidelines for ground loop installations which are not as cost effective as they could be. This is particularly true for Victorian and Australian conditions where direct geothermal energy is just starting to take effect.

The overall project described in this paper will develop comprehensive in-ground design data for Victorian conditions. The factors requiring assessment include the geometrical arrangement of components, the materials used, the importance of orientation, depth and component spacing, ground fluid types and flow rates, and the operating characteristics of the heat pumps used. The data will be collected from instruments in direct geothermal systems that will be installed in a number of buildings constructed around the state. Instrumentation inside and outside the individual buildings will monitor the adequacy of the geothermal systems to provide heating and cooling and the external temperatures against which this energy is to be provided. The energy efficiency of each building will also need to be assessed.

The main short-term outcome of the project is a clear demonstration that direct geothermal energy can make a major contribution to a sustainable future with a significant reduction of greenhouse gas emissions. In the longer term, the project aims to make the technology an everyday sustainable alternative to conventional systems to economically and effectively heat and cool buildings in Victoria.

10. ACKNOWLEDGEMENTS

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