Assessment of potential for a Borehole Closed Loop System

102 Example Road

GEOREPORT

For:
Example Ltd

by

Carbon Zero Consulting
Seaton Grange Offices
Grange Lane
Seaton
Rutland
LE15 9HT

Tel. 0844 8550115
E-mail. info@carbonzeroco.com
Web. www.carbonzeroco.com

June 2015

TABLE OF CONTENTS

LEGEND

GSHP	Ground Source Heat Pump
BGS	British Geological Survey
COP	Coefficient of Performance
CZC	Carbon Zero Consulting
FLEQ	Full load equivalent (hours)
EA	Environment Agency
GSHC	Ground Source Heating and Cooling
m bgl	Metres Below Ground Level
m bwt	Metres Below Well Top
m OD / mAOD	Metres Above Ordnance Datum
RWL	Rest Water Level
PWL	Pumped Water Level
SPF	Seasonal Performance Factor
DHW	Domestic hot water
HLR	Heat loss report
TD	Total Depth
uPVC	Unplasticised Polyvinyl Chloride

Appendix
Closed Loop Borehole Design – DCLB v 2.4
BGS GSHP Report
Heat Loss Report

Carbon Zero Consulting Ltd. Registered office: Seaton Grange Offices, Grange Lane, Seaton, LE15 9HT

GEOREPORT

1 Background Information

Address:	102 Example Road
Site Grid Reference:	157454, 489523
Elevation:	~60mAOD
Type of System:	Closed loop boreholes
Heat pump selection	1 x 10kW

This Georeport is provided for Example Ltd on behalf of their client of the above address. The building is proposed to utilise 1 x 10kW Siebel Eltron Ground source Heat Pump (GSHP) to provide the complete heat demand for space heating and domestic hot water (DHW). The building heat loss calculation and heat pump sizing has been conducted by Example Ltd (see Appendix). The heat requirements are summarised as:

The main house:

- o The heat loss @ ambient minimum of -1.8 °C is 9.22 kW
- o Annual Energy required for DHW 1630 KWh
- o The total thermal energy requirement is 24,555 kWh/yr.

- Proposed flow temperature for space heating of 45°C.
- Approximate full load equivalent hours (FLEQ) is in total 2480

The heat pump is to be linked to a ground source to consist of vertical closed loop boreholes, although an estimate of trench length is also provided as a comparison for a shallow ground array.

Closed loop borehole length has been derived using reference to two methodologies.The geology and hydrogeology of the site has been evaluated using in-house databases, 1:50,000 scale geology map sheet 312 for Yeovil in addition to BGS borehole records.

2 Summary

- Sandstone from the Bridport Formation forms the uppermost layer. The thickness on site is unlikely to exceed 15m.

- Deeper geology consists of interbedded silts and marls of Jurassic to Triassic age (Dyrham Formation underlain by Blue Lias).

- For heat pump operation of up to 2500 hours per annum two boreholes each of 110m depth and 150mm diameter are recommended, to be spaced *a minimum* of 12m apart.

  - o By comparison, a shallow (trench) ground array of 540m of straight pipe buried to a depth of 1m would be required

- The rest water level within the drilled formations will be at or below 7mbgl. Although artesian conditions are present nearby (to the south), artesian water flow is not predicted here.

- The site is not in an area of risk of mining or historical industrial contamination.
- The site is located at the northern edge of a ‘total catchment area’ for a public groundwater supply source protection zone. This will have no impact on your ability to drill closed loop boreholes.
- A search should be made for the presence of water, power or sewerage services prior to drilling.
- Further guidance on borehole design is provided in the body of this report. It is recommended to follow the guidelines set out in the GSHPA Vertical Borehole Standard.

3 Summary of Geology and Thermogeology

Site Description / local Water features

- Elevation of approximately 60mAOD.
- Two water supply boreholes within 1km of the site

Geology

Group/Formation	*Description*	*Expected Thickness*
Bridport Sandstone Formation	- Sandstone, gray to brown in colour, fine to very fine sand grains. 176 - 183 million years ago in the Jurassic period.	Up to 15m
Dyrham Silt and Sand formation	- pale gray to light blue silty to sandy mudstone. Silt and very fine grained sandy muds. 183- 190 million years ago in the Jurassic Period.	From 15m to 50m
Blue Lias formation of silts and Marls	- Silts and Marls with increasing clay content with increasing depth. 183-204 million years ago between the Jurassic and Triassic periods.	From 50m to 135m

Geological Structure

- The site is situated within 500m of a number of fault structures. Although unlikely to have a major impact on the ease of drilling at this location, there might be some fracturing of the drilled rocks leading to additional drilling fluid loss.

BGS Records

Borehole records within 1km of the site:

- Borehole with BGS reference - is located 1km north-east of the site. This records 30m of brown to gray silts and sands with intermittent limestone.

Hydrogeology

Rest Groundwater Level	Groundwater RWL approximately 7mbgl within a shallow borehole (although potential for superficial groundwater at a level of 3mbgl)	
Aquifer Potential	Yeovil sands	Major Aquifer; Unlikely to be fully saturated at this location. Domestic supply only

Thermal Conductivity

Formation / Group	*Thermal Conductivity (W/mK)*
Bridport Sand Formation	2.23
Dyrham Formation	1.76
Blue Lias & Charmouth Mudstone	1.87

Combining the thermal conductivities of the geological strata, we calculate an Average Thermal Conductivity (Weighted arithmetic mean, based on a 120 m borehole):

- Average thermal conductivity (weighted arithmetic mean): 1.88W/mK
- Conservative value (minus 5%) 1.78W/mK

Closed Loop Borehole Construction

The borehole void between the closed loop U-tube and the borehole wall should be sealed with a low-permeability, thermally enhanced grout. The grout should be emplaced using a tremie pipe to fill from the base upward to ensure the borehole is full with grout with no void spaces. Filling of boreholes to within 20m of surface with suitable rounded gravel is also acceptable. The final 20m should be grouted as defined above.

Boreholes are to be drilled to depth with a diameter of 150mm and a spacing of *at least* 10m. For ground loop materials it is recommended to follow the guidelines set out in the GSHPA Vertical Borehole Standard.

MCS recognised thermal transfer fluid should be used to fill the pipework. Pressure and flow testing must be performed on each borehole.

4 Method 1; Borehole length calculation using DCLB software.

The borehole length for one x 10kW heat pump has been calculated using in house DCLB v.2.4 software. When using this tool, we have assumed the following:

Peak heating load to be met by heat pump of capacity (kW)	10
Seasonal performance factor of heat pump (SPF)	An SPF of 3.2 is a guidance value for a heat-only installation (OFGEM) A value of 3.7 used for this calculation based on Example Ltd calculations. A higher SPF requires a greater proportion of heat to be extracted from the ground and so is a more conservative figure.
Peak operating hours per year (hours)	2480 (Using given kWh figures and building heat loss calculations plus 'normal' DHW production)

The client should be aware of the peak operating figure. The client should check that calculations correspond to their known or predicted use.

Assumed figures:

Peak load minimum mean carrier fluid temperature	-1.5^{o}C (min temp entering heat pump ~ 0^{o}C)
Winter baseload mean carrier fluid temperature	Does not drop below 0^{o}C
Assumed borehole diameter (mm)	150
Undisturbed ground temperature (average over 120m depth, see attached BGS data) (^{o}C)	12
Seasonal Performance Factor	3.7
Heating season duration (months)	7
Borehole grout thermal conductivity (W/mK)	1.8 (approx industry average)
Borehole thermal resistance (Km/W)	0.11 (approx industry average)
Duration of peak load on coldest day (hours)	13
Assumed volumetric heat capacity of ground (MJ/m^3/K)	2.2
Simulation period (years)	25

The length of borehole required is related to the thermal conductivity of the ground (among other factors). Our best estimate of the average ground thermal conductivity is 1.87 W/m/K, averaged over the predicted borehole depth, see Section 3. This value (minus 5% to provide some design redundancy) has been applied to the DCLB model (Appendix A). DCLB utilises three additive step functions, corresponding to (i) An annual, year on year baseload, (ii) an additional winter heating season load, (iii) a short duration peak load. For UK conditions, it is suggested that a heating season of 7 months duration gives good comparison with more sophistocated programs such as Earth Energy Designer (EED).

It is recommended to model the borehole length using EED or similar software for multiple boreholes. However, this method provides good results assuming each borehole is thermally independent of all others. The boreholes should be placed at a maximum distance from each other, with a *minimum* of 12m spacing.

DCLB calculates a borehole length of 219m to support a peak load of 10kW. Two boreholes each drilled to a depth of 110m is recommended.

5 Method 2; Borehole length calculation using MIS 3005 v3.0.

This Microgeneration Installation Standard MIS 3005 has been issued by the Department of Energy and Climate Change (DECC). The standard provides methods for calculating heat emitter and borehole lengths for ground source heating systems.

This report uses the *'MCS 022: GROUND HEAT EXCHANGER LOOK-UP TABLES - SUPPLEMENTARY MATERIAL TO MIS 3005, Issue 1.0'.*

The 'look-up' tables require the following inputs in order to derive a figure for '*Maximum power to be extracted per unit length of borehole*'.

Formation thermal conductivity (W/mK)	1.87 (see Section 1)
Average borehole temperature °C (See BGS data)	12
Seasonal performance factor of heat pump (SPF)	3.7
Peak heating load to be met by a heat pump of capacity (kW)	10
Heat pump evaporator capacity (W) [1-(1/SPF)]	7290 (a)
Full load equivalent operating hours FLEQ (Hours)	2400 (table with nearest hours)

The 'Look-up' table yields a result for *Maximum power to be extracted per unit length of borehole*' of;

- 33W/m of borehole. (b) (Note that some 'iteration' is required to obtain a figure from the look-up tables).

For the given evaporator capacity the required borehole length is calculated as;

- (a) ÷ (b) = 220m to support a peak load of 10kW.

This result is sufficiently close to the result obtained from our DCLB calculation above. Note that the MIS3005 approach assumes the 'worst case' in terms of using 32mm borehole pipework.

6 Viability of a shallow (trenched) ground array

Assuming a soil composition of sand and clay (consistent with local deposits), the soil thermal conductivity is estimated to be in the region of 1.6W/mK. This should be measured with a soil thermal conductivity survey to confirm if this method is to be pursued.

The 'look-up' tables requires the following inputs in order to derive a figure for '*Maximum power to be extracted per unit length of trench'*.

Soil thermal conductivity (W/mK)	1.5
Average temperature °C	10.3 (mean air temp for the site)
Mean soil temperature °C	11.3 (BGS report, attached)
Seasonal performance factor of heat pump (SPF)	3.7
Peak heating load to be met by a heat pump of capacity (kW)	10
Heat pump evaporator capacity (W) [1-(1/SPF)]	7290 (a)
Full load equivalent operating hours FLEQ (Hours)	2500

The 'Look-up' table yields a result for *Maximum power to be extracted per unit length of trench* of;

- 13.5W/m of straight pipe. (b). Note that some 'iteration' is required to obtain a figure from the look-up tables.

For the given evaporator capacity the required pipe length is calculated as;

- (a) ÷ (b) ≈ 540m of pipe

Note that the MIS3005 approach assumes the 'worst case' in terms of using 25mm pipework.

Sufficient ground to accommodate 5 trenches each of 108m length would be required. Straight pipe trenches should be of 1m width with a minimum of 1m separation.

7 Other assumptions and comments

Boreholes should be backfilled with a thermally enhanced, low permeability grout. MIS 3005 recommends a grout of thermal conductivity not less than 2.4W/mK. However, an industry average value of 1.8W/mK should be regarded as a minimum. The shanks of the U-tube should be separated using spacers. Depending on borehole stability, the installation of rounded pea gravel to within 20m of ground level can also be considered.

Pipe diameters and carrier fluid type should be selected to yield turbulent fluid flow within the borehole U-tube (to maximise heat transfer) and laminar flow in the surficial "header" pipes (to minimise heat loss), under the operational fluid flow rate.

This report has been prepared based on available geological and thermogeological information. Although we have applied our experience and expertise to the data available, no guarantee can be made as to the performance of the system.

Development of boreholes has an inherent risk. Developers should be aware that it is possible that unforeseeable ground conditions may exist that result in increased development costs.

Carbon Zero Consulting Ltd standard terms of engagement apply to this report. Copies can be supplied on request.

References

- MCS 022: GROUND HEAT EXCHANGER LOOK-UP TABLES. SUPPLEMENTARY MATERIAL TO MIS 3005, Issue 1.0. DECC 3 Whitehall Place, London,SW1A 2HH.
- Ground Source Heat Pump Association, Vertical Borehole Standard
- Environment Agency Environmental good practice guide for ground source heating and cooling
- BGS GSHP Report (Basic) – see Appendix
- BGS Geology map for Yeovil

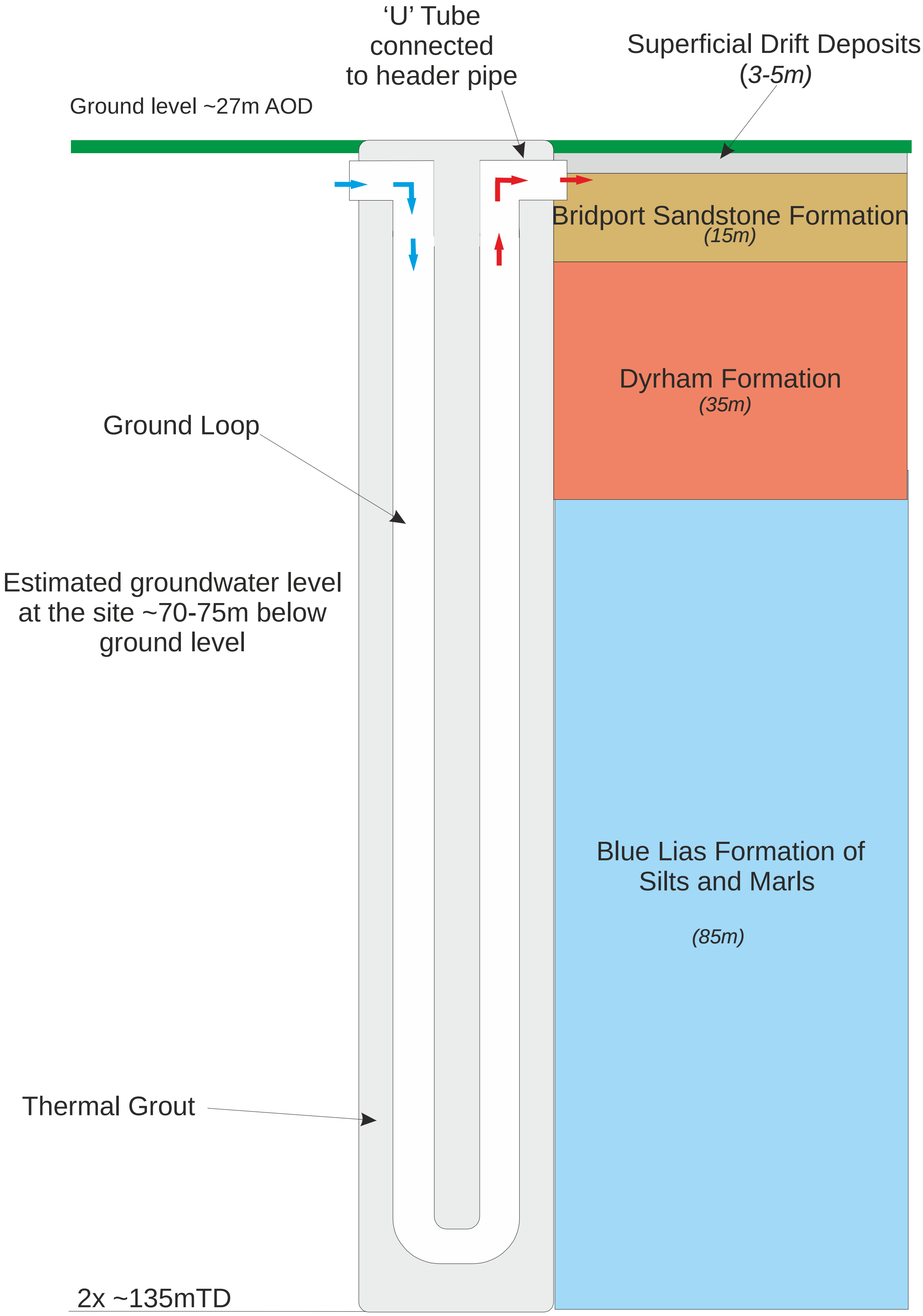


Diagram assumes 2 boreholes to 135m to meet the required energy demand
Alternatively 3 boreholes may be drilled to depths of 90m.
Diameters to be confirmed by drilling contractor
Depths may vary depending on the geology encountered

carbonzero CONSULTING

Figure - 1	Example - 1

Input parameters - thermogeology			**HEATING**
Undisturbed ground temperature	12.0	°C	*Default assumption = 12°C*
Thermal conductivity	2.70	W/m/K	
Ground volumetric heat capacity	2.20	MJ/m3/K	*Default assumption = 2.2 MJ/m3/K*
Thermal diffusivity	1.23E-06	m2/s	*Calculated*
Euler's Constant	0.57721567		
SQRT 4.5	2.12132034		
Input parameters - borehole			63
Borehole diameter	150	mm	*Default assumption = 150 mm*
Borehole thermal resistance	0.11	Km/W	*Default assumption = 0.13 Km/W*
Borehole Length	220	m	
Input parameters - loads and heat pump			
Heat Pump Capacity	13	kW	*Assumed to be peak load*
Seasonal Performance Factor	3.5		*Default assumption = 3.5*
Assumed peak hours per year	2400	hrs	*Default assumption = 2400 hrs*
Heating season duration	7	months	*Default assumption = 7 mths*
Winter heating load	31.2	MWh	*Calculated*
Duration of peak load on coldest day	13	hrs	*Default assumption = 13 hrs*
Month of heating season with peak	4		*Default assumption = 4 (Jan)*
Average duration of peak heat	11.3	hr/day	*Calculated*
Simulation period	25	years	*Default assumption = 25 years*

Domestic Closed Loop Borehole (DCLB v. 2.4) 16/12/09

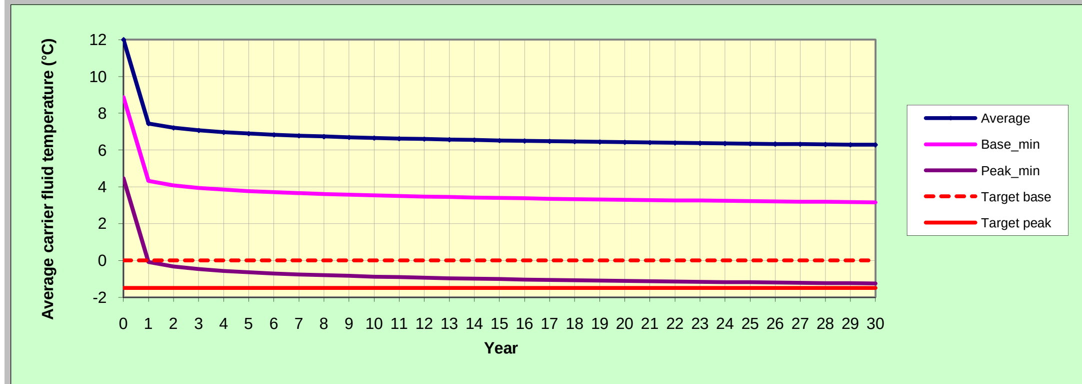
The DCLB program is developed by © Holymoor Consultancy Ltd, 2009, of 8 Heaton Street, Chesterfield, Derbyshire, S40 3AQ. Its use is licensed to Carbon Zero Consulting Ltd. of Seaton, Rutland.

DCLB is designed to give an approximate solution to the extraction of small quantities of heat from a single closed loop borehole. (i) An annual, year on year baseload, (ii) an additional winter heating season load, (iii) a short duration peak load. For UK conditions, it is suggested that a heating season of 7 months duration gives good comparison with more sophistocated programs such as EED.

Peak Load		
Heat extraction	9286	W
Borehole radius	0.075	m
t	0.54	days
t (sec)	46800	seconds
q (W/m)	42.21	W/m
U	2.45E-02	
Temp drop in rock mass	8.55	°C
Temp drop at borehole	4.64	°C
Temp. at time t	-1.19	°C
Temp must not drop below	**-1.50**	**°C**

Winter Seasonal Load		
Heat extraction	4358	W
Borehole radius	0.075	m
t	213	days
t (sec)	18408096	seconds
q (W/m)	19.81	W/m
U	6.22E-05	
Temp drop in rock mass	6.60	°C
Temp drop at borehole	2.18	°C
Temp. at time t	3.22	°C
Temp must not drop below	**0.00**	**°C**

Average Annual Load		
Heat extraction	2542	W
Borehole radius	0.075	m
t	9131	days
t (sec)	788940000	seconds
q (W/m)	11.56	W/m
U	1.45E-06	
Temp drop in rock mass	4.38	°C
Temp drop at borehole	1.27	°C
Temp. at time t	6.35	°C



Lower compliance limit	22917	seconds
for valid approximation	6	hours
Upper compliance limit	12.4	years
for valid approximation	=ts/10	
Time for steady state	3.90E+09	seconds
ts	45165	days
	124	years
Temp drop in rock mass	4.93	°C
Temp drop at borehole	1.27	°C
Steady State Temperature	5.80	°C