Characterising Ground Thermal Properties in Ireland – an approach to improving ground source collector design

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ABSTRACT

The Irish Ground Thermal Properties (IGTP) project aims to characterise the geothermal properties of Irish ground conditions and their suitability for deployment of closed loop collectors. IGTP has developed the first comprehensive database of thermal conductivity measurements from different Irish ground conditions to facilitate design and sizing of geothermal collectors by installers and professionals.

Bedrock core samples from up to 42 mapped lithological units have been tested using a divided bar apparatus. Thermal response testing results completed as part of this project have also been made available with a view to understanding potential heat extraction rates from vertical closed loop collectors. The lab and field test results have also been considered during the monitoring of operating geothermal systems with a view to understanding their performance.

The data obtained through laboratory testing and thermal response tests, has informed the compilation of ground source collector suitability maps and has been used to quantify potential heat extraction rates and develop ground loop sizing tables for small scale residential closed loop collectors. The results of the projects have facilitated the dissemination of the potential of shallow geothermal resources in Ireland and have informed professionals involved in system design and installation.

1. INTRODUCTION

The rapid growth of the ground source heat pump market up to 2009 in Ireland led to the installation of mostly small-scale residential system. The level of training of the professionals involved in these installations, in mostly limited to the installation of heat pumps through the certification of plumbing contractor. The design aspect of the systems and in particular the ground parts of the systems are often completed using basic rules of thumb or guidance documentation from other countries. One example of these guidelines includes the MIS 3005 ground loop sizing tables (DECC, 2011) from the UK and the VDI4640 guidelines. Data from recent research on the thermal conductivity of Irish rock formations has demonstrated that many differences existing in the thermal properties of Irish rock compared to similar lithologies considered in other parts of Europe (McGuinness, 2013). These differences are mainly attributed to density, porosity and mineralogical compositions (Murray, 2014). The lack of data specific to the Irish bedrock lithologies and the lack of overall best practice in the design of ground source systems has often resulted in the completion of incorrectly sized vertical closed loop collectors.

The IGTP project was funded as public good project by the Sustainable Energy Authority of Ireland to develop a database of Irish bedrock thermal conductivity values and provide any thermal response test information for specific areas of the country where this was available (figure 1). The project was funded in two phases in 2014 and 2015 and the results are disseminated through the project website (www.irishgroundtherm.com).

2. LABORATORY THERMAL CONDUCTIVITY MEASUREMENTS

Thermal conductivity data from Irish bedrock formation was initially measured in early research project at University College Dublin (Hemmingway, 2012, McGuinness, 2013 and Murray, 2014).

The Geological Survey of Ireland developed vertical closed loop collector suitability maps (Pasquali, 2016) made use of these data. The data inputs for these maps identified 26 lithological classes from the 1:500,000 bedrock geological map. The data from previous research accounted for 6 of these classes.

The first phase of the IGTP project in 2014 focussed on testing a further 20 classes to complete the 1:500,000 scale dataset. The 2015 phase further improved this scale by considering formations at 1:100,000 scale and identifying available core material for testing in the GSI core store. A further 22 samples, giving a total dataset of 42 samples were tested by the end of 2015 (table 1).

Table 1: Thermal Conductivity of different Lithologies from GSI Core Samples (Pasquali, 2015).

Formation name	Lithology	Average Thermal Conductivity (W/mK) Saturated	Average porosity (%)	Average Saturated Density (kgm^{-3})	Average Dry Density (kgm^{-3})
	Granite	3.07	1.58	2589.12	2602.51
	Muddy Shelly Limestone	2.96	1.31	2702.48	2733.68
	Unknown Conglomerate	2.19	1.50	2639.40	2654.43
	Schist	3.84	0.10	2771.34	2772.18
Clashabeema	Rhyolite Tuff	2.47	1.68	2767.04	2783.88
Ballynakill	Chlorite Schist	2.53	0.19	2818.21	2820.13
Early Gabbro	Gabbro	1.80	0.24	2982.30	2984.74
Ballyneale	Tuff	1.91	0.38	2821.62	2825.46
Dolerite Dyke	Dolerite	1.40	2.01	2898.11	2918.22
Knockroe Basalt Lava Flow	Volcanoclastic	1.72	4.80	2616.60	2664.62
Cregganbaun	Quartzite	3.56	2.63	2531.87	2558.13
Errisbeg Townland	Granite	2.19	0.93	2621.81	2631.12
Ballynakill	Chlorite Schist	2.35	1.54	2682.11	2697.51
Calp/Lucan	Dark Lst And Shale (Calp)	2.66	2.14	2680.00	2695.33
Cratloes	Laminated Siltstone & Sandstone	3.18	0.21	2710.67	2712.67
Old Red Sandstone	Red Conglomerate, Sandstone & Mudstone	3.71	1.95	2647.44	2666.94
Malahide	Agrillacaeous Bioclastic Limestone And Shale	2.43	5.06	2672.24	2722.82
Boston Hill	Muddy And Modular Limestone And Shales	2.14	1.75	2683.49	2700.98
Tobercolleen	Calcareous Shale Lst Conglomerate	2.68	1.12	2658.62	2669.78
Mornington	Dark Lst + Calc Shale	1.97	0.91	2656.58	2665.71
Tullyallen	Pale Micritised Grainstone-Wackestone	2.02	0.75	2662.85	2670.34
Crufty	Peloidal Wackestone	2.25	11.68	2249.40	2366.19
Ballysteen	Fossiliferous Dark Grey Limestone	2.95	1.18	2656.01	2667.85
Boston Hill	Muddy And Modular Limestone And Shales	3.70	1.02	2743.60	2753.77
Waulsortian	Massive Unbedded Lime-Mudstone	2.77	5.01	2613.98	2664.06
Calp/Lucan	Dark Lst And Shale (Calp)	2.75	1.84	2631.18	2649.56
Carrighill	Calc Greywacke And Shale	2.70	2.47	2645.44	2668.11
Feighcullen	Miciritic Limestone	3.23	0.42	2683.07	2684.02
Glen Ding	Chloritic Greywacke	2.96	0.71	2742.00	2749.53
Carna Type Grano Diorite	Grey Granodiorite	2.32	0.40	2640.63	2644.93
Calp/Lucan (Lu)	Dark Lst And Shale (Calp)	3.21	5.69	2441.93	2782.16
Maulin Fmt	Dark Blue-Grey Slate, Phyllite & Schist (Qzt Member)	4.93	0.23	2605.78	2649.78
Maulin Fmt	Dark Blue-Grey Slate, Phyllite & Schist (Schist Member)	1.80	1.70	2825.16	2842.12
Lisgorman Shale	Thin-Bedded Calcareous Shale, Limestone	2.64	0.30	2685.92	2688.96
Moy Sandstone	Sandstone, Pebbly Conglomerate	2.36	1.47	2672.29	2687.00
Termon (TERM)	Banded Semi-Pelitic & Psammitic Schist	2.69	1.11	2615.38	2626.51

Cranford Limestone	Quartzite Breccia & Marble	1.69	0.52	2624.88	2630.06
Upper Falcarragh Pelite	Pelitic, Semi-Pelitic, Psammitic Schist	1.84	0.11	2740.21	2741.28
Metadolerite	Hornblendic And Sometimes Schistose	1.60	0.81	3051.24	3059.37
Main Donegal Granite	Coarse Biotite Granite & Granodiorite	2.18	0.40	1765.17	1769.21
Carracastle	Intermediate Volcanic Breccia, Tuff	2.33	3.05	2889.27	2919.74
Kilmore Quay Group	Banded Quartzo-Feldspathic Paragneisses	2.27	4.31	2529.50	2572.65

The laboratory phase of this project involved testing of rock cores using the UCD Divided Bar Apparatus (DBA). Each rock core is divided into three samples, so as to serve as a check against each other and to obtain an average reading. These were tested for thermal conductivity in addition to measurements of density and porosity. The thermal conductivity was measured in both oven dried and water saturated conditions. These were combined with previously assessed conductivity values from the work of McGuinness, T. (2012). Table 1 summarises all the results and values obtained to date.

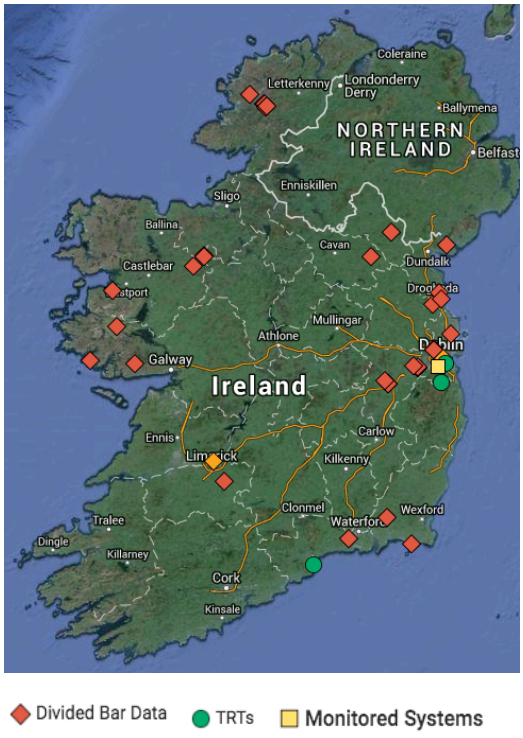

Figure 1: Location of thermal conductivity data in Ireland provided through the IGTP website (Map Data Google Imagery, 2016 – Terramatics, 2016).

3. GROUND LOOP SIZING TABLES

The ground loop sizing tables completed as part of this project provide guidelines values, based on a set of assumptions, for possible heat extraction rates from vertical closed loop collectors.

The data obtained from lab tests and TRT tests from both projects was used as reference and the operational data from operating systems used to model the heat extraction rate that can be expected given different ground conditions in Ireland.

Similar guidelines values published in the VDI 4640 in Germany, the MIS 3005 Ground Loop Sizing tables in the UK and the Geotrainet training manual are commonly used by professionals in Ireland to size ground source collectors. The thermal conductivity database developed as part of this project has highlighted some considerable differences in thermal conductivity values for references lithologies compared to these guidelines. Table 2 below presents average heat extraction rates for Irish geological conditions based on different rock thermal conductivity values, an average full load equivalent hours of operation of a heat pump and an average annual ground temperatures over a 25 year period.

Table 2: Guideline Heat Extraction Rates for Irish Ground Conditions (1800 FLEQ – Single-U 40mm – 10kW installed capacity).

1,800 FLEQ hours		Average Peak Extraction Rate (W/m)							
	Average Ground T (°C)	14	13	12	11	10	9	8	7
Thermal Conductivity (W/m/K)	4	58	54	51	48	45	42	39	36
	3.8	56	53	50	47	44	41	38	36
	3.6	54	51	49	46	43	40	37	35
	3.4	53	50	47	44	42	39	36	34
	3.2	51	48	45	43	40	38	35	33
	3	49	46	44	41	39	36	34	31
	2.8	47	45	42	40	37	35	33	30
	2.6	45	43	40	38	36	34	31	29
	2.4	45	41	39	36	34	32	30	28
	2.2	43	39	37	35	33	31	29	27
	2	41	36	35	33	31	29	27	26
	1.8	38	34	33	31	29	28	26	24
	1.6	36	32	30	29	27	26	24	23
	1.4	31	30	28	27	25	24	23	22
	1.2	28	27	26	25	23	22	21	20
	1	26	24	23	22	22	21	20	19

A series of tables were completed simulating 1,200, 1,800 and 2,400 hours of operation of a heat pump.

Table 2 above presents guideline heat extraction values for 1,800 full load equivalent hours.

The tables allow the designer to reference the thermal conductivity values measured by the project for a given formation or lithology and estimate an average peak extraction rate of a geothermal closed loop vertical collector based on a local average ground temperatures. The values highlighted in orange represent potential typical values for ground conditions in Ireland.

The tables provide indicative values only applicable in the case of small-scale residential systems and have been compiled considering systems between 8kW to 12kW installed capacity ranges operating in heating mode only. Larger systems that exceed 18-20kW installed capacities should not be sized using these tables. In the case of these systems, a site-specific assessment, site-specific information on the local ground conditions or thermal response test data should be obtained in order to achieve a sustainable design.

4.1 Assumptions

The assumptions listed in table 3 have been made for the purposes of modelling and compilation of the heat extraction rates identified.

Table 3: Heat Extraction Rate Modelling Assumptions.

ASSUMPTIONS	
FLEQ hours	1200, 1800 or 2400
Collector Type	Single-U
Pipe Size (mm)	40
Pipe Material	PE100
Pipe Thermal Conductivity (W/m/K)	0.42
Pipe Wall Thickness (mm)	3
Shank Spacing (mm)	60
Backfill - Thermally Enhanced Grout (W/m/K)	2
Fluid Type	Monoethylene Glycol
Fluid Concentration (%)	33
Borehole therm. res. internal	0.52 (m·K)/W
Reynolds number	1.052E4
Thermal resistance fluid/pipe	0.004731 (m·K)/W
Thermal resistance pipe material	0.06159 (m·K)/W
Contact resistance pipe/filling	0.1 (m·K)/W
Borehole therm. res. fluid/ground	0.1476 (m·K)/W
Effective borehole thermal res.	0.1477 (m·K)/W
Heat Pump Operation	Heating Mode only

4.2 Methodology

Heat Extraction rates were modelled based on considering each combination of the following parameters:

- Ground temperatures – between 7°C and 14°C at 1°C intervals;
- Thermal conductivity 16 values at increments of 0.2 w/m/K between 1 and 4 W/m/K;
- Three full load equivalent hour scenarios:
  - 1,200 hours;
  - 1,800 hours;
  - 2,400 hours;
- Heat Pump Installed capacities – 8kW, 10kW and 12kW for each of the above conditions;
- 2 No. Collector Types including Single-U 40mm pipe diameter and Double-U 32mm pipe collectors – both SDR11 (PE100) material for each scenario.

As part of this methodology over 1,500 permutations of above parameters were tested using Blocon Earth Energy Designer (EED) software to obtain the peak extraction rate based on an averaged MWh heat demand throughout the winter months.

The peak extraction rates were given by the heat extracted in W/m at the coldest time of the year in January and averaged over a 25 year period. This is considered comparable to the expected lifetime of a heat pump using a geothermal collector.

Where average ground temperatures are lower than 9°C, the decrease in the extraction rate can exceed 15% to 20% of the 11oC ground temperature value.

Peak average extraction values can be derived for each temperature scenario with a variance of ± 2 W/m extraction rate.

Further modelling over the averaged heat extraction values observed was performed using Ground Loop Design 2014 to ascertain that the modelled values were consistent with other modelling tools.

The sizing tables that illustrate average peak ground extraction rates have been circulated to installers, drillers and engineers that are actively involved or have participated in the design and testing of ground source systems. Feedback on the proposed values based on known heat pump operating conditions of heat pump not considered in this project or known to the authors is expected and will help inform final revisions of these tables before making these available on the project website.

3. CONCLUSIONS

The following findings were observed as part of the permutations tested:

- A variance of approximately 2 W/m extraction rate was observed for 8kW with higher rates and 12kW heat pumps with lower rates from the median value reported which represents a 10kW system. This was mostly true of any given ground temperature modelled;
- A variance of approximately 1 W/m extraction rate was observed between single-U 40mm collectors and double-U 32mm collectors;
- Ground conditions with thermal conductivity lower than 1.4 W/m/K have significantly lower heat extraction rates potentially requiring double the collector surface area than those with higher TC values;

The results of the project have shown that further continued research into the thermal properties of Irish rock conditions should be undertaken in order to facilitate the completion of a more comprehensive database. Future work should be aligned with the work of both exploratory drilling operations and borehole drilled to prove stratigraphy.

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