

## IN SITU THERMAL RESPONSE TESTS IN GREATER TORONTO AREA

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**Abstract:** With the fast increasing of installations of geothermal heat pumps, the demand of accurate design of the system is growing. In situ thermal response test (TRT) provides a necessary method to accurately evaluate site-specific geothermal properties in the design of heat pump systems. Results of 31 in situ thermal response tests, carried out in closed loop boreholes in the Greater Toronto Area (GTA) have been analyzed. Derived samples of geothermal conductivity yield a median of 2.07 W/(mK), with 25% and 75% percentiles of 1.84 and 2.19 (W/m/K), respectively. The lowest value, 1.61 W/(mK) was derived from the area of northern part of downtown Toronto, where a thicker overburden of clayey silt till, Halton formation, was reached to 72 meters in depth. Test borehole was drilled to 154 meters, from ground surface, and no free water was encountered. The highest value of geothermal conductivity is tested from the east part of GTA in the town of Uxbridge, where artisan water was encountered during test borehole preparation. Advective heat transfer with groundwater flow is believed to have led to an elevated apparent conductivity. Borehole thermal resistance exhibits, 25%-ile, median and 75%-ile magnitude, of 0.066, 0.073 and 0.084 (Km/W). Undisturbed ground temperatures, measured by TRT in GTA, varied from 8.91 to 11.41 °C, and about 55% of samples were within the range from 10.2 to 10.4 °C.

**Key Words: Ground source heat pumps, conductivity, thermal resistance, groundwater, efficiency**

### 1 INTRODUCTION

A proper design of borehole heat exchanger (BHE) system for thermal energy storage and as an energy source for heat pumps or as a sink for air conditioning requires better understanding of encountered geothermal properties, heat transfer conditions and the efficiency of the proposed BHE. Thermal Response Test (TRT) has become a worldwide recognized method to define geothermal properties and the heat transfer efficiency of BHE system (Reub et al., 2009).

Thirty-one (31) in situ TRTs were carried out in “closed loop” boreholes in the Greater Toronto Area (GTA), Ontario, Canada. GTA is located in the area between Lake Simcoe and Lake Ontario, and consists of the City of Toronto and four regional municipalities of Durham, Halton, Peel and York Region, in a total area of 7,125 km<sup>2</sup> (Sharpe et al., 1997).

Geographically, locations of the 31 in situ tests were well spread to the entire GTA, from the south of the City of Toronto to the north of the Town of Georgina, and from east of the region of Durham to west of the City of Burlington.

The in situ test boreholes were explored to depth ranged from 61 to 164 m. The median of depth was 122 m and diameter of the boreholes was advanced as 150 mm. Subsurface

soils were sampled at two meter intervals. Soil samples were placed in clean plastic bags in the field and were transported back to our laboratory where they were examined further for soil characterization and rock classification.

High density plastics, 42 mm diameter single U-loop, consisting of plastic pipes, was installed in thirty (30) boreholes and a coaxial heat exchanger, Thermacouple Earth Energy System (TEES) was constructed by Kelix heat transfer systems on May 7<sup>th</sup>, 2009 (Xia, R. 2010a).

U-loops and the coaxial well of TEES were installed right after completion of borehole drilling to prevent caving from over burdens. Boreholes were backfilled, around the heat exchanger pipes, using designed grouting material. The fill material, normally, consists of thermally enhanced grout comprising a sand-rich mix of quartz sand and bentonite. BHE was initially pressure tested before installation and retested on completion of grouting to ensure no damage was encountered during installation.

## 2 GEOLOGICAL FORMATION

Geological formation of overburden material in the GTA is complex due to the history of glacier’s advancing and retreating. Region-wide layers of sand and gravel were deposited by melting ice during extended periods of warm weather. The sandy soil was subsequently covered by layers of clayey soil (till) when ice sheets spread over the area during cooler intervals (Barnett and Gwyn, 1997).

Based on the soil conditions encountered in the locations of BHE, the formation of glacial deposit comprises predominantly Newmarket Till, which is underlying Oak ridges moraine (ORM) or Halton sediments. The formation of Newmarket till mainly consists of silty sand to sandy silt till with trace to some of gravels. Underlying Newmarket till is Lower drift deposits comprise thick, complex, sediments resting on bedrock. Sediments of Lower deposits are mainly sand, silt and clay (Sharpe et al., 1999).

Simcoe Group of limestone dominated the east and north parts of the GTA. Shale bedrock of Georgian Bay Formation (GBF) and Meaford-Dundas Formation (MDF) mainly is in the centre part of the GTA. The soft and red shale of Queenston Formation is located at the west part of GTA in Burlington area. Cataract Group of shale bedrock, sandstone; dolomite is locally formed in area of Niagara Escarpment (Sanford and Baer, 1981). Geological formations encountered at the locations of BHE are summarized in Table 1.

**Table 1: Geological Conditions of the in situ TRT in GTA**

	<b>Depth of Overburden (m)</b>	<b>Depth in Bedrock (m)</b>	<b>Total Depth of Borehole (m)</b>	<b>Percentage of Overburden (%)</b>	<b>Percentage of Bedrock (%)</b>
Mean	47.4	75.7	123	41.08	58.92
Median	41.1	72.0	122	36.28	63.72
25%-ile	19.2	46.3	116	18.13	42.26
75%-ile	71.0	100.3	126	57.74	81.87
Minimum	3.5	0.0	61	2.13	0.00
Maximum	122.0	160.0	164	100.00	97.87

The ORM consists of four major wedges of stratified sediment forming plains, hummocks, kettles, narrow beads, and gaps. Rhythmically inter-bedded fine sands, gravel and silts are the dominant near surface sediments (Sharpe et al., 1999). Halton till and related sediments occur as thin surface tills and inter-bedded lake sediments. The Halton sediment complex

covers 150 – 200 km<sup>2</sup> as predominantly clayey silt to silt till with inter-bedded sand, silt and clay material.

Surface of bedrock formation has a regional southward slope from the mapped Paleozoic outcrop (Brennand et al, 1998), north of the GTA, to Lake Ontario. Topography of bedrock formation also sloped from east to west and from west to east towards the bedrock valley of Laurentian Channel.

### 3 THERMAL RESPONSE TEST

In situ thermal response tests (TRT) were conducted using a portable thermal response test unit (PTRTU). The PTRTU was constructed in a thermal insulate fridge box and housed in a trailer. The depths of the tested BHE ranged from 61 m to 150 m with median depth of 122 m. Tests were normally carried out one week after the borehole/U-loop was completed, to provide sufficient time for temperature of the grout and U-loop water to be stabilized to ambient earth temperature.

The PTRTU, placed as close as possible to the test borehole, was connected to the loop pipes with fittings and clamps. All connected pipes were filled with water and purged to air free. All exposed parts, between the borehole and the PTRTU, were well insulated to alleviate energy dissipation during the test (Xia et al., 2010).

A three-phase generator, Wacker G25, was used for a power source to ensure reliable, constant power supply throughout the test. A circulation pump of 1.75 kW was selected to circulate the heat carrier fluid through BHE pipes installed in the test borehole. Water flow in BHE was kept in the range of 1250 to 1550 l/h. An electrical heater with adjustable power rate, in the range of 3 – 12 kW, was employed to supply heat for water circulation. Duration of TRT was ranged from 24.9 to 79 hours with mean of 54.7 hours.

Fluid’s temperatures were measured by thermistors installed inside the PTRTU inlet/outlet of the U-loop. Fluid temperatures, ambient air temperatures, inside and outside of test unit, and power rate applied for heating were collected every 5 seconds and recorded for average of every 10 seconds by data logger. Data were automatically transferred to office through wireless communication system (WCS). The data/characteristics of TRT carried out in GTA are listed in Table 2.

**Table 2: Properties of the 31 in situ TRT in GTA, Ontario, Canada**

	<b>Total Energy Input (kW)</b>	<b>Distributed Energy (W/m)</b>	<b>Flow rate (L/hour)</b>	<b>Heating Time (hour)</b>	<b>Depth of BHE (m)</b>
Mean	7.28	61.17	1390	54.7	123
Median	7.80	62.21	1396	53.8	122
25%-ile	6.00	50.50	1367	45.1	116
75%-ile	8.50	71.48	1432	67.4	126
Minimum	3.00	19.74	670	24.9	61
Maximum	9.00	98.35	1814	79.0	164

### 4 TEST RESULTS

Results of in situ TRT are undisturbed ground temperature, geothermal conductivity, volumetric heat capacity, geothermal diffusivity and thermal resistance between the fluid in the pipes and the wall of BHE.

#### 4.1 Undisturbed Ground Temperature

Prior to each test, the average undisturbed ground temperature (UGT) along the length of the test borehole was obtained by circulating heat carrier through BHE, and measuring the flow temperature at short time intervals (every 5 seconds), prior to heater switches on. Duration of the measurement was about half hour and the first 1000 seconds were used in the analysis of undisturbed ground temperature.

Friction heat, caused by pumping, was gradually added to the fluid after 16 to 17 minutes (960 to 1020 seconds). To eliminate friction heat effects, the measured mean fluid temperature within the first 15 minutes (900 seconds) was estimated as the undisturbed ground temperature (Gehlin and Spitler 2002). The frequency distribution of measured undisturbed ground temperature was shown in Figure 1.

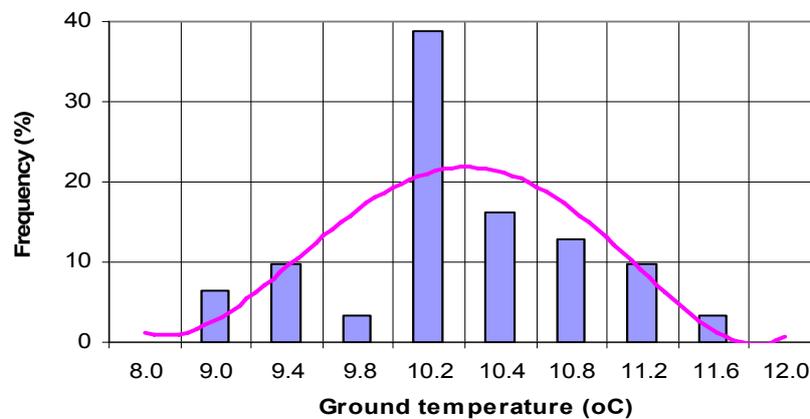


Figure 1: Undisturbed ground temperature

Ground temperatures varied from site to site. Majority samples of undisturbed ground temperatures precisely determined during in situ TRT in GTA are fell in the range from 9.4 to 10.8 °C. The highest value of 11.41 °C was measured from a deep borehole at Wellington Street, St. Thomas, Ontario, Canada. The Town of St. Thomas is located at the southwest part of GTA.

The lowest value 8.91 °C of undisturbed ground temperature was detected at our research centre located at north area of GTA, in the Town of East Caledon, Ontario. The borehole was explored on top of an esker, which is a long, winding ridge of stratified sand and gravel, deposited by a stream flowing in or under a decaying glacial ice sheet.

#### 4.2 Geothermal Conductivity

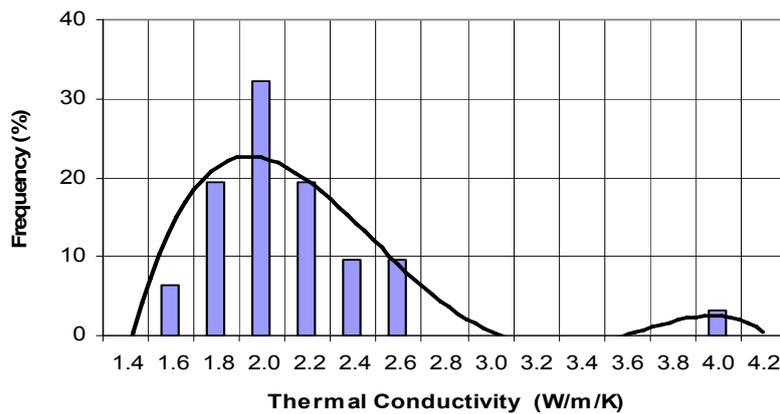
The methodology of define geothermal conductivity (GTC) by in-situ TRT, has been well documented (Gehlin S. & Spitler, J. D. 2002, Mogensen, P., 1983). The process of heat transfer in drilled borehole was simplified as line source heat conduction.

Theoretically, temperature field, as a function of time and radius around a line source, with constant rate of heat injection can be described as:

$$T_f(t) = \frac{q}{4\pi\lambda} \left[ \ln\left(\frac{4\alpha t}{r^2}\right) - \gamma \right] + qR_b + T_o \quad (1)$$

Where  $T_f$  is fluid temperature measured during test ( $^{\circ}\text{C}$ );  $q$  is heat flow applied for the test ( $\text{W/m}$ );  $\lambda$  is geothermal conductivity ( $\text{W/m/K}$ );  $\alpha$  is coefficient of diffusivity ( $\text{m}^2/\text{s}$ );  $t$  is time countered by minutes (s);  $r$  is radius (m);  $\gamma$  is Euler's constant = 0.5772;  $R_b$  is borehole thermal resistance ( $\text{Km/W}$ ) and  $T_o$  is undisturbed ground temperature ( $^{\circ}\text{C}$ ).

Figure 2 shows the frequency distributions of measured geothermal conductivity by in situ TRT in GTA, Ontario, Canada. The bulk of thermal conductivities fall in the range from 1.8 to 2.4  $\text{W/m/K}$ , with the lowest value of 1.61  $\text{W/m/K}$  derived from 8 Chichester Place, Toronto, Ontario, Canada. The test borehole was 150 mm in diameter and drilled to a depth of about 154 m. About 72 m overburden consisted of clayey silt till, Halton formation, with some sand and gravel was encountered at the test borehole location (Xia 2010b).



**Figure 2: Geothermal Conductivity**

Three (3) relatively high values of geothermal conductivity 2.58, 2.60 and 2.64  $\text{W/m/K}$  were derived from the south west part of GTA and Hamilton Wentworth area. Glacial deposit consisted of sandy silt till with some gravel was encountered. Over burden was brown, moist to wet, and extended to depths ranged from 5 to 8 m at borehole locations. Grey and hard shale bedrock was detected below the glacial deposit and extended to the maximum depth of drilling of about 122 m.



**Figure 3: Artisan groundwater flowing out at the site of 4 Victoria Drive, Uxbridge, Ontario, Canada.**

One anomalously high value of 4.03  $\text{W/m/K}$  was generated from the site of 4 Victoria Drive, in the Town of Uxbridge, Ontario, Canada (Xia, R., 2010 c). Test borehole was 150 mm in diameter and drilled to depth of about 122 m. Glacial deposit, consisting of clayey to sandy silt till with some gravel, was encountered during borehole exploration. Overburden was

brown to grey, moist to wet, and extended to depth of about 91.4 m at borehole location (Xia 2010c). Artisan groundwater was encountered during borehole preparation and U-loop installation – see Figure 3. Groundwater seeping out, at the nearby area of the project site, was observed during in situ TRT, from April 27 to 30, 2010. Advective heat transport with groundwater flow is believed to have led to an elevated apparent geothermal conductivity.

### 4.3 Volumetric Heat Capacity

Volumetric heat capacity (VHC) of soil describes the ability of a given volume of soil to store internal energy while undergoing a given temperature change, without a phase change. A weighted mean value along borehole depth was approximated as the magnitude of VHC:

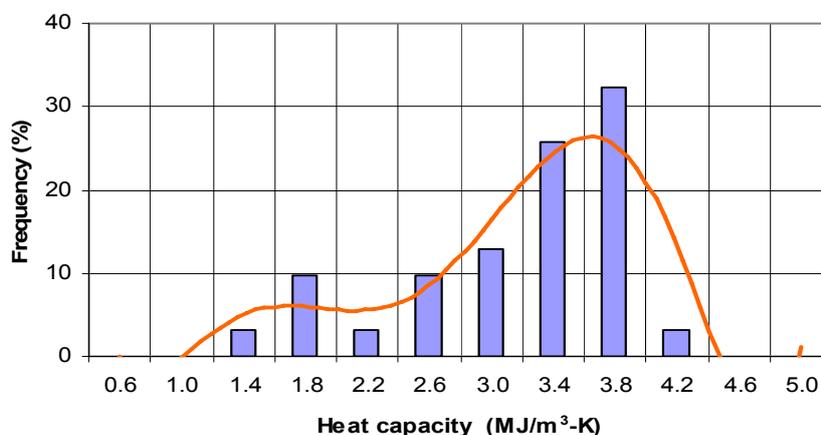
$$c_v = \frac{\sum_{i=1}^n c_{vi} \cdot h_i}{\sum_{i=1}^n h_i} \tag{2}$$

Where  $c_i$  is volumetric heat capacity for individual soils;  $h_i$  is the length for each corresponding soil component distributed along borehole depth profile. Typical occurring ranges of values of soil/rock thermal properties are listed in Table 3.

**Table 3: Typical Values of Soil Volumetric Heat Capacity (after Chiasson et al., 2000)**

Soil Classification	Porosity	Heat Capacity (MJ/m <sup>3</sup> -K)
Gravel (dry)	0.24 – 0.38	1.4
Coarse sand (dry)	0.31 – 0.46	1.4
Fine sand (dry)	0.26 – 0.53	1.4
Silt	0.34 – 0.61	2.4 – 3.3
Clay	0.34 – 0.60	3.1 – 3.6
Limestone	0.34 – 0.60	2.13 – 5.5
Karst limestone	0.05 – 0.50	2.13 – 5.5
Sandstone	0.05 – 0.30	2.13 – 5
Shale	0 – 0.10	2.38 – 5.5
Fractured igneous and metamorphic rock	0 – 0.10	2.2
Unfractured igneous and metamorphic rock	0 – 0.05	2.2

Depth of each soil type was defined by borehole drilling/sampling and further testing results in soil laboratory. Information was recorded on borehole log sheets. VHC was computed according to borehole log data. The frequency distribution of obtained VHC during in situ TRT in GTA are presented in Figure 4.



**Figure 4: Volumetric Heat Capacity**

The magnitude of VHC detected within GTA varied from 1.49 to 4.06 MJ/m<sup>3</sup> with 3.18 MJ/m<sup>3</sup> in average. The bulk of VHC fell in the range of 2.6 to 3.8 MJ/m<sup>3</sup>. The lowest value of 1.49 MJ/m<sup>3</sup> was obtained from the site of 15 Bernard Avenue, Richmond Hill, Ontario, where overburden was reached to depth of about 117 m and no bedrock was encountered.

The highest value of 4.06 MJ/m<sup>3</sup> was defined at the site of North Wentworth Arena, Hamilton, Ontario. Test borehole was advanced to depth of about 122 m, and about 117 m, in thickness, of bedrock was encountered.

#### 4.4 Coefficient of Thermal Diffusivity

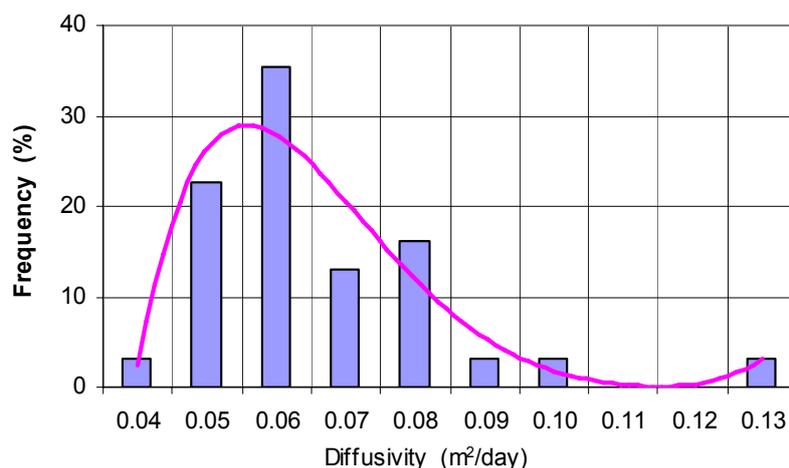
Coefficient of thermal diffusivity (CTD) is defined as the ratio of thermal conductivity to volumetric heat capacity, and obtained as:

$$\alpha = \frac{\lambda}{\rho c_p} \tag{3}$$

Where  $\lambda$  is thermal conductivity (w/m-K);  $\rho$  is density of soils (kg/m<sup>3</sup>) and  $c_p$  is specific heat capacity (J/kg-K). The denominator of the thermal diffusivity expression,  $\rho c_p$  can be identified as the volumetric heat capacity with SI units of J/m<sup>3</sup>-K.

The high thermal diffusivity soil rapidly adjusts temperature to that of the surroundings, because it conducts heat quickly, in comparison to their volumetric heat capacity or ‘thermal bulk’ of soil. The thermal diffusivity is higher the heat conducted is quicker.

The computed CTD varied from 0.0395 to 0.1274 m<sup>2</sup>/day, with a mean value of 0.0611 m<sup>2</sup>/day. About 85% of sample data was populated in the range from 0.05 to 0.08 m<sup>2</sup>/day. Frequently high number of CTD obtained was consequently associated with high GTC and low VHC value. Figure 5 shows the frequency distribution of the coefficient of thermal diffusion obtained in area of GTA.



**Figure 5: Coefficient of Thermal Diffusion**

The lowest number, 0.0395 m<sup>2</sup>/day, of computed CTD was from the site of 8 Chichester Place in the City of Toronto, where the lowest GTC of 1.61 W/m/K was tested (Xia, R., 2010 b). The highest CTD record of 0.127 m<sup>2</sup>/day was tested from the site of 15 Bernard Avenue, Richmond Hill, Ontario, where the lowest magnitude of VHC (1.49 MJ/m<sup>3</sup>/K) was encountered.

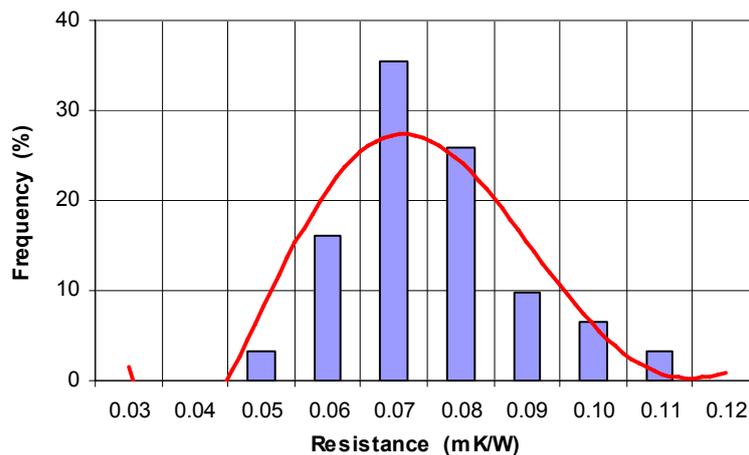
#### 4.5 Borehole Thermal Resistance (BTR)

Borehole thermal resistance (BTR), between the heat carrier fluid in the borehole flow channels and the borehole wall, for a certain specific heat transfer rate, was defined by in situ TRT. Analytical model of line source theory was adopted in BTR computation:

$$R_b = \frac{1}{q} (T_f - T_0) - \frac{1}{4\pi\lambda} \left[ \ln(t) + \ln\left(\frac{4\alpha}{r_0^2}\right) - \gamma \right] \quad (4)$$

Where  $r_b$  is borehole radius (m);  $T_f$  represents the arithmetic mean of the inlet fluid temperature ( $T_{fin}$ ) and outlet fluid temperature ( $T_{fout}$ ) of the closed loop BHE at time  $t$ , and is defined as  $T_f = (T_{fin} + T_{fout}) / 2$ .

The temperature difference between the heat carrier fluid and the borehole wall is proportional to the heat injection rate of TRT and depends on the construction type and the formations of sediment depositions and bedrock geology. Grouting material and groundwater positions also have significant effect on heat transfer of a designed BHE system. Results of tested BTR, in GTA, varied from 0.053 to 0.110 m.K/W with 0.0752 m.K/W in average. The frequency distribution of BTR is shown in Figure 6. Majority records, about 87%, of BTR determined by in situ TRT were populated in the range of 0.06 to 0.09 m.K/W.



**Figure 6: The Frequency distribution of BTR**

The lowest BTR was derived from the thermocouple earth energy system (TEES), a coaxial type BHE installed at the site in Town of Caledon East, Ontario (Xia, R., 2010a). Project site is located on top of an esker consisted of sand and gravel. Borehole was explored to depth of about 80 m and 64 m of overburden was encountered. Plenty of groundwater was encountered during test borehole preparation and BTE installation.

The highest magnitude of 0.110 mK/W was tested at the site of 430 Wyecroft Road, Oakville, Ontario. Borehole was constructed 150 mm in diameter and was drilled to 152 m deep. About 4.6 m overburden was encountered and underlain grey, hard shale bedrock was extended to the bottom of the test borehole. Water circulation is about 1374 l/hr and test was continued about 52 hours with energy injection of about 3 kW of total. It is believed that the less amount of heat injection, about 19.7 W/m, is the main reason to lift up the apparent quantity of BTR.

Again, grouting material and fluid flow rates are important factors of BTR and borehole efficiency performance. Poor grouting may cause detrimental effects to borehole

performance. Low or not fully turbulent fluid flow rates, in U-loop pipe, could be associated with high borehole thermal resistance (Banks et al. 2009).

Borehole thermal resistance varies with power load was observed during the thirty one in situ thermal response tests in GTA, Ontario, Canada. Higher thermal resistance is always to be expected with a lower heat injection rate. A recommendation is therefore to run the response test with a power load similar to the designed/expected operational load to obtain an accurate estimation of the thermal resistance.

Figure 7 shows the distribution of tested BTR plotted against GTC. The records of test results were concentrated in the centre area defined by 0.05 to 0.11 Km/W of BTR and by 1.6 to 2.6 W/m/K of GTC.

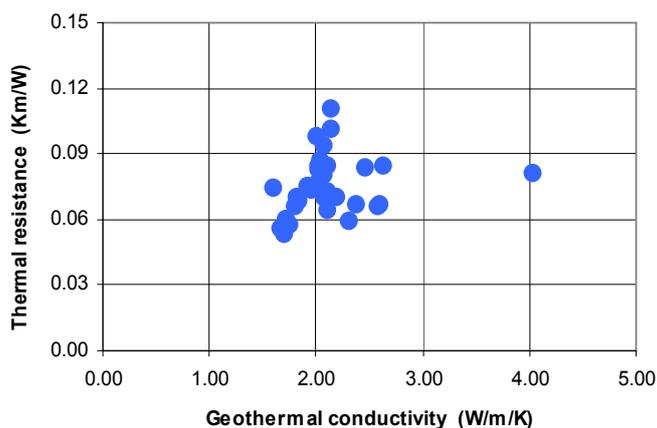


Figure 7: Borehole thermal resistance vs geothermal conductivity

## 5 TEST RESULT VERIFICATION

Results of TRT were verified by back calculations of borehole temperatures, using Equation 1, and computed data/parameters of GTC, VHC, CTD, BTR and UGT. The back calculated borehole temperatures were compared with the arithmetic mean of the inlet and outlet fluid temperatures of the BHE, measured during in situ TRT. Results of the verification were reached in a close range.

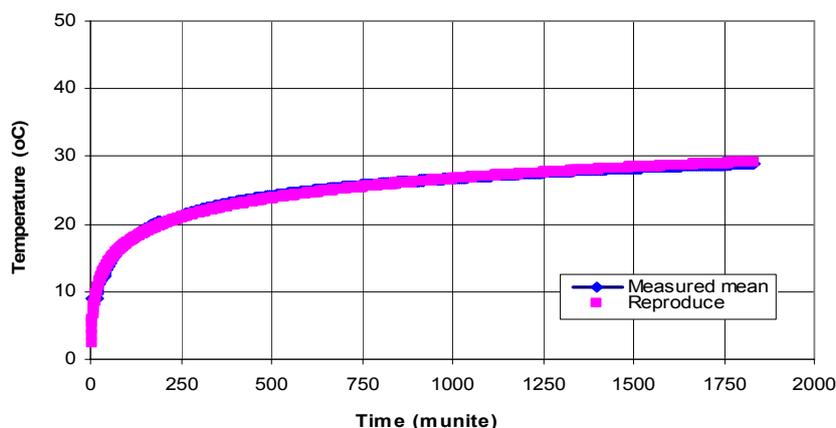


Figure 8: Mean fluid temperatures of measured and back calculated

Figure 8 shows the results of verifications for the project conducted at our research centre, Caledon East, Ontario, Canada, in the year of 2009. The In situ measured mean fluid

temperatures and the back calculated borehole temperatures were plotted versus same time series of the in situ TRT.

The reproduced borehole temperature was compared with the in situ measured temperature and evaluated by the method of variance analysis. Root-mean Square (RMS) was utilized in the accuracy calculation of simulated data versus collected data during in situ test:

$$RMS = [N^{-1} \sum_{i=1}^N (P_i - O_i)^2]^{0.5} \quad (5)$$

Where N is the number of values or record of data used in verification;  $P_i$  is the  $i^{th}$  simulated value of borehole temperature and  $O_i$  is the  $i^{th}$  observed value of the mean borehole temperature.

About 1831 sets of data were verified and the calculated error of RMS is less than 0.26 °C, which is well within the required testing norm. It has to be noted that by using Eq. 1 to carry out a back calculation for borehole temperature development with testing time increasing, the initial time t has to be greater than  $e^{\gamma - \ln(4\alpha/r^2) - 4\pi\lambda R}$ .

A comparison of back calculated borehole temperature and measured mean fluid temperature of the circulating fluid is shown in Figure 9.

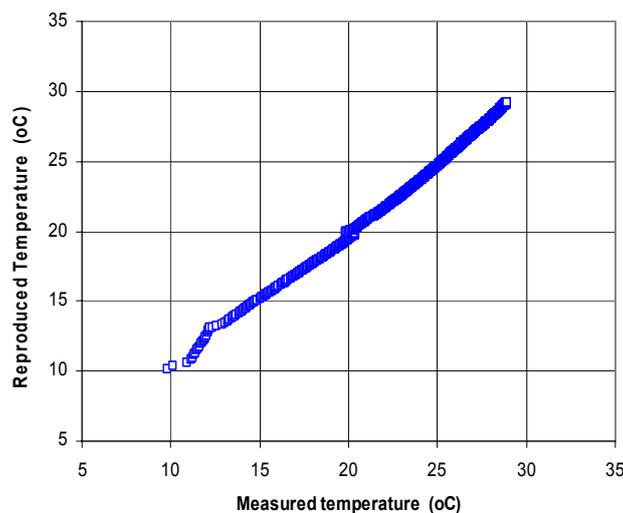


Figure 9. Comparison of calculated temperature with in situ measurements

## 6 CONCLUSION AND DISCUSSION

### 6.1 Test Results

Thirty-one (31) in situ TRTs were performed, from the years of 2008 to 2010, in closed loop boreholes, by McClymont & Rak Engineers and collaborated by Groundheat System International in Greater Toronto Area, Ontario, Canada. Data were analyzed by using line source theory in an Excel spreadsheet environment. Tested results were verified by back calculation of borehole temperature with Eq. 1 and the recorded temperature data during in situ test. The in situ tested data/parameters including GTC, VHC, CTD, BTR and UGT were utilized in the back calculation of borehole temperature.

Results of the thirty-one in situ tests were summarized in Table 4. Data and parameters, acquired from In situ tests, were successfully supplied to design and installation of BHE system. Meanwhile, Information obtained from TRTs was also applied to the evaluation of grouting material, selection of heat exchangers and quantification of groundwater effects.

**Table 4: Summary results of TRT in GTA, Ontario, Canada**

	<b>Ground Temperature (°C)</b>	<b>Thermal Conductivity (W/mK)</b>	<b>Heat Capacity (MJ/m<sup>3</sup>K)</b>	<b>Diffusion Coefficient (m<sup>2</sup>/day)</b>	<b>Thermal Resistance (mK/W)</b>
Mean	10.33	2.13	3.18	0.0611	0.0752
Median	10.25	2.07	3.50	0.0555	0.0734
25%-ile	10.08	1.89	2.71	0.0494	0.0662
75%-ile	10.80	2.17	3.71	0.0689	0.0836
Minimum	8.91	1.61	1.49	0.0395	0.0534
Maximum	11.41	4.03	4.06	0.1274	0.1100

## 6.2 In Situ Thermal Response Test

TRT is a useful tool/technique to examine thermal properties of the underground and to obtain reliable information / data / parameters for the design of borehole thermal exchange and storage system. It may also be applied for the performance evaluation of the borehole energy exchange/storage system.

Borehole preparation, stable power supply, suitable discharge of fluid circulation and proper duration of test are important factors of in situ TRT. Better understanding of geological formations and groundwater conditions will help to increase the accuracy of thermal response test and improve the quality design of geothermal heating/cooling system. It may also provide useful information for thermal performance of different types of borehole heat exchangers, grouting materials and the arrangement of flow channels.

## 6.3 Geothermal Properties

It has to be noted that thermal properties of the underground are site specific and strongly governed by soil variations, bedrock constituents and groundwater conditions (Xia et al., 2010). Geothermal properties change with geographical locations and geo-hydrological conditions.

Groundwater impacts on geothermal properties were observed during in situ tests. Coupling geotechnical investigation with in situ TRT is an effective way to better understand ground water influence. Data of water well record acquired from the Ministry of Environment (MOE) supplied necessary information of phreatic surface for the testing site.

Heat transfer from borehole wall to the fluid inside the pipes is controlled by borehole diameter, pipe size and configuration, pipe material and the grout filling inside the annulus. Proper selection of borehole diameter and depth, improving thermal conductivity of pipe and grouting material are subject to efforts of increasing the efficiency of BHE system.

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