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Aquatic Centre Retrofit of Hybrid Vertical and Horizontal Ground Heat Exchanger

Donald J. B. PAYNE[1], Ed LOHRENZ[2], Greg BENVENUTI[3], Amir V. KIVI[1] and Tony CHISHOLM[4]

[1]Direct Energy Australia (DEA), 4/820 Princes Hwy, Springvale, VIC 3171

[2]GEOptimize Inc., 1503 – 220 Portage Ave, Winnipeg, MB R3C 0A5

[3] Energy Made Clean (EMC), PO Box 1268, West Perth, WA 6872

[4]WML Consulting, PO Box 10309, Kalgoorlie, WA 6433 (formerly City of Kalgoorlie-Boulder)

Donald@directenergy.com.au ; Ed@geoptimize.com ; Greg.Benvenuti@energymadeclean.com ; Amirvk@directenergy.com.au; TChisholm@wml.com.au

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ABSTRACT

Rising gas prices (accelerated by upcoming international price-parity - Liquefied Natural Gas plants) are motivating uptake of direct geothermal systems in Australia. Aquatic centres use a substantial amount of energy for heating (typically gas) and are thus motivated to consider more energy-efficient options. One of the first aquatic centres to implement closed-loop direct geothermal is the Goldfields Oasis Recreation Centre (GORC) in Kalgoorlie, Western Australia. Ground Heat Exchanger (GHX) configurations are typically either vertical or horizontal however for GORC an innovative solution with both vertical or a horizontal GHX was implemented. The horizontal GHX operates differently from a vertical GHX because of the impact of the atmosphere on the piping that is buried only 1-2m from the surface. Heat rejected into the horizontal piping dissipates more quickly to the atmosphere during colder weather and, in summer, solar energy warms the earth around the shallow piping while the impact on the earth around a vertical borehole at depth cannot be measured. With both vertical and horizontal GHXs, it is possible to take advantage of both the storage & dissipation properties. With innovative controls and the pending addition of cooling capabilities, these advantages can be enhanced for optimal management of the overall GHX and energy efficiency. During the first month operation savings on gas usage was 618 GJ worth approximately $21,000.

1. INTRODUCTION

The City of Kalgoorlie-Boulder (CKB) Goldfields Oasis Recreation Centre (GORC) is the largest regional recreation Centre in Western Australia and provides swimming, fitness training, programmed sports and games, together with the social aspects of sporting, recreational and leisure pursuits to approximately 500,000 visitors per annum (Figure 1).

Figure 1: Goldfields Oasis Recreation Centre (GORC) Olympic Pool & one of the Leisure pools.

GORC was consuming approximately 5 000 GJ of electricity per annum at a cost of $224,056 and 15,237 GJ of gas per annum at a cost of $255,197 (2010 figures). GORC has experienced a significant increase in utility prices in recent years. The price of Natural Gas, which is used to heat the Centre's pools, rose by 43% from 2008-2010 and electricity costs increased by 16% from 2008-2010 and will continue to rise in coming years. This was the primary driver for the Council to look at options for mitigation of these effects.

CKB, EMC & DEA undertook significant analysis of the various energy-saving technologies that could be implemented at GORC and identified Ground source Heat Pumps (GSHPs) as the best fit for the needs of the Oasis Leisure Centre. To further enhance savings and provide power for the GSHPs, solar thermal and solar photovoltaic (PV) systems were added to the project scope. The Solar PV panels generate electricity to power the GSHPs during daylight hours and during lower heat demand times of the year (summer months) to offset the facilities electricity demand from the grid.

The total project cost (GSHP, Solar thermal & Solar PV) was circa \$2.6 Million. CKB received \$533,790 for the project through the Low Emissions Energy Development (LEED) Fund of the Western Australia Government and \$622,725 through the Community Energy Efficiency Program (CEEP) Fund of the Federal Government. The system offsets 8,309 GJ of natural gas and 206,000 kWh of electricity per year that would otherwise be used to warm the pools and heat and cool the centre. The savings in natural gas consumption translates to monetary savings of circa \$260,000 a year. This reduces CKB's CO_2 emissions by over 500 tonnes a year which is the equivalent of offsetting the electricity use of 75 average households, taking 104 passenger vehicles off the road permanently or planting 13,000 trees and growing them for 10 years. CKB is thus expecting a 4-5 year simple payback on its investment.

The project entails innovative design features which, to the knowledge of the authors, are a world-first: scale combination of Ground Heat Exchanger (GHX), Solar Thermal & Solar PV for a municipal aquatic centre; combined horizontal & vertical GHX (GEOptimize & DEA). Further, cooling capability has been added to the design to enhance overall efficiency. CKB continues to live up to its reputation as a *Sustainable City of the Future* by committing to a staged conversion of its conventional, electricity-powered air-conditioning units to GHX compatible units (and installation of associated pipework connecting GHX plant room to roof top) commencing in the second half of 2014.

In this paper, we outline the GHX design highlighting the hybrid vertical-horizontal GHX combination selected, review the control strategy implemented to further optimise long-term performance, summarise some of the initial data yielded form the system whose solar component was completed in early 2013 and GSHPs commissioned in May 2014.

2. POOL AND BUILDING ENERGY MODELLING

Wherever possible, the optimal path to a GHX design starts with an accurate building model and that was the approach adopted for this project. Wherever possible it is best to balance energy loads to and from the GHX. The pools have a heating only load and thus cooling loads were sought to balance this somewhat (in order to recharge the GHX). A large gymnasium, fitness centre and various offices contribute to cooling load. The pool specifications are the key input to this model and are summarised below:

Olympic Pool - Target temperature range: 26 – 28 ^{o}C
Volume: 2264 m³ (including balance tanks)
Surface area: 1287 m² (51.5 m x 25 m)
Estimated Heat Usage: 6280 GJ/yr

Leisure Pools - Target temperature range: 30 – 32 ^{o}C
Volume: 515 m³ (ex. Balance tanks)
Surface area: 432 m² (sum total)
Estimated Heat Usage: 4431 GJ/yr

Being inland, the Kalgoorlie-Boulder climate is hot and dry with maximum summer temperatures as high as 46 ^{o}C but very cold temperatures below freezing in winter (Figure 2).

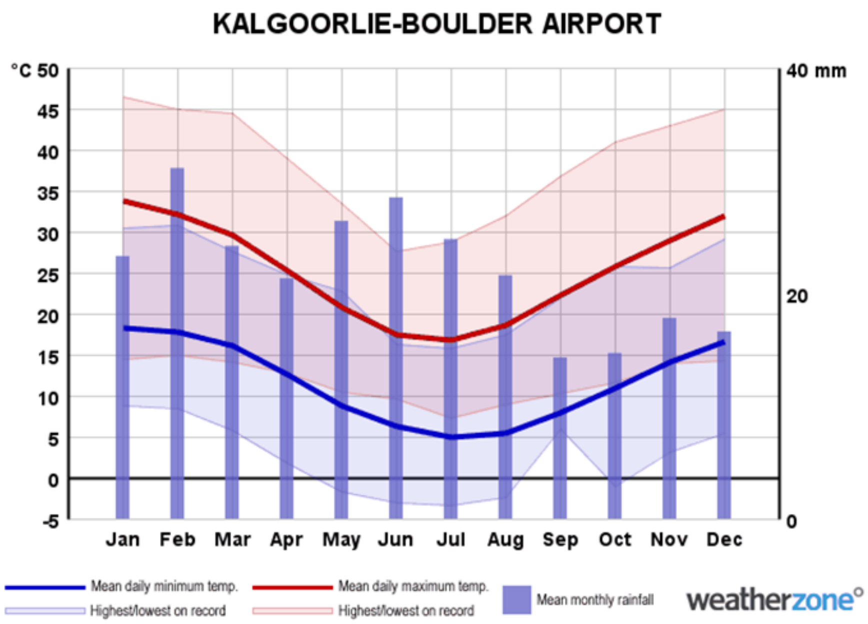

Figure 2: Climate data for Kalgoorlie-Boulder.

The monthly loads of the Olympic & Leisure pools were estimated from GORC's gas usage throughout the year:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
kWh	52,136	47,511	67,429	77,363	132,078	147,999	159,884	145,981	125,126	93,845	94,181	76,466	1,220,000

A building model of GORC was developed which takes into account the following areas:

- Fitness centre
- Gym
- Basketball Court
- Change Rooms
- Crèche
- Office
- Café
- Olympic Pool heat
- Leisure Pool heat
- Pool hall

There was no accurate information available on occupancy levels. To assist and facilitate provision of a preliminary model indicative maximum occupancy numbers from the reception of GORC were used:

- 200 people in gym;
- 300 on basketball court; and
- 500 in swimming pool.

For the gymnasium, fitness room and basketball courts, software program Trane Trace 700 v.6.2.9 was used to model the heating and cooling requirements. An 8760-hour weather profile for Kalgoorlie, Western Australia was used in estimating peak and aggregate heating and cooling requirements. Basic room dimensions were taken from the CAD drawings provided for calculating envelope losses. ASHRAE lighting and ventilation standards were used accordingly. Estimates on occupancy based on room type and size were used for the remainder of the internal loads.

The following is a summary of the assumptions made:

- Roof and Walls: R20 (RSI 3.522)
- Glass: U-factor of 0.28 BTU/h-ft^2-^{o}F (1.590 K-m^2/W) and shading coefficient of 0.57.
- Temperature set-points: 75^{o}F (23.8^{o}C) cooling and 72^{o}F (22.2^{o}C) heating
- Ventilation: ASHRAE 62.1: Gym, stadium (play area) = 0.3 CFM/ft^2 (1.5L/s-m^2) scheduled to be on during operating hours
- Occupancy: Gym and Fitness, assumed max occ. of 40 people, scheduled to partial occ. during the day, with peak in early evening. Basketball court max occ. of 230, scheduled for peaks in the early evening and weekends.

The resultant loads, which become the input to GHX design, are summarized in Table 1.

Month	Geo Cooling		Geo Heating	
	kWh	kW	kWh	kW
January	105818	368	62820	224
Februay	88780	351	57247	203
March	72349	274	81246	208
April	38445	184	93476	247
May	15309	163	160987	387
June	2924	81	185428	436
July	3341	98	199220	422
August	5197	135	181890	427
September	17528	181	150476	390
October	42884	230	113362	332
November	73061	293	113480	310
December	89985	299	92135	265
	555,621	368	1,491,767	436
DirectEnergy	EFLH	1,284	EFLH	4,244

Table 1: Heating & Cooling loads.

The electricity tariffs for GORC are substantially lower overnight than during the day (26c vs 10c per kWh). Given this, Thermal Energy Storage (TES) tanks were also modelled and recommended for this project.

3. GROUND HEAT EXCHANGER DESIGN

When designing a Ground Heat Exchanger (GHX), to achieve optimal results, it is best to develop a detailed hourly energy model of the facility which can be used throughout the design process to develop a good understanding of the energy requirements of the facility and the energy loads to and from the ground. In almost all GHX modelling, a choice is made between horizontal and vertical configurations. For a project of this scale, following desktop modelling (which targeted 120m bores in this case), it is justified to undertake ground testing: shallow ground conductivity tests were completed to assist with horizontal GHX design (October 2012) and in considering a vertical GHX, a Thermal Response Test (TRT) was completed by DEA in December 2012.
Extremely hard granite was encountered over 100m and at 108m depth it was decided to stop that due to prohibitive costs. Expansive clay layers in the upper 40m led to difficulty inserting the ground loop and another hole was drilled to 78m with casing to 40m through which the ground loop was installed.

The results are as follows:
Topsoil 0-18m
Red clay 18-24m
White clay 24-52m
Granite 52-100m

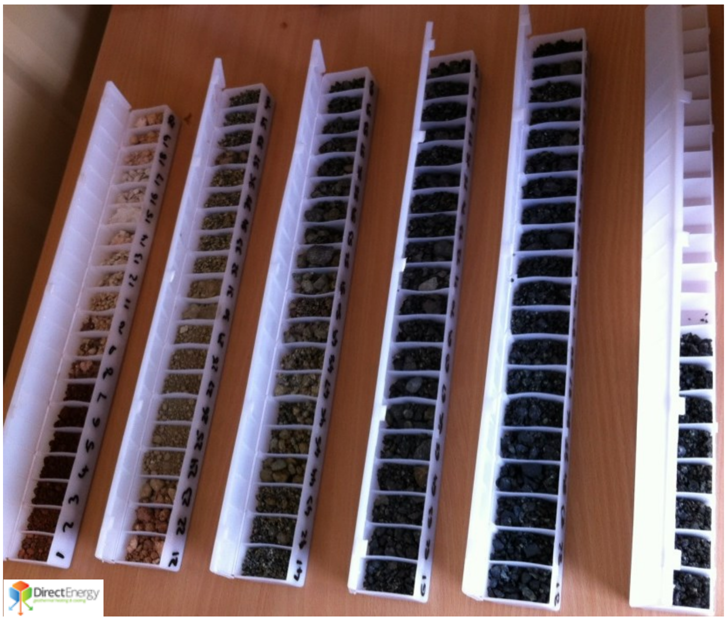

Figure 3: Soil assays at 1m intervals to 108m.

Shallow soil Thermal Conductivity (2m deep) = 1.1 W/m-K
Shallow soil Moisture Content (2m deep) = 29.39% (Borehole 1), 34.83% (Borehole 3)
Formation Thermal Conductivity = 1.96 W/m-K
Thermal Diffusivity = 0.0079 cm^2/s
Mean Earth Temperature = 23.2 C

The GHX considerations for GORC are summarized below:

1. **Vertical GHX**: requires the least land area for installation, accesses the constant ground temperatures at depth and has been the driver for undertaking a Thermal Response Test (TRT). Design of the vertical GHX involves optimization of land area; bore spacing, thermal capacity, drilling cost, grouting and design objectives. Options included:
    a. 105 x 78m bores (depth obtainable within a day by drilling contractor given knowledge of the ground as described in the RFT);
    b. 195 x 42m bores (depth to which casing is required due to pressurized clay, caveat is that PVC casing employed during TRT failed);
2. **Horizontal GHX**: requires the most accessible land area for installation, is much more affected by the outdoor air temperature than the vertical GHX, is less prone to overheating or cooling too much over the long term and has been the driver for undertaking Shallow Ground Monitoring. Options include:
    a. Parallel trenched pipes: can be laid with single flow & return or multiple pipes appropriately spaced or layered to achieve capacity;
    b. Slinky pipes: Used to achieve the equivalent of 5 or more pipes in a single trench with 4 to 12 m of pipe per metre of trench;
3. **Combination: Horizontal & Vertical GHX**: allows a compromise between land area and the exchange of heat with the surface. In a heating dominant facility such as GORC, the horizontal GHX can be used as a solar collector to recharge the vertical GHX during the summer. This was the compelling reason for engaging a combination GHX for this project. Options included:

a. 56 x 78m bores + 30 x 400m Slinky coils (depth obtainable within a day by drilling contractor, Slinky earthworks to overlap manifold & header lines of vertical GHX component); and
b. 44 x 96m bores (10m spacing) + 30 x 400m Slinky coils.

The above presented GHX designs were validated by appropriate software packages including Ground Loop Design (GLD), GLHEPro and Earth Energy Design (EED). The benefits of the hybrid GHX design include:
• The reduction of vertical size required for the project providing a significant reduction in the cost of the GHX for the project (keeping it within budget) because of the high cost of drilling at the site.
• The ability to take advantage of the heat dissipation and heat absorption characteristics of a shallow horizontal GHX and the energy storage characteristics of the vertical GHX. By integrating the two GHX configurations and controlling the operation of the GHX modules, it is possible to manipulate the temperature of the heat transfer fluid delivered to the heat pumps. This is used to optimize the performance of the system.

Option 3(b) above was selected based on the scheduling efficiency of three drilling rigs that were mobilized to site and the time to drill & case the upper (expansive clay) ground layer vs. drilling the lower (granite) ground layer. The loads of the combination GHX were broken up across the horizontal & vertical GHX for modelling with several iterations of the integrated combination to seek optimal efficiency & economics: the design horizontal GHX was designed on 23% of the cooling and 36% of the heating energy load.

Figure 4: Vertical GHX design option (105 x 78m bores).

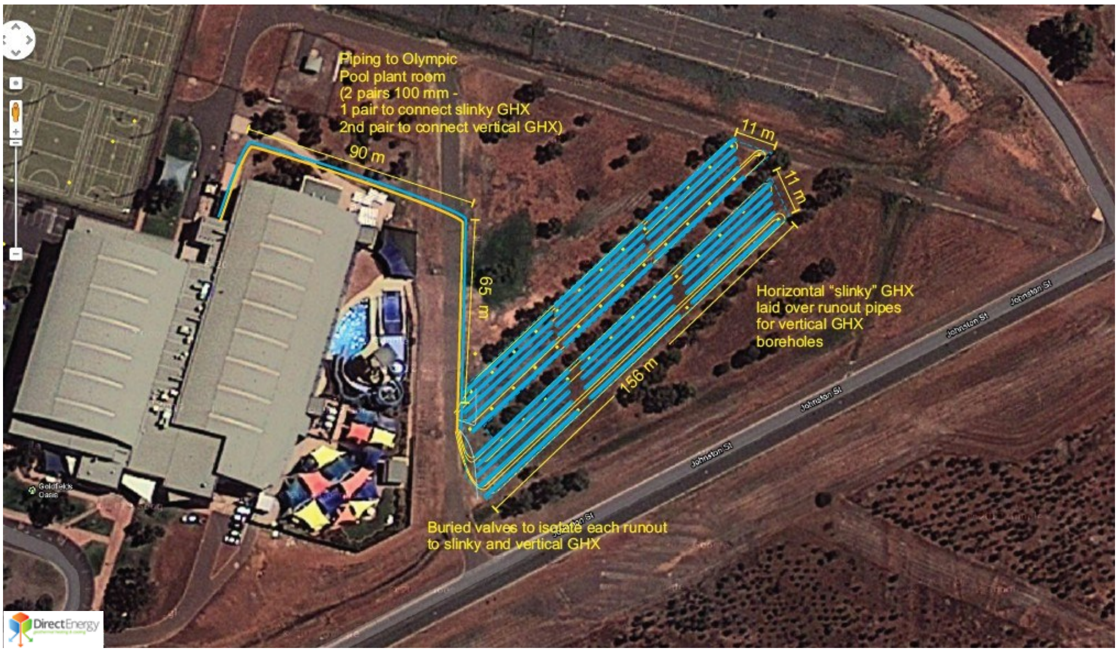

Figure 5: Combined Vertical & Horizontal GHX design option (56 x 78m bores + 30 x 400m Slinky).

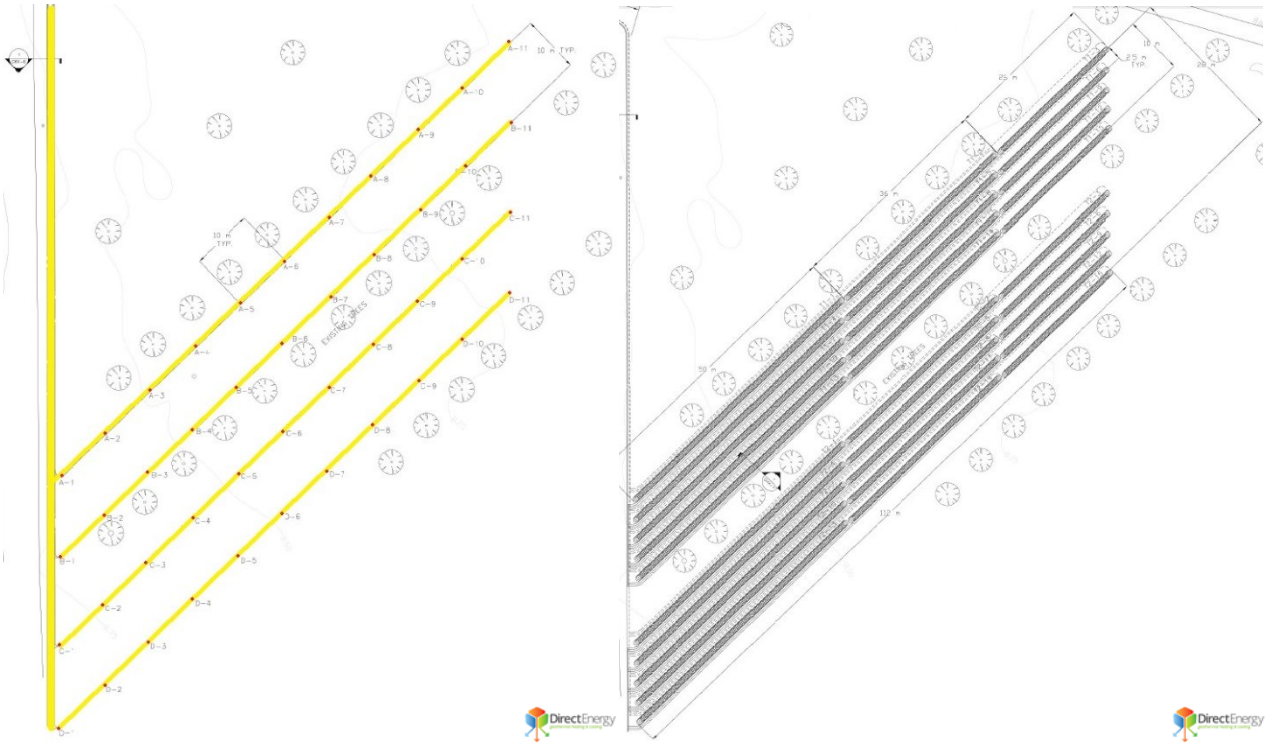

Figure 6: Combined Vertical & Horizontal GHX final design (44 x 96m + 10 x 25m, 10 x 36m, 10 x 50m Slinky).

The final GHX design entailed 4 rows of 11 bores spaced by 10m. A 10m trench was excavated between each pair of borehole rows and the horizontal Slinky GHX was laid in this trench. 6 headers return to the Olympic Pool plant room (4 x 11 vertical + 2 x 15 Slinky sets).

Figure 7: Installation of combined Vertical & Horizontal GHX (44 x 96m + 10 x 25m, 10 x 36m, 10 x 50m Slinky).

Figure 8: Photo of Drilling - 3 drilling rigs were mobilized to meet a tight schedule.

4. SYSTEM CONTROLS

To satisfy the loads, and make provision for cooling loads 4 x 100 kW (nominal) GSHPs were specified. Hot and chilled water is supplied to the building via a 4-pipe system with the GHX as an alternative heat source & sink. When a GSHP produces hot water, it simultaneously produces chilled water. Hot water is used to provide space heating, domestic hot water or heat the pools, while the chilled water is used directly to provide cooling in other parts of the facility. If both hot and chilled water can be used at the same time, the overall system efficiency increases greatly.

The temperatures of individual GHX modules, of which there are 6 (4 x 11 vertical + 2 x 15 Slinky sets), are monitored to allow the system to use the warmer GHX for heat extraction & cooler GHX for heat rejection, as well as to transfer energy from one to the other to take advantage of the storage capacity of the vertical GHX. Having multiple GSHPs allows flow from each heat pump to be individually controlled and gives the system redundancy. The main operating modes include:

- **Cooling only mode**: hot water from condensers (GSHPs) is directed to GHX piping whilst chilled water is directed to the building air handling units;
- **Simultaneous heating & cooling**: hot water from condensers is directed to building hot water piping whilst chilled water from evaporators is directed to building chilled water piping. If building loads are equal then all flow from condensers and evaporators of each heat pump is directed to the building; and
- **Heating only mode**: hot water from the condensers is directed to building hot water piping whilst chilled water from evaporators extracts heat from the GHX.

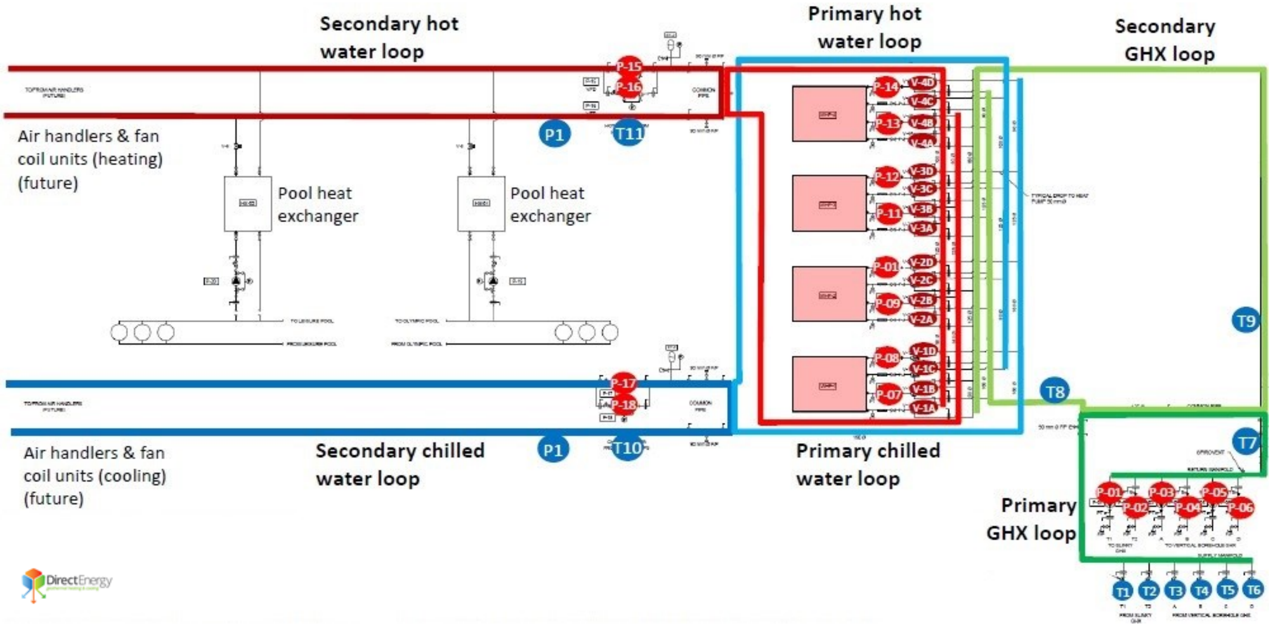

Figure 9: System Control Diagram.

Figure 10 illustrates the different modes of operation. The system operates by drawing energy from the GHX to heat the pool (Panel B), or cool the building and reject heat to the GHX if it's not needed in the building (Panel C). If Thermal Energy Storage (TES) were incorporated, when the pool temperature is satisfied the system can build ice using less expensive, off-peak electricity, and cool the building the following day (Panel D). Also, the same excess energy can be stored in the pool overnight though this is limited by comfort. Heat extracted from the ice/water can be used to heat the pools directly (Panel E). The following day, the ice can be used to provide some of the cooling for the facility with or without operating the GSHPs (Panel F).

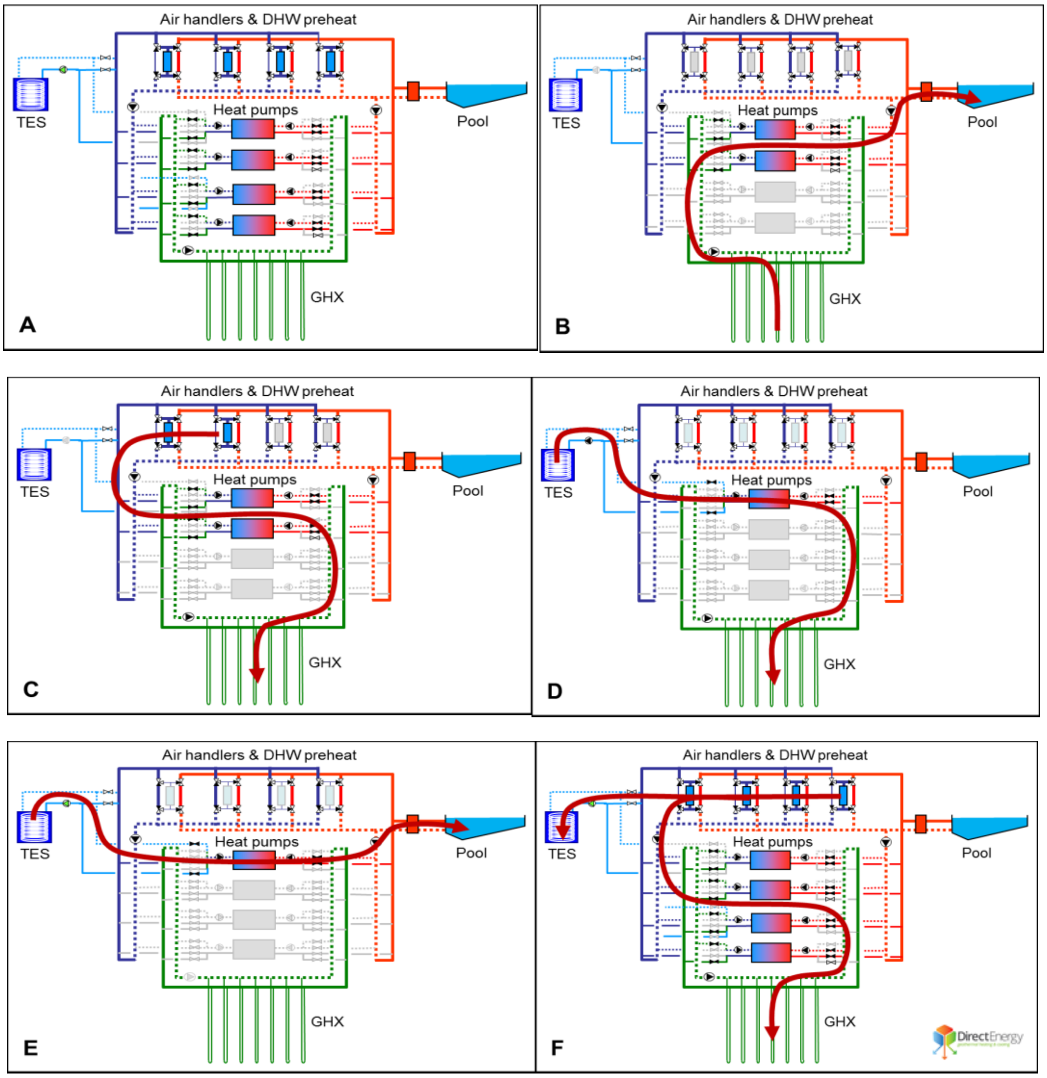

Figure 10: System Operation Modes.

4.1 Vertical and Horizontal GHX Optimization

Temperatures in the horizontal GHX lag circa 60 days behind the temperatures in the vertical GHX in typical operation. There can be as much as 10 C temperature difference between the GHX's in the shoulder seasons because of the ambient temperature's impact on the horizontal GHX and energy storage in the vertical GHX. Selection between each gives rise to an optimization strategy.

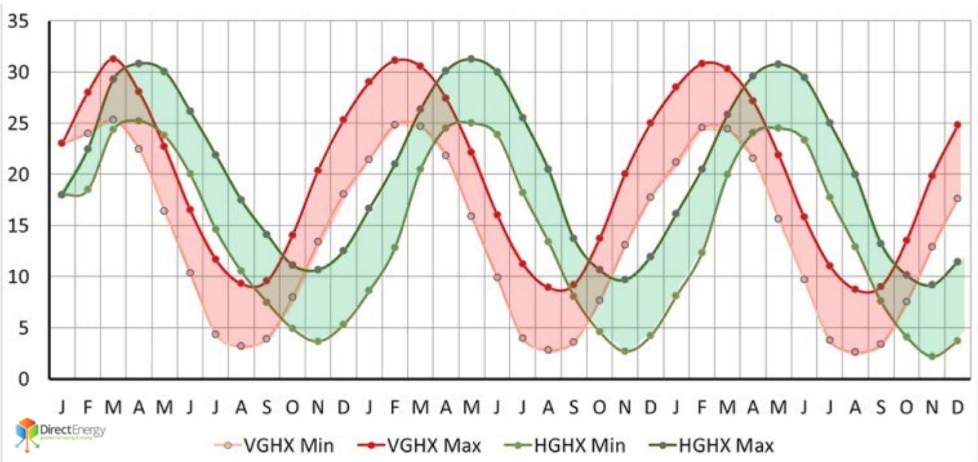

Figure 11: Seasonal temperature variation of vertical & horizontal GHX.

With the vertical and horizontal GHX's connected to a common manifold, if pumps on 2 GHX modules are activated, fluid will circulate through both modules. If the fluid temperature in the 2 modules is different energy will transfer from one to the other. The GSHP system connected to the two GHX's can be controlled to:

- Prioritise the use of the GHX with higher or lower temperature depending on the time of year and mode of operation; and
- Transfer energy from one GHX to the other to dissipate excess energy or store energy if required.

When circulating warm fluid from the horizontal GHX through the cooler vertical GHX module, energy is moved to the vertical GHX. This reduces the temperature difference between GHX's and leads to more optimal operation as indicated in Figure 12.

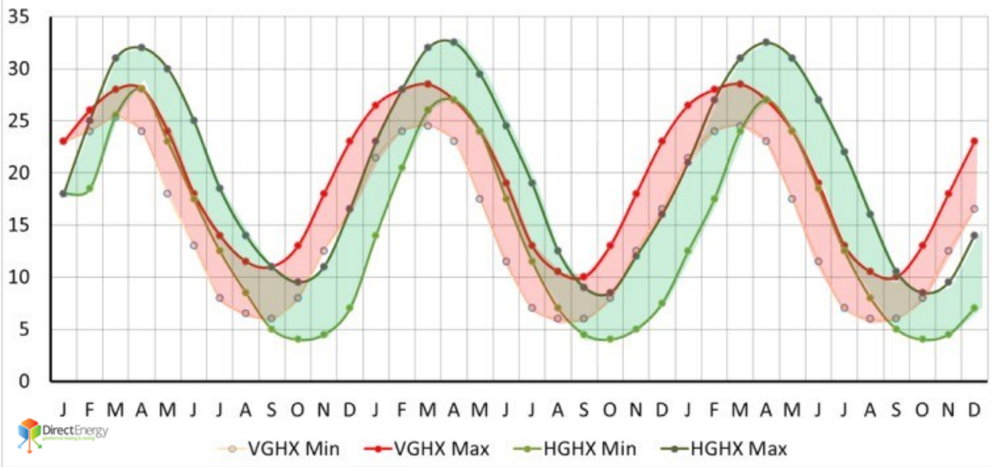

Figure 12: Seasonal temperature variation of vertical & horizontal GHX (with control strategy).

From November to March energy is transferred from the warmer vertical GHX to the cooler horizontal GHX, providing cooler fluid temperatures for the GSHPs to reject heat to, when cooling. During the southern hemisphere fall and winter, energy from the warmer horizontal GHX is transferred to the cooler vertical GHX, providing a warmer energy source for the GSHP system. Figure 13 illustrates this. By controlling the GHX module pumps the horizontal GHX acts as a heat dissipation device during cooler weather and a solar collector during the warmer months and is used to moderate the temperature of the vertical GHX. With changes in building use over time and changes in weather from one year to the next, the GHX pumps are used to moderate the temperature as required.

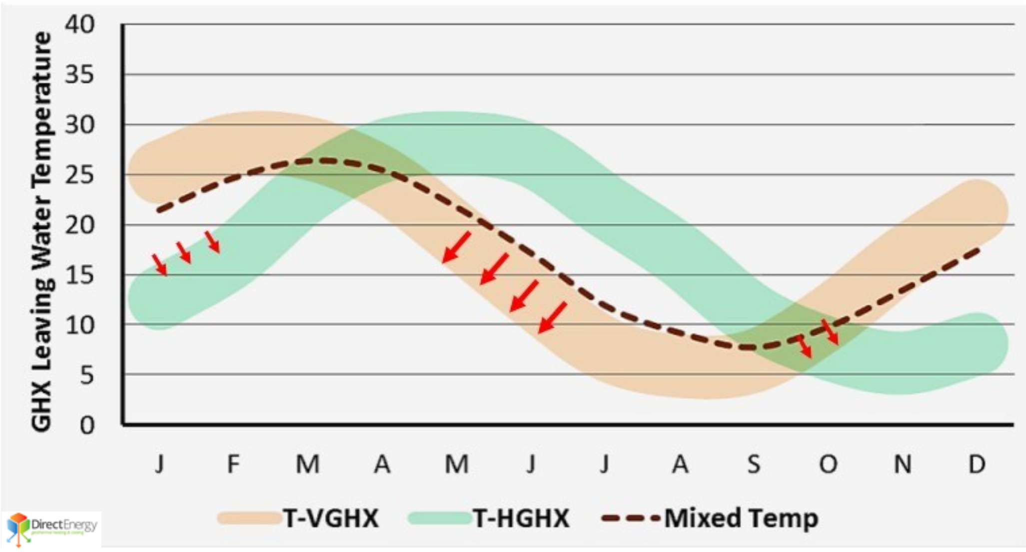

Figure 13: Heat transfer between vertical & horizontal GHX.

Figure 14 and 15 show installed GSHPs, pumps, heat exchangers and pipes to GHX.

Figure 14: Four GSHPs (left) and 6 pipes leading to GHX (right).

Figure 15: Pumps & Header pipes for GSHPs (left) and Pool Heat Exchanger & Pumps (right).

5. RESULTS

During the first full month of operation (July 2014) the gas consumption decreased by 617.869 GJ (603.415 GJ in July 2014 cf. 1221.284 GJ in July 2013) with similar weather data (temperature range was 5.5 – 17.8 ^{o}C in July 2014 cf. 4.9 – 17.7 ^{o}C in July 2013) corresponding to a dollar savings of $20,981.05. The GSHP was off for four days during July 2014 due to the connection of the pipework on the roof for the air-conditioning.

6. CONCLUSION

The GORC has implemented a world-first hybrid GSHP, Solar thermal and Solar PV system with hybrid vertical & horizontal GHX optimally controlled. The horizontal GHX operates differently from a vertical GHX because of the impact of the atmosphere on the piping that is buried only 1-2m from the surface. Heat rejected into the horizontal piping dissipates more quickly to the atmosphere during colder weather and, in summer, solar energy warms the earth around the shallow piping while the impact on the earth around a vertical borehole at depth cannot be measured. With both vertical and horizontal GHXs, it is possible to take advantage of both the storage & dissipation properties. With innovative controls, these advantages can be enhanced for optimal management of the overall GHX and energy efficiency.

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