NI GeoEnergy Demonstrator
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Stormont Geothermal Feasibility

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Tetra Tech Consulting (Northern Ireland) Limited: No. NI667243

Tetra Tech Belfast, 1 Locksley Business Park, Montgomery Road, Belfast, United Kingdom BT6 9UP

Registered Office: 1 Locksley Business Park, Montgomery Road, Belfast, United Kingdom, BT6 9UP

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Acronyms/Abbreviations

Acronyms/Abbreviations	Definition
BHE	Borehole Heat Exchanger
EED	Earth Energy Designer
GSHP	Ground Source Heat Pump
FLEQ	Full Load Equivalent Hours
mBGL	Metres below ground level
MCS	Microgeneration Certification Scheme
TRT	Thermal Response Test

Executive Summary

The GeoEnergy NI Demonstrator Project is a Northern Ireland Government initiative, funded by the Department for the Economy (DfE) to showcase and demystify geothermal energy. Geothermal energy is a low carbon, natural, and renewable energy source from beneath the Earth's surface and is already widely used successfully across the world. The GeoEnergy NI Demonstrator Project aims to familiarise the public with the subsurface, help build the geothermal energy sector, promote geothermal as a source of heating and cooling, gain public support and social acceptance for geothermal energy, de-risk future investment and support market sector development.

The Stormont Estate component of the study was aimed primarily at assessing the potential for use of shallow geothermal energy through investigation of sub-surface conditions by drilling and testing of boreholes at 5 No. locations.

The scope of works specified the drilling and testing/instrumentation of 4 No. boreholes, completed to up to a maximum depth of 250m and the drilling and coring of 1 No. geological stratigraphic borehole up to a maximum depth of 500m. Once drilled, two of the boreholes were to be subject to pumping tests to investigate the volume of water that could be abstracted sustainably, to inform the assessment of use of an open loop geothermal system at the site. Another borehole was to be subject to a Thermal Response Test (TRT) to confirm the thermal parameters of the rocks beneath the site and inform consideration on the use of a closed-loop geothermal system.

Drilling operations ran through from May 2024 until February 2025. Prior to the investigation drilling, available geological mapping and data had indicated that a relatively thick sequence of Triassic Sherwood Sandstone bedrock would be present beneath glacial deposits. The boreholes however encountered only a thin section of the targeted Sherwood Sandstone aquifer. This was underlain by a thick sequence of Permian Enler Group comprising mudstones, sandstones and breccias with dolerite intrusions also encountered. Beneath this, at the deepest borehole drilled, the top of the underlying Palaeozoic sequence was encountered within the expected depth range.

The absence of a thick sequence of the target Sherwood Sandstone Group (bedrock which has proven to be a good aquifer resource elsewhere in the Belfast area) may reduce the viability of shallow open-loop solutions (where heat is extracted from groundwater pumped from one or more boreholes) being implemented at the site with confidence. However, for the one pumping test completed at the site, the yield sustained by the borehole was significant and demonstrated that the Permian rocks may have the potential to support some level of open loop solution at certain locations. More investigation would be needed to further de-risk this option.

A closed-loop geothermal solution is likely to be a more favourable solution for the Stormont Estate site, as there is more certainty with respect to the amount of heat energy that can be obtained for a specified number of boreholes. Published Permian strata thermal properties are similar to (in some cases better than) Sherwood Sandstone strata, this was confirmed during the TRT and the Permian rocks are therefore likely to be well suited for closed loop systems. Results from the rock section drilled, confirm that the heating needs of key Stormont buildings could be met by installation of a series of arrays of closed-loop borehole heat exchangers, connected via an ambient loop district heat network. There is still some subsurface uncertainty and it is recommended that viability of use of geothermal across the Stormont Estate should be tested by installation of an initial 30-40 borehole array to provide heating to only the Stormont Castle buildings.

1.0 Introduction

1.1 Purpose

The GeoEnergy NI Demonstrator Project is a Northern Ireland Government initiative, funded by the Department for the Economy (DfE) to showcase and demystify geothermal energy. It aims to familiarise the public with the subsurface, help build the geothermal energy sector, promote geothermal as a source of heating and cooling, gain public support and social acceptance for geothermal energy, de-risk future investment and support market sector development.

1.2 Scope and Objectives

A key element of the Demonstrator project is the evaluation of the geothermal potential of the Permo-Triassic rocks underlying the Stormont Estate in Belfast. The principal component of this evaluation was investigatory drilling of 5 No boreholes to assess sub-surface geology and hydrogeological/thermogeological properties. One borehole was planned to be drilled to a depth of up to 500m to confirm the overall stratigraphic sequence to final drilled depth, while four further boreholes were planned to be drilled to 250m to evaluate the ground’s potential for geothermal heating and cooling. This targeted geological setting is a low temperature, or low enthalpy, geothermal setting where ground heat would be used in conjunction with heat pumps. It was proposed to undertake borehole testing to inform the assessment of both open loop and closed loop borehole solutions and to evaluate how these could be employed at Stormont through the construction of an ambient loop district heat network to link the boreholes and the buildings.

This report considers the results from the ground investigation completed at the site and assesses the options available for shallow geothermal deployment at the Stormont Estate to meet some or all selected buildings heating requirements.

1.3 Methodology

The principal components of this assessment are:

- Building of a sub-surface model, describing the rock units beneath the site and establishing their geological, hydrological and thermogeological parameters (Section 3 and Section 4).
- Modelling of the possible thermal outputs from boreholes drilled at the site (Section 5).
- Evaluation of the heating loads of the target buildings and outline designs for multi borehole geothermal arrays to meet some/all of those loads (Section 6).
- Discussion on the feasibility of a geothermal scheme and associated costings (Section 7).

This report includes consideration on the residual risks and uncertainties for scheme implementation and provides conclusions and recommendations.

1.4 Site Location / Description

The geothermal demonstrator site is located within the Stormont Estate and in proximity to Dundonald House, Upper Newtownards Road, Belfast, BT4 3SB 9, Irish National Grid Reference J 40520 74097 (latitude/longitude 54.596"N 5.826"W) (Figure 1). The site is located around 6km east from Belfast City centre. The Stormont Estate itself comprises a mix of open amenity ground, government office buildings, the Stormont Parliament buildings, access roads, car-parking and with an adjacent large sports complex (NICSSA) with cricket, hockey and football pitches.

Drilling operations were carried out around 1km to the SSE of the Stormont Parliament Buildings, housing the NI Assembly. The site is bounded on the east by Stoney Road and the headwaters of the River Knock, and the grounds of the Knock Golf Club beyond that. The campus of the Ulster Hospital is located around 1 km east of the site. The site is bounded on the south by the main A20 Upper Newtownards Road, beyond which lies residential housing and the Dundonald Cemetery. Further residential housing is present to the west of the Stormont Estate site.

The topography slopes down broadly from north to south towards the Upper Newtownards Road. The elevation of the ground is around 30m.

1.5 Low Enthalpy Geothermal Principles

There are two principal types of low enthalpy geothermal systems typically used in conjunction with Ground Source Heat Pumps (GSHP):

- Open-loop, where water is taken from the environment (aquifer, lake, river or estuary), passed through a heat exchanger, and is then returned to the environment. For this solution at Stormont, groundwater would be abstracted from one or more boreholes drilled into the aquifer beneath the site and then returned to that same aquifer via other recharge borehole(s).

- Closed-loop, where a carrier fluid is passed through sealed pipework or heat exchanger within the ground, collecting heat from the ground (or releasing it in cooling mode) in the process. At Stormont the heat exchangers would be installed in boreholes drilled into the underlying bedrock, with the boreholes sealed up with grout and the associated pipework connected to sub-surface collector pipework systems.

2.0 Subsurface Characterisation

2.1 Geological Setting

2.1.1 Superficial Geology.

The GSNI Geoindex and published geological maps indicate that the site is immediately underlain by deposits of Quaternary age. Previous geological assessments (Tetra Tech 2023) and models broadly agree that this comprises glaciofluvial sands and gravels overlying a mantle of boulder clay, over bedrock. This was confirmed by drilling.

- Glaciofluvial ice contact deposits, comprising silt, sand, gravel and boulders. Cooper et al. (2023) describe the sands and gravels as loose, dominated by clast-supported, angular to sub-rounded greywacke, varying dramatically in terms of grainsize and sorting. These appear to thin out towards the north of the site. The thickness of the glaciofluvial deposits is reported on the basis of GSNI fieldwork in 2022 (Cooper et al. 2023), to vary from 5m to at least 20m. The section was 2m to 4m thick in the 5 No boreholes drilled.
- Glacial till (Boulder Clay), comprising a “matrix of poorly sorted clay, silt and sand grade material, containing cobbles and boulders, with occasional sand and gravel horizons” (Tetra Tech 2023). The till may be reddish-brown where it overlies Lower Palaeozoic greywackes and brighter red where it overlies the Sherwood Sandstone (Cooper et al. 2023). The thickness of the till is reported to vary from 5 m up to 30 m in the vicinity of the Newtownards Fault or other major faults. The section was 11m to 32m thick in the 5 No boreholes drilled as part of this project.
- There are also some small areas of alluvium and peat (the latter possibly associated with fine-grained glaciolacustrine deposits – Cooper et al. 2023). Alluvial deposits (sediments of clay, silt, sand, gravel, deposited by rivers or streams in postglacial time) also lie along the line of the Enler-Knock valley (Figure 2.).

2.1.2 Bedrock Geology

Sherwood Sandstone

The Sherwood Sandstone aquifer is regarded as the most important aquifer in Northern Ireland, reaching a thickness of 648 m in the deep Larne No. 2 borehole and being typically around 300 m below Belfast (Robins 1996). It is regarded as being of Triassic age. BGS (1994) cite it as being around 300 m thick in the Lagan Valley and below Newtownards. It was the principal target of the recent Stormont drilling campaign but proved to be less than 25m in thickness at the site.

The study area lies above a roughly E-W half-graben structure infilled by Permo-Triassic sedimentary rocks. The trough is bounded on the northern margin by the Newtownards normal fault and is referred to here as the Belfast-Newtownards Trough. This links and combines the two sedimentary basins at either end of the structure (the Belfast-Lagan basin and the Newtownards basin). Smith et al. (1991) cite the Sherwood Sandstone's thickness in the Newtownards trough as greater than 160 m.

The Sherwood Sandstone was deposited in a predominantly shallow lacustrine (Robins 1996) or fluvial (Smith et al. 1991) environment and its lithology can vary laterally and vertically. Sporadic evidence of aeolian conditions occurs towards the top of the formation (Smith et al. 1991). Smith et al. (1991) describes it as a "succession of reddish, fine- and medium-grained sandstones with subordinate dark red-brown mudstone and siltstone intercalations". The grains are often well-sorted and weakly cemented by haematite and limonite, although calcite may also be present as a cement. It contains thin mudstone partings and tends to become finer towards the base (Robins 1996). Some researchers have proposed a basal "Loughside Formation" (Cooper et al. 2023) with a particularly high proportion of thin, dark brown mudstones intercalated with sandstones.

Close to Palaeogene dolerite sills and dykes, the sandstones are metamorphosed to a pale buff colour (Smith et al. 1991). The thickness of the Sherwood Sandstone within the Belfast-Newtownards Trough is unknown, but Smith et al. (1991) note that it oversteps the earlier Permian deposits.

Permian Sedimentary Rocks

Below the Sherwood Sandstone is a sequence of Permian sedimentary rocks. These are indicated as a little over 100 m thick at the Belfast end of the trough and up to 300 m thick at the Newtownards end (Smith et al. 1991). Smith et al. (1991) suggests that the Permian sequence thins out between the Belfast and Newtownards basins, near the centre of the trough – i.e. approximately around the Stormont site. The Permian sedimentary rocks are subdivided into:

The Upper Permian Marls or Belfast Group – these comprise:

- the Connswater Marl – calcareous brick-red and brown silty mudstones, with subordinate sandstone. Gypsum and anhydrite can occur towards the base (Smith et al. 1991).

- the Belfast Harbour Evaporite Formation – shelly limestone (the equivalent of the Magnesian Limestone) and marls, with evaporite (anhydrite) beds (Smith et al. 1991).

The Lower Permian Enler Group. This comprises

- a sandstone formation (the Carnamuck Formation at the Belfast end and the Kennel Sandstone Formation at the Newtownards end). The Carnamuck Formation comprises medium-to coarse grained red-brown sandstone units, some of which fine upwards, with interbedded subsidiary breccia (Cooper et al. 2023).
- a basal Coolbeg Breccia Formation, comprising "greywacke sandstone and mudstone clasts set in a red–brown sandy matrix" (Cooper et al. 2023).

GSNI mapping (Figure 3) suggests that the Belfast Harbour Evaporite Formation has thinned out west of the site / investigation area at Stormont and is unlikely to be present in boreholes drilled at the site. This view was supported by Cooper et al. (2023) and is confirmed by the recent drilling campaign.

GSNI mapping (Figure 3) suggest that the Connswater Marl is present to the west of the GeoEnergy NI investigation area but thins rapidly eastward and *may* not be present beneath the whole the area. This also appears to have been confirmed by the recent drilling campaign where a thin Sherwood Sandstone sequence appears to rest directly on the Enler Group (and may thus be in hydraulic continuity with it). GSNI mapping (Figure 3) indicates that the Permian sequence thins substantially around the Dundonald sill in the centre of the Trough but drilling of the Stratigraphic borehole in this investigation indicates a thickness of at least 230m of Permian.

Lower Palaeozoic "basement"

The Permian (and Carboniferous, if present) sedimentary rocks unconformably overlie Lower Palaeozoic rocks of the Longford-Down orogenic belt (deformed during the Caledonian orogeny and continuous with the Southern Uplands of Scotland). The formations outcropping immediately north and south of Dundonald and Stormont in the sides of the trough belong to the:

- Silurian Gala (formerly Strangford) Group, dominated by turbiditic sandstones with some mudstones. The BGS lexicon of rock-forming units describes it as "Graded beds that may include wacke sandstone, siltstone and mudstone in variable proportions, interpreted as turbidites. Rare interbedded graptolite-bearing beds", up to 6000m thick[1].

- Ordovician Leadhills Supergroup (formerly Gilnahirk Group). This is described as "Greywackes, shales, siltstones and mudstones with conglomerates[2]" .

GSNI mapping (Figure 3) suggests that the likely Lower Palaeozoic bedrock beneath the GeoEnergy NI site will be the Ordovician Leadhills Supergroup. While the age of the sequence (Silurian/Ordovician) is still to be confirmed, drilling at the Stratigraphic borehole location indicated the Palaeozoic sequence being reached within the predicted depth range.

Palaeogene intrusive rocks

The Permo-Triassic sequence is intruded by Palaeogene basalt / dolerite dykes (which can range from a few cm to 18 m width - Robins, 1996) and sills. One large sill sub-crops on the south side of the Newtownards trough, south of Dundonald (Figure 3). Tetra Tech (2023) and Cooper et al. (2023) note that the dykes typically have a predominately NW–SE to NNW–SSE trend and in the Belfast Lough area have an average separation distance of approximately 80m. Cooper et al. (2023) do not exclude the possibility that sills may also extend below the Stormont area of interest and drilling did prove a series of dolerite units, the thickest reaching 21m thickness in EB3.

Geological Structure

The Sherwood Sandstone beneath Dundonald is continuous with that beneath Belfast and the Lagan Valley. The study area lies above a roughly E-W half-graben structure infilled by Permo-Triassic sedimentary rocks, formed during a late-Carboniferous / early Permian transtensional phase (Smith et al. 1991), bounded to the north by a major east-west trending normal fault, the Newtownards Fault. The Newtownards fault downthrows the Sherwood Sandstone on the south against outcrop of Ordovician metasediments on the north, with additional minor north– south trending offset faults (McConvey 2023). This structure is referred to as the Belfast-Newtownards Trough and links the two sedimentary basins at either end of the structure (the Belfast-Lagan basin and the Newtownards basin).

The trough contains north-easterly dipping Permo-Triassic sediments. The Permo-Triassic strata typically dip at 8 to 18° to the north east, with a dip of 10° being recorded some 3km from the GeoEnergy NI Stormont site (McConvey 2023).

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[1] https://webapps.bgs.ac.uk/lexicon/lexicon.cfm?pub=GALA

[2] https://webapps.bgs.ac.uk/lexicon/lexicon.cfm?pub=LHG

The Permo-Triassic sub-crop within the trough coincides with the valley of the westward-flowing Knock River (to Belfast Lough) and the south-eastward flowing River Enler (flows from Dundonald to Comber and then into Strangford Lough).

Prior to the investigation works a 3-D geological model of the GeoEnergy NI Stormont investigation area was constructed, based on best available geological mapping and on the shallow resistivity and seismic geophysical profiles carried out in 2022 (Cooper et al. 2022). In the model, the base/thickness of the Sherwood Sandstone and base of the Permian were both still highly uncertain, due to the absence of deep boreholes drilled in the area. An elevation of the base of the Sherwood Sandstone beneath the site was predicted at around -125mOD (150 m depth derived from the model and ultimately based upon extrapolation of a uniform dip value of 20° in the model). These depths ultimately proved to be overestimates and the Sherwood Sandstone sequence was much thinner with base of the sequence interpreted at only 62.6mBGL = -33.5mOD see Section 3.2 below. While base Triassic was shallow to prognosis, the Permian is thicker and the Palaeozoic metasediments were encountered within the predicted range, suggesting the original structural interpretation is broadly correct. The basin fill is simply older but with consequent changes to the thickness of the predicted units. A revised 3D model is included as Figure 4.

2.2 Hydrogeological Setting

2.2.1 Introduction

Discussion at the pre-drill stage was dominated by consideration of the hydrogeological characteristics of the Sherwood Sandstone which is regarded as the most significant bedrock aquifer in Northern Ireland. It has a thickness of 648m in the deep Larne No. 2 borehole and typically around 300m below Belfast and around Newtownards (BGS 1994, Robins 1996). However as discussed in Section 2.1 above, the Sherwood Sandstone sequence was much thinner than anticipated when drilled at the Stormont site, with a thickness of only 23.7m in the cored stratigraphic borehole and with the sequence typically being weathered and poorly consolidated.

The underlying Enler Group is however also an aquifer and Tetra Tech (2023) describes it as follows, based on the GSNI Geoindex classification:

- Enler Group (Permian) Bh(I-f): High potential productivity fracture / intergranular flow. High to moderate yields probable, however part dependence on fracture flow makes poorer yields possible. Dual porosity. Generally, includes element of regional flow.

According to Wilson et al. (2023), in the Enler Group sandstones, intergranular permeability is more important than in the Sherwood Sandstone, and fracture flow somewhat less important. According to the GSNI hydrogeological map of Northern Ireland (BGS 1994), typical sustainable yields borehole yields are of the order of 5 l/s to 25 l/s from the Enler group sandstones.

Yield reported historically at the Knock Tramway Company stables borehole (130SE001) west of the investigation site, believed to penetrate to -91m OD with perhaps 70m of Permian Enler Group with Palaeogene intrusives, was 2000 gallons per hour (gph) = 2.5L/s, for 2 hours per day. There is no indication that this was necessarily a maximum yield.

2.2.2 Ground Water Quality

Groundwater quality can have an influence on the sustainability of an open loop abstraction-re-injection system.

If the water is soft, of low pH and/or saline, there can be a risk of corrosion of metal components and fixtures (screen, pumps, casing, pipework, heat exchangers). In some cases, highly reducing water, especially that containing hydrogen sulphide (H_2S), can enhance the risk of corrosion even of some stainless steels (the protective oxide layer that protects the steel may not form under reducing conditions). A representative water analysis should ideally be provided to suppliers of pumps, pipe materials and heat exchangers, to make sure that the choice of materials (and their combination) are compatible with minimising corrosion risk from the water chemistry. In cases where elevated concentrations of sulphate are present, it is recommended that water is not allowed to stagnate in pipework during periods of non-operation, as sulphate-reducing, corrosive micro-niches can develop in pipework.

In hard, higher pH waters, there may be a risk of scaling of borehole screens, pipes and (especially) heat exchangers due to precipitation of calcite or other carbonates. If elevated concentrations of iron and manganese are present in the groundwater, this can also lead to a potential for iron / manganese oxyhydroxides (“ochre”) to precipitate out of the water.

To minimise these chemical scaling risks, it is important that abstracted water is not allowed to come into contact with atmospheric oxygen, that degassing of CO_2 is minimised, and that pressures are managed within the abstraction-heat-exchange-discharge line. This is most easily achieved by means of a “closed” abstraction-heat exchange-re-injection circuit. In any reinjection well, water should be reinjected sufficiently below the water table to prevent cascading and exposure to oxygen. Reinjection pressures and velocities should also be managed:

- to prevent suction developing,
- to prevent cavitation and the formation of bubbles,
- to maintain an adequate positive pressure and
- to allow any bubbles to escape by rising in the injection well, rather than be entrained into

- the formation.

It should also be noted that, for an abstraction- reinjection doublet system, it is very important that the reinjected water be free of particulate matter or chemical flocs. During test pumping the water should be carefully tested for total suspended solids and for turbidity. Empirical tests, based on pumped water samples, are available to evaluate the potential for particulate clogging and fouling of reinjection wells (Schippers & Verdouw 1980, Olsthoorn 1982).

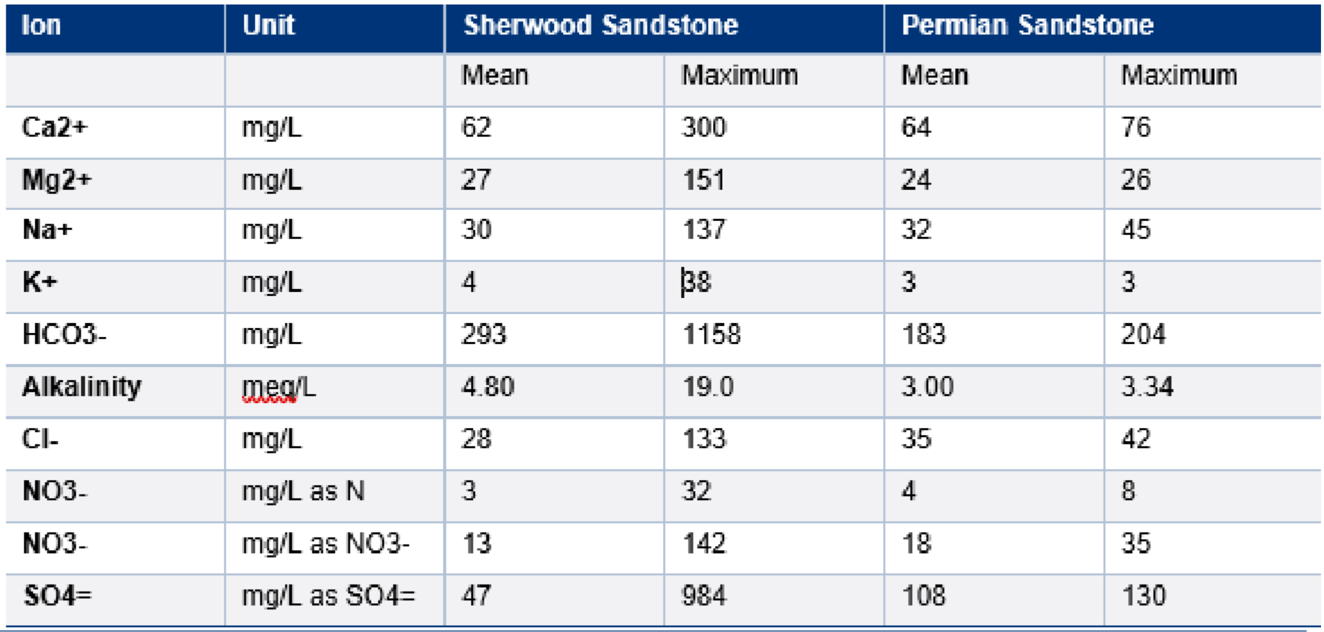
If found at unacceptable levels, and if long term operation of a thermal abstraction-reinjection well doublet is planned, steps should be taken to either remove particulate matter from the water prior to reinjection, and/or for regular back-pumping of reinjection wells to waste, to remove accumulated particulate “cake”.

Routine monitoring of yield and water levels should be undertaken, and a program of regular maintenance should be undertaken to minimise the risk of corrosion, mineral precipitation and biofouling. The system should be designed to allow routine cleaning of the heat exchange circuit, for example by flushing with weak acids or other cleaning agents.

2.2.3 Groundwater Chemistry

According to Robins (1996) groundwaters of the Permian and Sherwood Sandstone aquifers of the Belfast area are generally moderately mineralised and of calcium-magnesium-bicarbonate type (Table 1). In the Sherwood Sandstone, the mean bicarbonate concentration is 293mg/L (c. 4.8meq/L) and the mean sulphate is 47mg/L.

Table 1 Concentrations of major ions in Sherwood Sandstone (N-=67) and Permian Sandstone



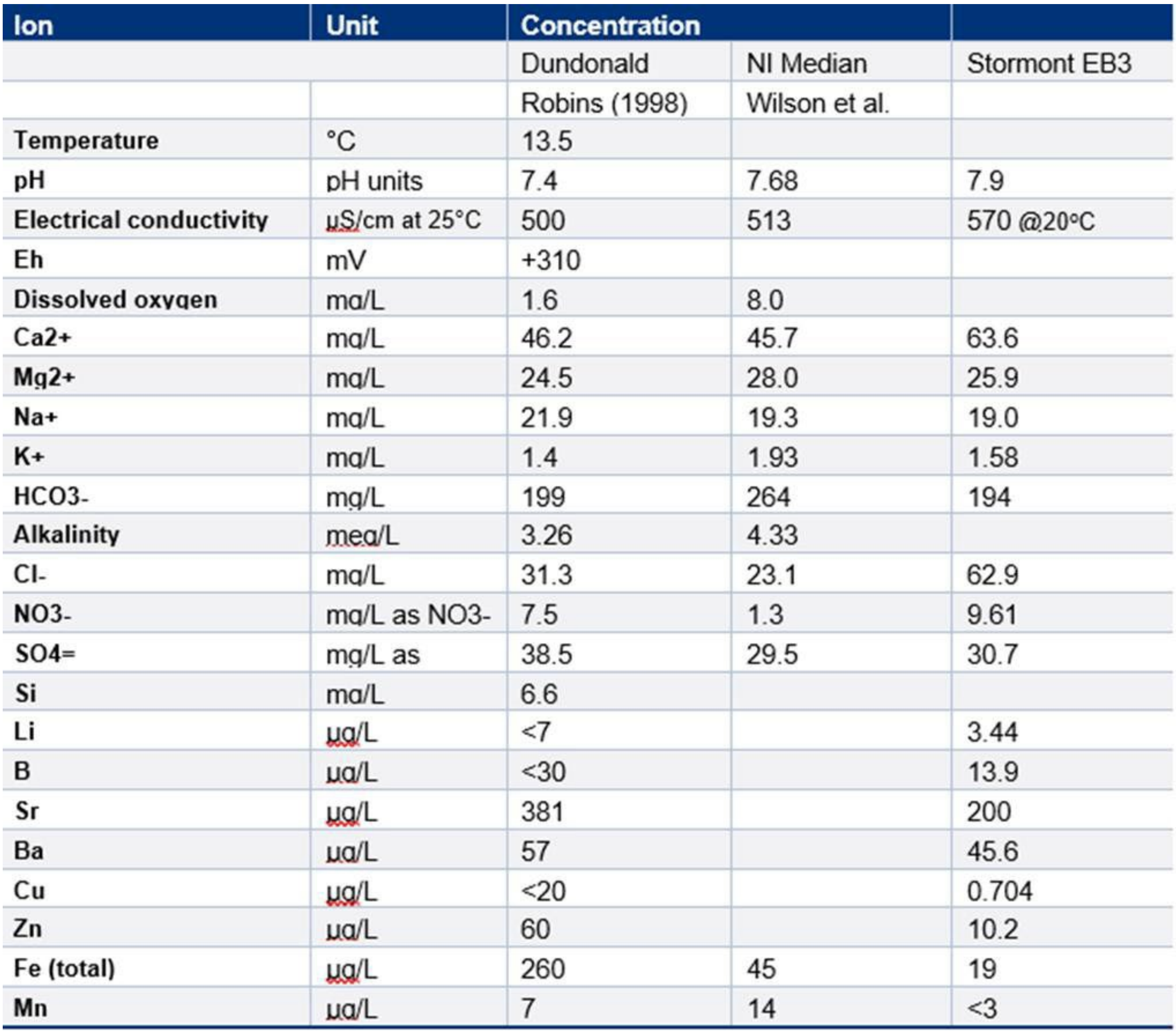
Ion	Unit	Sherwood Sandstone		Permian Sandstone	
		Mean	Maximum	Mean	Maximum
Ca2+	mg/L	62	300	64	76
Mg2+	mg/L	27	151	24	26
Na+	mg/L	30	137	32	45
K+	mg/L	4	38	3	3
HCO3-	mg/L	293	1158	183	204
Alkalinity	meq/L	4.80	19.0	3.00	3.34
Cl-	mg/L	28	133	35	42
NO3-	mg/L as N	3	32	4	8
NO3-	mg/L as NO3-	13	142	18	35
SO4=	mg/L as SO4=	47	984	108	130

Robins (1998) notes that groundwaters in the Sherwood Sandstone and Permian sandstone are often mildly reducing, with Eh in the range +50 to +200mV and elevated concentrations of iron and manganese. pH is typically circumneutral to mildly alkaline.

Robins (1998) also provides an analysis from a 90m deep Sherwood Sandstone borehole at Dundonald (NGR 34304 37420, 54.5959°N 5.7873°W – Table 2). The concentrations of most major ion parameters as shown here slightly lower than the means in Table 2.

Analysis of water sampled from the EB3 borehole as a part of this study (Table 2) shows values that are within these established ranges.

Table 2 Water quality data for 90m deep Sherwood Sandstone borehole at Dundonald (NGR 34304 37420), with rest water level at 16.7m bgl (Robins 1998), compared with median concentrations reported from Permo-Triassic aquifers of Northern Ireland (based on 47 groundwater sources) by Wilson et al. (2023) and analysis of Stormont borehole EB3.



Ion	Unit	Concentration		
		Dundonald	NI Median	Stormont EB3
		Robins (1998)	Wilson et al.	
Temperature	°C	13.5		
pH	pH units	7.4	7.68	7.9
Electrical conductivity	µS/cm at 25°C	500	513	570 @20°C
Eh	mV	+310		
Dissolved oxygen	mg/L	1.6	8.0	
Ca2+	mg/L	46.2	45.7	63.6
Mg2+	mg/L	24.5	28.0	25.9
Na+	mg/L	21.9	19.3	19.0
K+	mg/L	1.4	1.93	1.58
HCO3-	mg/L	199	264	194
Alkalinity	meq/L	3.26	4.33	
Cl-	mg/L	31.3	23.1	62.9
NO3-	mg/L as NO3-	7.5	1.3	9.61
SO4=	mg/L as	38.5	29.5	30.7
Si	mg/L	6.6		
Li	µg/L	<7		3.44
B	µg/L	<30		13.9
Sr	µg/L	381		200
Ba	µg/L	57		45.6
Cu	µg/L	<20		0.704
Zn	µg/L	60		10.2
Fe (total)	µg/L	260	45	19
Mn	µg/L	7	14	<3

3.0 Drilling Outcomes and Future Borehole Design

3.1 Drilling Outcomes

3.1.1 Drilling Results

The site investigation borehole locations at Stormont are shown on Figure 5 and an initial plot of the prognosis for the cored stratigraphic borehole versus the drilled results is shown on Figure 6 with the drilling results tabulated below in Table 3. In summary and as indicated earlier in this report, the Sherwood Sandstone Group was found to be relatively thin with a maximum penetrated thickness of only 23.7m and determined as occurring directly above the Permian Enler Group section. This is by contrast much thicker than expected, reaching 230.7m thickness in the Stratigraphic borehole. The basement greywacke sequence came in at 288.9m depth, within the expected target range of 250-320m.

While the lack of thickness of the Sherwood Sandstone aquifer target was a disappointment, the information gained from the investigation is important to understand the local geological setting and associated shallow geothermal potential.

Full details on the investigation boreholes drilled at Stormont as part of the NI GeoEnergy Demonstrator investigation, including borehole logs, are provided in the Borehole Drilling and Geophysical Logging Report (TetraTech, 2025).

Table 3 Drilling Outcomes from the 5 Stormont Boreholes

Borehole	Geology
Strat Borehole 13/5/24-27/5/24	Drilled depth 302.6m Superficials 0-34.5m Sherwood Sandstone 34.5- 58.2m (23.7m), Permian 58.2-288.9m (230.7m) Greywacke 288.9- 302.6m (13.7m) Intrusion 147.15-149.12m, 163.5-169.63m
EB1 2/12/24-21/1/25	Drilled to 148m Superficials 0-34.5m Sherwood Sandstone 34.5- 58.2m (23.7m), Permian 58.2-148m (89.8m) Intrusion 93-94m

Borehole	Geology
EB2 30/8/24-3/12/24	Drilled to 110.4m Superficials 0-28m Sherwood Sandstone 28- 36.6m (8.6m), Permian 36.6-110.4m(73.8m) Drilled to 110.4m. Limited Sherwood sandstone, Permian Mud drilled with bentonite and PAC 125mm OD pVC well liner installed. No gravel pack.
EB3 2/12/24-18/12/24	Drilled to 46m Superficials 0-12.9m Sherwood Sandstone 12.9- 16.8m (3.9m), Basalt/dolerite in mudstone (Permian) 16.8-17.85m (1.05m) Dolerite 17.85m -38.6m (20.75m) Basalt/dolerite in mudstone (Permian) 38.6-42.2m (3.6m) Permian Mudstone 42.2-46m (5.8m) Bedrock at ~13m. Potentially intrusion affected Sherwood Sandstone. Completed in Permian below igneous intrusion at 46m depth. Open hole below 17.7m.
EB5 6/1/25 – 14/2/25	Drilled to 118m Superficials 0-28m Basalt/Dolerite 28-33m (5m) Permian 33-118m (85m)

3.2 Borehole Design

The initial designs and final completion details of the investigation boreholes drilled at Stormont as part of the GeoEnergyNI Demonstrator project are described in full in the Borehole Drilling and Geophysical Logging Report (TetraTech, 2025).

The objectives and the consequent designs evolved with learnings on ground conditions as drilling progressed and this section of the report focusses on the application of those learnings to the design of boreholes that may potentially be drilled as part of a future geothermal system at Stormont.

Drilling and testing operations continued at the Stormont Estate site until the last week of the contract period at the end of March 2025. The TRT results are included in Appendix A

With regard to designing/implementing a shallow geothermal scheme at Stormont:

- While the overall thickness of the Permo-Triassic sequence is approximately as predicted, the initially targeted Sherwood Sandstone sequence is much thinner and the underlying Enler Group much thicker than expected, based on the pre-investigation geological conceptual model. However

  - It should still be possible to implement closed-loop boreholes up to ~ 200m into the Enler Group, which available information (see Section 4.2.4) indicates would have comparable thermal properties to the Sherwood Sandstone.
  - Consideration of an open loop solution, prior to the investigation, assumed the presence of Sherwood Sandstone, with good aquifer characteristics. The Permian sequence can also be characterised as an aquifer, but further drilling and investigation would be required to de-risk the implementation of this option.
- Top hole sections should preferably be drilled through the superficials (glacial deposits) to top of competent bedrock and steel casing set to seal off this upper unstable sequence and protect the deeper open-hole section during follow on drilling. Due to the nature and thickness of the superficial deposits, this steel casing may not be able to be recovered in closed loop boreholes following installation of the loop/ during grouting. This is due to the depth of casing required to reach competent rock and the gripping nature of the sand rich deposits on the steel casing. The retained presence of steel casing (with steel a good conductor) will have some influence on the transfer of heat from the surrounding ground to the collector loop, but this is expected to be minimal. The use of retained steel also increases overall project cost.
- Drilling techniques need further consideration to establish the most reliable and cost-effective way to drill up to 200m into the mainly Permian bedrock. This can be achieved through wider discussion with drilling expertise across UK and Ireland, especially with drilling companies who operate in similar geological settings. Key issues to resolve include the drilling methodology that can be adopted in the predominately hard-standing ground (i.e. carparks) where multi-borehole schemes would most likely be implemented on the site, and the requirement to manage groundwater encountered in superficials /bedrock during drilling, with no viable permitted discharge route for drill flush water. This should be the subject of further work.
- Final design needs to optimise the thermal benefits of deeper boreholes with double U-tubes against the cost and operational complexities of drilling wider diameter and deeper. Preliminary investigation suggests this may be boreholes of between 100 and 150m with double U-tubes but this should be the subject of further investigation.

4.0 Geothermal Resource Assessment

4.1 Introduction

It was originally believed that both open-loop and closed loop geothermal solutions would be applicable at the site and could be assessed in preliminary designs. However, as described above, the Sherwood Sandstone bedrock sequence (main aquifer) was found to be thin and weathered across the site. The local hydrogeological setting is more complex than anticipated with less knowledge of Permian bedrock hydrogeological properties and with the presence of igneous intrusions confirmed in several boreholes. Consideration of an open-loop system has therefore not been taken forward as part of this assessment, however as mentioned earlier, yield testing of one of the investigation boreholes (EB3) did indicate a relatively high volume of groundwater could be abstracted, at least at that location (possibly associated with the influence of faulting/intrusion) and as such open loop remains an option, albeit one requiring further investigatory work to confirm viability.

For closed-loop, operational issues delayed completion of a Thermal Response Test (TRT) in the final drilled borehole (EB5) until very late in the overall project cycle. As such it was necessary to complete assessment of the likely heating yield from a closed loop borehole array based solely on the encountered stratigraphic section and in conjunction with published thermal property parameters for those lithologies (rather than parameters derived from in-situ testing). The following sections of this report are therefore based upon the published thermal parameters. Updated results derived from the TRT are included as Appendix C. .

4.2 Closed-Loop Thermogeological Parameters

4.2.1 Introduction

The principal thermogeological parameters that are required to design a ground source heating scheme (and cooling where applicable) are as follows:

- Annual average soil temperature. This is typically slightly in excess of annual average air temperature under natural conditions. In urban areas, heat loss through cellars, poorly insulated floors and buried services can elevate the ground temperature significantly down to depths of 50m or more.
- Geothermal heat flux. In conjunction with thermal conductivity, this allows one to assess the rate at which ground temperature increases with depth.
- Ground thermal conductivity (λ). This is measured in W/m/K and describes how efficient the ground is at transferring heat by conduction. It varies within a rather narrow range. In a UK

context, a thermal conductivity of less than 1.7W/m/K might be considered rather poor. A conductivity in excess of 2.5 W/m/K would be considered relatively good.

- Ground volumetric heat capacity (SVC). This describes how good the ground is at storing heat and is typically in the range 1.9 to 2.5MJ per m^3 per °C ($MJ/m^3/K$) for saturated sediments/rocks. In other words, if SVC = 2 $MJ/m^3/K$, then 2 million Joules of heat can be released by dropping the temperature of $1m^3$ of ground by 1°C.
- Thermal diffusivity (α) is defined as the ratio between thermal conductivity and volumetric heat capacity and is measured in m^2/s or m^2/d.

4.2.2 Ground Temperature

The average annual air temperature in Dundonald (2001-2012) is reported as c. 9.7°C[3]

Maps of annual average soil temperature (1981-2010) provided by the Meteorological Office suggest that the estimated annual mean soil temperature at 30cm depth is just over 10°C. A value of 10.2°C is therefore assumed for this study.

4.2.3 Geothermal Heat Flux

The British Geological Survey's heat flow database (Busby 2014) projects a rather low average geothermal heat flux of 60-70mW/m^2 at Dundonald (best estimate c. 62mW/m^2).

4.2.4 Thermal Conductivity

Upon completion of the drilling programme, a theoretical 200m depth closed loop borehole heat exchanger was modelled assuming a stratigraphic sequence based on drilled averages:

- 1m glaciofluvial sand / gravel (unsaturated)
- 27m glaciofluvial silt/sand / gravel – Till - (saturated)
- 172m Permo-Triassic. Sherwood Sandstone, Permian Belfast & Enler Groups (marl/sandstone/breccia)

As regards thermal conductivity of the superficial deposits, Blomberg et al. (2019) recommend:

- Sand (moist) 1.0 W/m/K (range 0.58 to 1.75 W/m/K)
- Sand (saturated) 2.4 W/m/K (range 1.73 to 5.02 W/m/K)
- Gravel (saturated) 1.8 W/m/K
- Boulder clay (till) 2.0 W/m/K (range 1.0 to 2.5 W/m/K)

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[3] https://en.climate-data.org/europe/united-kingdom/northern-ireland/dundonald-27719/

Rollin (1987) suggests the following values of thermal conductivity of the bedrock geology:

- Sherwood Sandstone Group sandstone 3.41 ± 0.09 W/m/K (N=64)
  Rollin (1987) also lists 8 samples characterised as Bunter Sandstone (which is now also part of the Sherwood Sandstone Group) with a lower thermal conductivity of 2.54 ± 0.07 W/m/K (N=8)
- Sherwood Sandstone Group mudstone 2.37 ± 0.23 W/m/K (N=6)
- Permian marl 2.12 ± 0.28 W/m/K (N=6)

Blomberg et al. (2019) recommend:

- Sandstone 2.3 W/m/K (range 1.28 to 5.10 W/m/K)
- Breccia 2.8 W/m/K (range 2.26 to 4.11 W/m/K)
- Marl 2.1 W/m/K (range 1.75-3.36 W/m/K)
- Dolerite is assumed to be 1.8 W/m/K (midway between the values for basalt and gabbro).

For the expected stratigraphy in a 200m closed loop borehole at the Stormont Estate, Table 4 shows a conservative best estimate = 2.49 W/m/K (thickness-weighted arithmetic mean) for overall thermal conductivity.

Table 4 Best estimate of composite thermal conductivity and volumetric heat capacity values for the strata expected to be encountered in a 200 m closed loop borehole at Stormont.

Formation	Thickness (m)	Thermal Conductivity (W/m/K)	Volumetric Heat Capacity (MJ/m3/K)
Unsaturated sand/gravel	1	1.00	1.60
Till	27	1.97	2.20
Permian Enler Group	172	2.58	2.17
Weighted mean	**200**	**2.49**	**2.17**

4.2.5 Volumetric Heat Capacity

Similarly, Blomberg et al. (2019) provide generic data for a variety of rock types. Those of relevance to the geology of the site are as follows:

- Sand (moist) 1.8 MJ/m^3/K (range 1.23 to 2.22 MJ/m^3/K)
- Sand (saturated) 2.5 MJ/m^3/K (range 2.20 to 2.86 MJ/m^3/K)
- Gravel (saturated) 2.4 MJ/m^3/K (range 2.28 to 2.88 MJ/m^3/K)
- Boulder clay (till) 2.1 MJ/m^3/K (range 1.51 to 2.45 MJ/m^3/K)
- Clay (moist-wet) 2.4 MJ/m^3/K (range 1.6 to 3.4 MJ/m^3/K)

- Sandstone (saturated) 2.0 MJ/m^3/K (range 1.56 to 2.78 MJ/m^3/K)
- Marl 2.3 MJ/m^3/K (range 2.0 to 2.57 MJ/m^3/K)
- Till 2.0 MJ/m^3/K (range 1.0-2.5 MJ/m^3/K)

For the expected stratigraphy in a 200m closed loop borehole at the Stormont site this results in a conservative best estimate = 2.17MJ/m^3/K (thickness-weighted arithmetic mean) for overall volumetric heat capacity (Table 4).

4.3 Thermal Response Test

Following on from the preliminary modelling which used published literature values for strata thermal properties, site specific data became available from Thermal Response Testing completed at borehole EB5 at the end of March 2025. This returned a value of 2.44 W/m/K for thermal conductivity and 0.083m^2/day for thermal diffusivity allowing calculation of volumetric heat capacity at 2.54 MJ/m^3/K. This test data therefore showed a higher thermal diffusivity[4] and is thus more positive with respect to developing a closed loop scheme at Stormont. The TRT test report is provided at Appendix A and revised modelling outputs are included at Appendix C.

4.4 Ground Energy Estimates Closed Loop

4.4.1 Heating Loads

Energy consumption data for five of the buildings on the Stormont site were available for this study[5]. (Stormont Energy Report, Chang, 2024). The main energy source is gas and gas use was taken as a proxy for heating energy use. Gas usage in individual buildings range up to 3800MWh/annum for the Castle Buildings with annual gas consumption estimated at 7200MWh/annum for all five

To establish the feasibility of using closed loop geothermal for the identified heating loads (and prior to the TRT) two initial models were constructed:

- The heating load that could be supported by a single closed loop borehole drilled to a depth of 200m through a geological section (superficials and bedrock) with parameters established in the recent drilling campaign.
- The heating load that could be supported by a small array of 30 No closed loop boreholes drilled to a depth of 200m through the same geological sequence.

The models have been constructed using Earth Energy Designer (EED) BHE design software V4.20. (Blomberg et al. 2019). Key modelling assumptions include:

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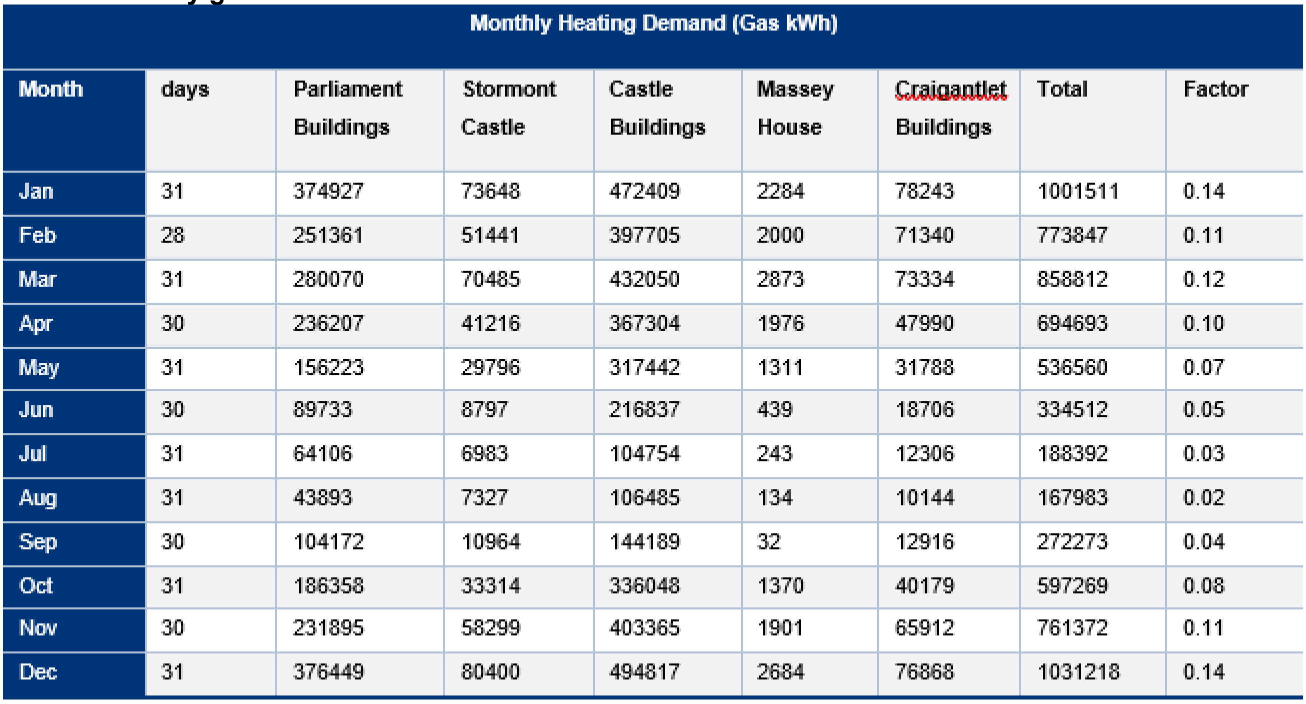
[4] Thermal Diffusivity is equal to thermal conductivity divided by the product of volumetric heat capacity and rock density

[5] Parliament Buildings, Stormont Castle, Castle Buildings, Massey House and Craigantlet Buildings

- heating loads are for up to approximately 2200 FLEQ (full load equivalent hours) per annum;
- peak thermal output demand is the annual heating demand divided by the FLEQ;
- the annual heating demand is distributed monthly according to data provided in the Stormont Estate Energy Report (2024) and documented in Section 5.2 of this report.

A monthly factor which represents the average percentage of energy used across the site in any specific month has been calculated based on that distribution to spread heating loads for the models using this data. These factors are documented in Table 5 below:

Table 5 Distribution of heating load for buildings at Stormont. "Factor" is the fraction of total annual demand for any given month.



Monthly Heating Demand (Gas kWh)								
Month	days	Parliament Buildings	Stormont Castle	Castle Buildings	Massey House	Craigantlet Buildings	Total	Factor
Jan	31	374927	73648	472409	2284	78243	1001511	0.14
Feb	28	251361	51441	397705	2000	71340	773847	0.11
Mar	31	280070	70485	432050	2873	73334	858812	0.12
Apr	30	236207	41216	367304	1976	47990	694693	0.10
May	31	156223	29796	317442	1311	31788	536560	0.07
Jun	30	89733	8797	216837	439	18706	334512	0.05
Jul	31	64106	6983	104754	243	12306	188392	0.03
Aug	31	43893	7327	106485	134	10144	167983	0.02
Sep	30	104172	10964	144189	32	12916	272273	0.04
Oct	31	186358	33314	336048	1370	40179	597269	0.08
Nov	30	231895	58299	403365	1901	65912	761372	0.11
Dec	31	376449	80400	494817	2684	76868	1031218	0.14

4.4.2 Single Vertical BHE

A TRT on a single 40mm loop was completed at EB5, which was drilled to 118m BGL. For the purposes of this modelling, it has been assumed that, for the efficiency of any implemented scheme and due to overall available space limitations, boreholes would be drilled deeper. As such the thermal modelling assumes a 200m borehole depth, with a double rather than single U-tube heat exchanger.

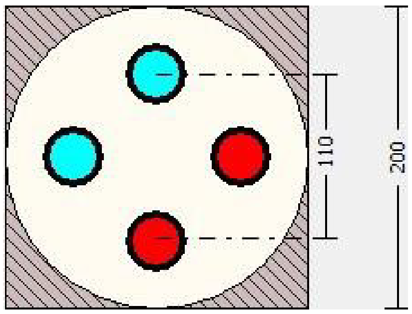
Further review of borehole design and costings will be required to make sure that it is achievable and economically efficient to install the double-U heat exchangers to such depth.

EED does not allow consideration of the fact that some of the upper section of the borehole will be cased and grouted with a non-thermally enhanced grout. This has the potential to impair the thermal efficiency of the borehole. This will lead to a slightly higher borehole thermal resistance than is simulated below and hence slightly lower thermal yields than the simulations predict. The exact influence will be dependent upon the length of the borehole section cased, whether shallow groundwater is present, the nature of the casing and nature of surrounding strata and is difficult to accurately assess.

The simulation makes the following assumptions

- Ground surface temperature 10.2°C – Section 4.2.2
- Geothermal heat flux 0.062 W/m² - Section 4.2.3

- Ground thermal conductivity 2.49W/m/K - Section 4.2.4
- Ground heat capacity 2.17 MJ/(m^3·K) – Section 4.2.5
- Borehole depth 200m
- Borehole diameter 200mm
- Grout thermal conductivity 1.5W/m/K
- Double U-tube 40mm, SDR 11 HDPE pipe
- Shank spacing 110mm
- Fluid flow rate 0.65L/s per borehole[6]
- Heat transfer fluid: 25% monoethylene glycol[7]
- Contact resistance grout-to-pipe 0.01Km/W (recommended by EED manual)
- Coefficient of performance COPH 3.5 (in heating mode)[8]



EED generated section of borehole, showing assumed 200 mm diameter and double tube with 110 mm shank spacing (blue downflow, red upflow).

Model simulation period has been set to 30 years, starting in January.

The models have been run to meet the Microgeneration Certification Scheme (MCS2017, 2021a) criterion that the return fluid temperature to the heat pump should stabilise and not fall below 0°C. A typical heat pump might extract around 3K of temperature from the heat transfer fluid. Thus, with a loop return temperature of 0°C, the loop entry temperature would be -3°C and the average fluid temperature (seen at the surface) would be -1.5°C. As EED simulates the average (of flow and return) fluid temperature, this equates to -1.5°C as the minimum fluid temperature value.

Using the defined parameters in EED version 4.2, it is estimated a 200 m borehole will sustain a heat output of 15 kW at 2200 FLEQ per year for a period of at least 30 years, with a maximum continuous peak load duration of 10 hr/day, without the average fluid temperature under peak load

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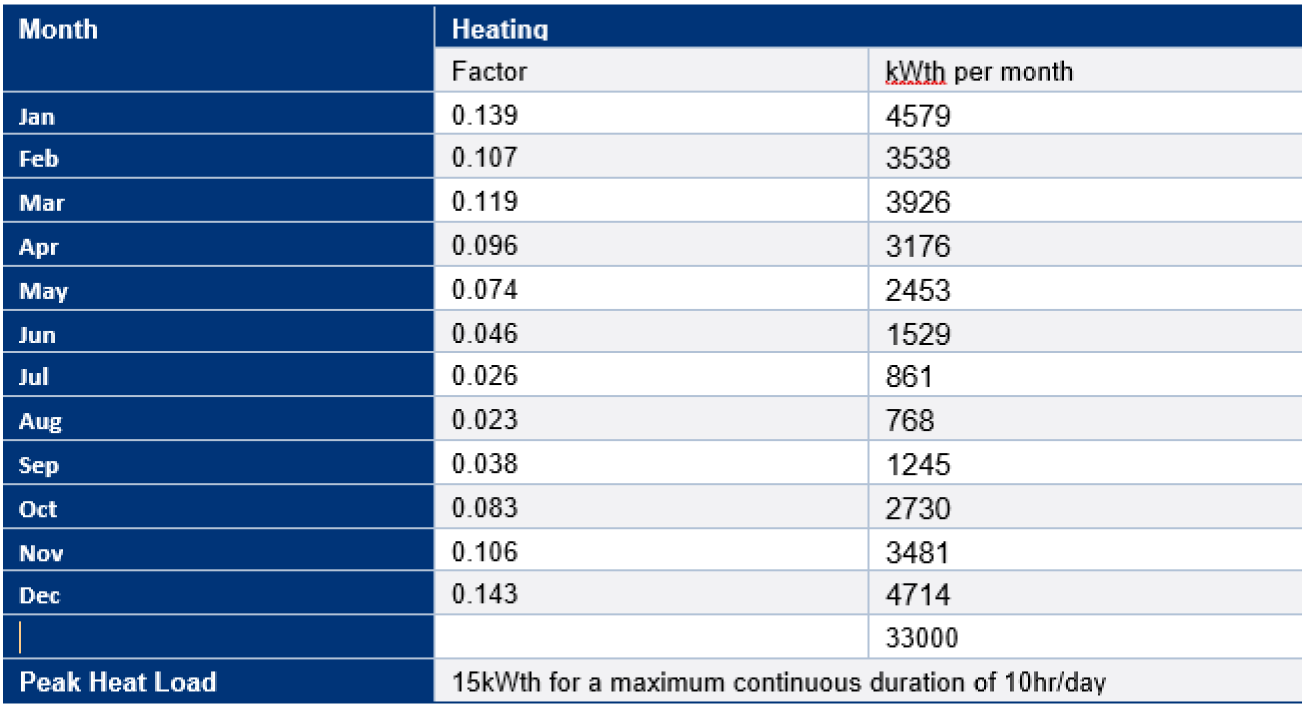
[6] sufficient to give a Reynolds Number > 2500 – i.e. transient turbulent flow

[7] This should not be construed as a recommendation. The final selection of the heat transfer fluid should be based on considerations of viscosity, density, necessary frost protection, cost and – importantly – toxicity and acceptability to NIEA. The 25% glycol gives a nominal frost protection to -14°C

[8] EED only allows a single COPH to be entered, which also functions as a the seasonal performance factor (SPFH), which is a slight weakness in the EED program. A moderately conservative (high) value has been assumed for a closed loop system.

conditions falling below -1.5°C (Figure 7). This equates to an annual heat supply of 33.0 MWh/yr (Table 6).

Table 6 Monthly heat demands predicted to be supported by a 200 m deep BHE heat exchanger at Stormont (assumptions listed in Section 4.4.1), with a peak output of 14.0 kW, an assumed (constant) COPH of 3.5, and a peak load continuous duration not exceeding 10 hours. The "profile" represents the data supplied in the Stormont Estate Energy Report (2024)



Month	Heating	
	Factor	kWth per month
Jan	0.139	4579
Feb	0.107	3538
Mar	0.119	3926
Apr	0.096	3176
May	0.074	2453
Jun	0.046	1529
Jul	0.026	861
Aug	0.023	768
Sep	0.038	1245
Oct	0.083	2730
Nov	0.106	3481
Dec	0.143	4714
		33000
Peak Heat Load	15kWth for a maximum continuous duration of 10hr/day	

The peak heat delivery is 15.0kW. This equates to a peak heat extraction of 10.7kW from the ground or 53.5W/m of drilled borehole. Around 32.4MWh heat are extracted from the ground each year (all this assumes a COPH of 3.5).

The calculated Reynolds Number is 2568 (which gives the required transient-turbulent flow for optimal heat transfer). The effective borehole thermal resistance is calculated as 0.0865 Km/W.

The fluid temperatures, under base load conditions, tend to remain within the range +3.5 to +11°C. Under peak load conditions, which are assumed to be approximately 10 hrs of continuous duration on the coldest day, minimum fluid temperature declines from around -0.3°C in year 2 to -1.47 in year 30 (Figure 7).

After year 30, the fluid temperatures have approximately stabilised (although they are, in fact, very slowly still declining). EED takes no account of the influence of groundwater flow through the strata, the effects of which will be to stabilise temperatures towards a steady state. If we allow for a modest influence of groundwater flow, it seems reasonable to assume that a steady state will have been reached within 30 years.

The heat profile supported in this simulation is given in Table 6.

4.4.3 Single Borehole Sensitivity Analysis

While the optimised borehole / heat exchange design might require boreholes as deep as 200m, as described above, drilling to this depth was not undertaken in the investigation phase. In consequence a series of model sensitivities have been run to look at the influence of drilling shallower and/or narrower diameter boreholes. The basic design above is a borehole 200m deep with a 200mm diameter containing a double U-tube heat exchanger. Alternatives have been run at 150m and 120m, with a 160mm diameter and with only a single U-tube heat exchanger (the last consistent with the EB5 test). Table 7 shows a summary of the results.

Table 7 Results of sensitivity analysis for thermal yield of a single borehole versus borehole depth, borehole diameter and U-tube loop number.

Depth (m)	Diameter (mm)	U-tube configuration	Peak output (kW)	Annual output (MWh/annum)
200	200	double	15	33
200	160	double	14	32
200	160	single	12	28
150	160	Double	11	25
120	160	single	7	15

The data demonstrate that a single shallow/narrower borehole with only a single U-tube might have less than half the output of that in the base model. While it is possible a future implementation project might be restricted to these lower yields, taking into account the heat demands and the practical limitations on available space where such schemes could be implemented on the Stormont Estate, the thermal energy gains from the deeper boreholes warrant definite consideration. Future design work should assess the economics of the project and establish whether deeper boreholes can be reliably, and cost effectively drilled to deliver the higher thermal yields.

4.4.4 Borehole Hydraulics

The borehole design needs to be hydraulically efficient as well as thermally efficient otherwise excessive energy is used running the pumps to circulate the fluid. Flow rate should be sufficient to generate turbulent flow giving a Reynolds number in excess of 2500.

To achieve this, the flow rate (for each borehole) is set at 0.65l/s, and for the modelled 200m double loop borehole (400m total pathway) this gives a Reynolds Number of 2568.

MCS guidelines (MCS 2019, 2021c) suggest that the total circulation pumping power should not exceed 2.5 % of the total thermal output of the system.

The pump power requirement (P) is given by:

$$P \quad (Q^{*}\Delta P)/\eta$$

Where: Q= flow rate (m3/sec), Δ*P*= Pump Pressure (Watts) and η= pump efficiency (decimal).

Pressure losses have been derived from MCS charts (Figure 8) which provide a figure of 0.32kPa/m or 128kPa and this generates a parasitic pumping load of 139W (Table 8).

Table 8 Borehole Hydraulics (single borehole, 200m x200mm double-U tube)

P= (Q*ΔP)/η		Stormont Single Borehole
P	Pump Pressure (Watts)	139
Q	Flow rate (m3/sec)	0.00065
ΔP	Pressure drop in Pascals	128000
η	Pump efficiency (decimal)	0.6

The borehole is modelled as having a peak capacity of 15.0 kW, and its parasitic pumping load is less than 1%, well within MCS guidelines.

4.4.5 Multiple vertical BHE arrays – heating only

Closed loop ground source heat is, to a large extent, a scalable technology provided adequate distance is maintained between boreholes. Arrays of multi-borehole closed loop BHE could be drilled across the Stormont Estate to satisfy a given heating (or cooling) load. As an example, a simulation has been constructed of an array of 30 No., 200m deep, 200mm diameter boreholes (with a double 40mm OD U tube, as above). The modelled layout assumes a 3 x 10 grid spaced at 12m.

If a single 200m borehole is estimated to yield 15kWth peak at 2200 FLEQ, it might be predicted that a 30 No borehole array might yield 450kWth. However, due to thermal interference, the 3 x 10 array of 30 No boreholes can only support 250kWth at 2200FLEQ (=550MWh/a) for a 30-year period, without the average fluid temperature falling below -1.5 (Figure 9).

The peak specific heat extraction has now fallen to 41.7W/m). This is because of the thermal interference within the multiple borehole array. It is also important to note that, after year 30, the borehole (at least in the absence of groundwater flow) has not reached a steady state and temperatures are still falling (Figure 9). If we extend the simulation to 50 years, the average fluid temperature would theoretically fall to - 2.18°C.

In fact, it turns out that, to keep fluid temperatures within acceptable limits (average >-1.5°C) for a 50-year period, the output would need to be reduced to 240kWth (=520MWhth/a at 2200 FLEQ), representing a peak extraction rate of 40.0W/m (Figure 10). Even after 50 years, equilibrium has not been fully reached. At some stage, it might be advisable to investigate this further through modelling with FEFLOW[9] to understand the influence of groundwater flow through the array and the degree to which this will assist with the system reaching thermal equilibrium.

4.4.6 Borehole Array Sensitivity Analysis

In parallel with the sensitivity analysis completed for the single borehole, a similar analysis was completed for the borehole array. The purpose of this modelled array is to provide a known 550MWh heat yield at up to 250kW, therefore instead of looking at reductions in thermal yield for a 30 No borehole array, this analysis established the increased number of shallow/slim boreholes required to deliver that same thermal output. The results are summarised in Table 9.

Table 9 Results of sensitivity analysis for thermal yield of a modelled borehole array versus borehole depth, borehole diameter and U-tube loop number.

Depth (m)	Diameter (mm)	U-tube configuration	Peak output (kW)	No. of boreholes required
200	200	double	250	30
200	160	double	250	30
200	160	single	250	33
150	160	double	250	39
120	160	single	250	65

The analysis demonstrates again that the shallow/slim borehole designs may require more than twice the number of boreholes to deliver the same thermal yield although depth is clearly the critical factor with the small diameter difference having negligible impact. Top balance the greater difficulty in drilling the deeper boreholes against the potential for positive variation due to groundwater flow a likely borehole array to meet this 550MWH load might therefore require between 25-40 boreholes.

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[9] FEFLOW is advanced groundwater modelling software that simulates groundwater flow including heat transport

5.0 Heat Utilisation

5.1 Introduction

Whilst the site investigation and this assessment provide an indication of the energy that can be extracted from the ground on the Stormont site, the feasibility of a geothermal scheme must also address distribution of the heat energy to the target buildings. A Heating Network Feasibility Study was commissioned and carried out by Hoare Lea (Tetra Tech Company) in December 2024 to better understand the viability of utilising geothermal energy to serve the heating demands of five selected significant buildings within the Stormont Estate:

- Parliament Buildings,
- Stormont Castle,
- Massey House,
- Craigantlet Buildings,
- Castle Buildings.

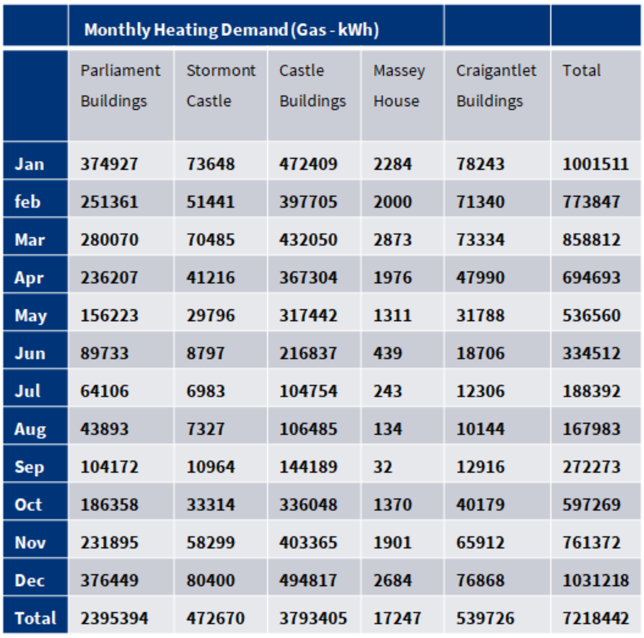
The primary objective of this study (Hoare Lea, 2024) was to evaluate the energy performance of these buildings and explore the potential for developing a Ground Source District Heating network to improve their efficiency.

5.2 Heating Demand

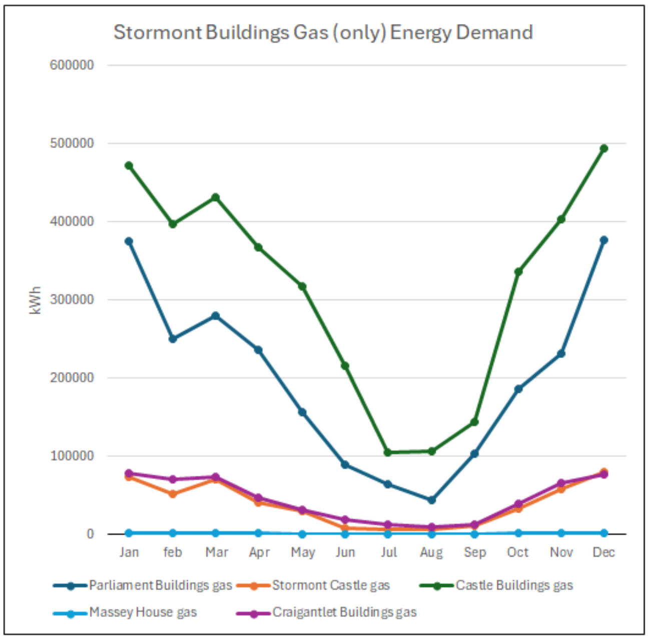
5.2.1 Monthly Gas (Heating) Demand

Table 10 below outlines a summary of the expected annual heat loads for the selected main energy using buildings on the Stormont Site.

Table 10 Stormont Monthly Usage.



	Monthly Heating Demand (Gas - kWh)					
	Parliament Buildings	Stormont Castle	Castle Buildings	Massey House	Craigantlet Buildings	Total
Jan	374927	73648	472409	2284	78243	1001511
feb	251361	51441	397705	2000	71340	773847
Mar	280070	70485	432050	2873	73334	858812
Apr	236207	41216	367304	1976	47990	694693
May	156223	29796	317442	1311	31788	536560
Jun	89733	8797	216837	439	18706	334512
Jul	64106	6983	104754	243	12306	188392
Aug	43893	7327	106485	134	10144	167983
Sep	104172	10964	144189	32	12916	272273
Oct	186358	33314	336048	1370	40179	597269
Nov	231895	58299	403365	1901	65912	761372
Dec	376449	80400	494817	2684	76868	1031218
Total	2395394	472670	3793405	17247	539726	7218442



The monthly gas usage data for the five buildings shows distinct seasonal variations throughout the year. Castle Buildings consistently records the highest gas consumption, peaking at nearly 500,000kWh in January and December. Its usage drops significantly during the warmer months, reaching the lowest point in July and August at just over 100,000kWh.

Similarly, Parliament Buildings also exhibits high gas consumption in the colder months, particularly in January (around 375,000kWh) and December (over 370,000kWh), while usage decreases steadily from February through August, hitting a low in June and July.

Stormont Castle, Craigantlet Buildings, and Massey House demonstrate lower overall gas usage compared to the two larger buildings. Stormont Castle shows a peak in January at around 73,000kWh, with a dip in midyear, followed by a gradual increase towards the end of the year. Craigantlet Buildings have a consistent pattern, with the highest consumption in January (around 78,000 kWh) and December (76,000kWh), but much lower usage during the summer months. Heating in much of Massey House is electrical and this shows minimal gas usage across the year, peaking at only 2,284kWh in January and falling below 500kWh during the summer.

In summary, and as expected gas consumption across all buildings is highest during the colder months (January, February, November, and December), likely due to the increased heating demand during these months, and lowest in the summer months (June, July, and August), when demand for heating decreases. Castle Buildings and Parliament Buildings are the largest consumers of gas, while Massey House consumes the least.

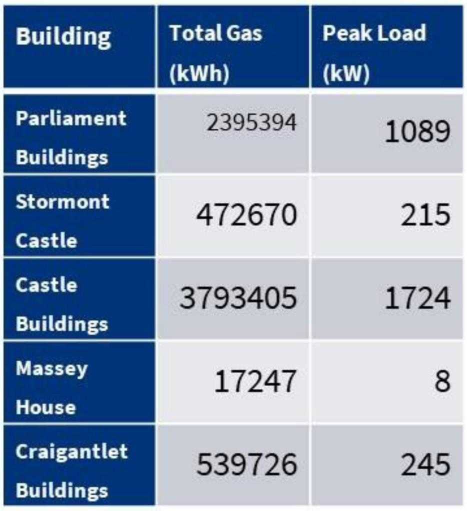
5.2.2 Peak Gas (heating) demand

Table 11 below summarises the total annual gas consumption (in kWh) and the peak load (in kW) for the five buildings. The peak load values are based on a full-load equivalent (FLEQ) of 2200 hours per year. This FLEQ represents the number of hours that each building operates at its peak capacity in a given year.

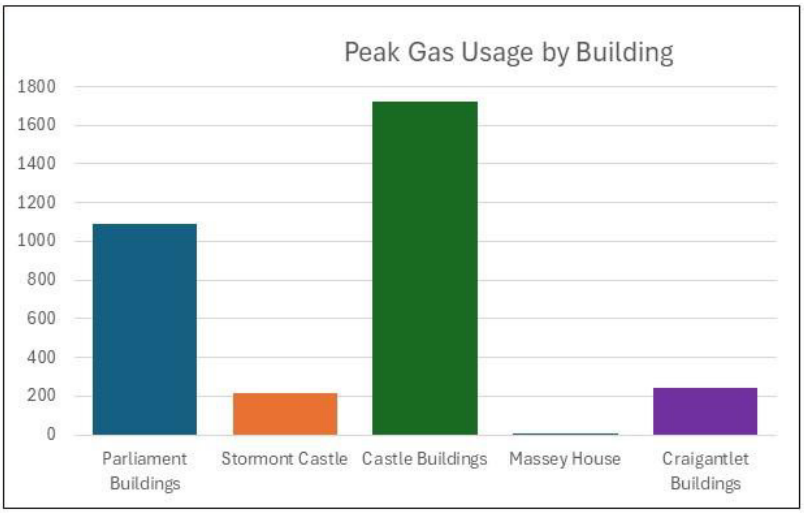
FLEQ, or Full Load Equivalent Hours, is a metric used to standardise and quantify the energy consumption of a system. It represents the total number of hours a system or piece of equipment would have to operate at full load (or maximum capacity) to consume the same amount of energy as it actually did under varying load conditions during a given period.

In essence, FLEQ allows for an apples-to-apples comparison of energy usage or operational workload by converting variable usage patterns into an equivalent "full load" measurement. This can help identify inefficiencies and optimise performance.

Table 11 Peak Gas Usage



Building	Total Gas (kWh)	Peak Load (kW)
Parliament Buildings	2395394	1089
Stormont Castle	472670	215
Castle Buildings	3793405	1724
Massey House	17247	8
Craigantlet Buildings	539726	245



1. Castle Buildings has the highest annual gas consumption at 3,793,405kWh, with a corresponding peak load of 1,724kW. This indicates that the building operates at a high demand throughout the year, with the peak load reflecting its operational intensity.
2. Parliament Buildings follows with 2,395,394kWh in total annual gas usage and a peak load of 1,089 kW. The peak load, calculated from the FLEQ of 2200 hours, suggests that the building's energy demand is substantial but lower than that of Castle Buildings.
3. Craigantlet Buildings consumes 539,726kWh of gas annually, and its peak load is 245kW. Although its gas consumption is relatively lower than the larger buildings, the peak load still indicates notable energy demands when the building operates at full capacity.
4. Stormont Castle has a total annual gas usage of 472,670kWh and a peak load of 215kW, reflecting moderate consumption and peak operational demands.

5. Massey House has the smallest gas consumption at 17,247kWh per annum, with a minimal peak load of 8kW. This low value aligns with the building’s small energy demands and lower operational requirements.

5.3 BHE Array Sizing

Borehole arrays can be scaled to meet the various heating loads. As an example, the heat load demand at Craigantlet Buildings (540MWh) can be met by the installation of the 30 No borehole (3x10 layout at 200m depth) 250 kW array described in Section 4.4.6. and this could fit (space-wise) comfortably within the northern section of the car park for Dundonald House (Figure 11)[10]. The proposed array design lies perpendicular to what is understood to be groundwater flow direction (NE to SW) which should improve the efficiency of a system installed in this location and may allow for subsequent connection of the minor load from the adjacent Massey House. Further efficiency gains could be generated by operating the system in cooling mode when required by the building demand which would stabilise (warm) the ground temperatures ahead of the longer winter heating demands.

At larger scale, EED modelling suggests that it is possible to meet the heating loads of Stormont Castle, the Castle Buildings, Massey House and the Craigantlet Buildings from a combination of 3 No. separate arrays constructed in the main car parks around and between those buildings (Figure 12). To meet this load would involve drilling more than 300 No x 200m deep boreholes (based on Permian thermal parameters) but is potentially replacing a gas load of >4800MWh per annum. With less space available in the north of the Stormont site, an array installed in the main visitor's car park for Parliament Buildings would supply up to 42% of the 2400MWh/annum heating load from a 63 No borehole array. (Figure 13). In total, 4 No. BHE arrays (as modelled) located only within available existing car park areas, could meet more than 80% of the site energy demand.

It should be noted that these arrays have all been modelled as simple rectangular grid layouts and the adoption of more complex configurations would impact the thermal interference between boreholes and that the resulting heat output would vary in detail. This impact could be positive or negative. An extended rectangular array might generate less interference and therefore a higher heat yield whereas a denser square grid would potentially have higher interference and therefore a lower yield. This nevertheless gives an indication of the number of boreholes required to build arrays capable of meeting the sites heating loads.

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[10] [10] Designs have been revised following the TRT and with feedback from DfE. Updated results are included at Appendix C and include a similar smaller array that could be tested at Stormont Castle.

It should be stressed again that there is still uncertainty around any final recommendation on borehole array configuration. It is known that groundwater flows from NE to SW across the site, this should improve thermal yield per borehole but on the downside and as described in section 4.6.6, sensitivity analysis suggests that if any future implementation were restricted to drilling shallower/narrower boreholes with only single U-tube loops this would reduce the thermal yield. In the latter case and as implementation is likely to be restricted to existing car park areas, additional boreholes may not be possible so overall yields would reduce. In the examples illustrated here, yield might be reduced to about 40% of energy demand of the entire site (50% in the southern area and perhaps 20% of the Parliament Building load).

5.4 Heat Network

A heat network has been designed to investigate the possibility of linking the borehole arrays to all the main buildings at Stormont. It will comprise a buried pre-insulated flow and return pipework network linking the borehole site(s) to the following main demand centres via a central energy centre:

- Parliament Buildings
- Stormont Castle
- Castle Buildings
- Massey House
- Craigantlet Buildings

5.4.1 Proposed Borehole Sites

This concept has been developed to determine the required areas for a closed borehole array based on the following assumptions:

- Replacing gas load only.
- Array design has been based on the load data detailed in Section 4.
- 12m borehole spacing.
- 200m double U pipe.
- Permian thermal parameters
- Load distribution data based upon existing Stormont energy use.

It has been further assumed that the closed-loop borehole arrays will need to be located beneath the main Stormont site car parks as described above. Figure 14 shows these areas as well as other potential sites that could provide additional capacity if this was required at a later date. The areas are tabulated below (Table 12). Detailed array layouts (depth and borehole number) can be updated once thermal parameters are confirmed and heating demand and network design are finalised.

Table 12 Areas of potential sites for closed-loop arrays

Main Car Parks	Area (m^2)
Parliament Visitors Car Park	7521
Castle East	12026
Massey West	12014
Dundonald East	11271
sub-total	42832
Other Car Parks	
Criminal Justice	929
Sports	1982
Stormont Castle	483
Stormont Castle 2	2461
Stormont Castle 3	857
Dundonald South	587
Dundonald West	3691
Orangerie Overflow	1334
sub-total	12324
Other Areas	
Stormont - Empty Site	1923
Stormont Lawn	3794
N. Stormont Verge	1264
Castle Building Lawns	8402
Dundonald Lawns	3467
sub-total	18850
TOTAL	**74006**

5.4.2 Heat Network Pipework Layout

Due to the location and layout of the borehole array locations relative to the heating demands of the site, it was deemed appropriate to focus on an Ambient Loop District Heat Network.

An Ambient Loop District Heat Network is a highly efficient, low-carbon system for distributing thermal energy across multiple buildings or zones. It operates using a central network of insulated pipes that circulate water at near ground or ambient temperature, typically between 10°C and 25°C, depending on the season and local conditions.

The system works in conjunction with individual heat pumps located at each connected building or facility. These heat pumps extract energy from the ambient loop and elevate it to the desired temperature for heating and / or domestic hot water, based on the specific needs of the end user.

Key features of an ambient loop district heat network include:

- Low Distribution Temperatures
- Reduced heat loss compared to high-temperature networks, improving overall efficiency.
- Enables integration with renewable energy sources like ground-source or water-source heat pumps, solar thermal systems, or waste heat recovery.

Decentralised Temperature Control

- End users manage their heating needs independently, enhancing flexibility and comfort.
- Supports diverse building types, within a single network.

Energy Source Versatility

- The loop can draw energy from various sustainable sources, including aquifers, rivers, or geothermal boreholes. This adaptability supports low-carbon and renewable energy goals.

Future-Proof Design

- Easily integrates with existing infrastructure, such as retrofitted buildings, or expands to serve new.
- Further additional Developments without extensive redesign.
- Compatible with future innovations in energy generation and storage.

Cost and Carbon Savings

- Centralised ambient temperature distribution reduces energy losses.
- Shifts heating and cooling loads to electricity, facilitating decarbonisation as the electricity grid become greener.

Ambient loop systems are particularly suited to mixed-use developments, where the demand for heating and cooling may offset each other. For example, waste heat from cooling systems in offices can be reused for heating in residential units, maximising resource efficiency.

This modern approach to district heating and cooling contributes significantly to sustainable urban development, offering scalable, resilient, and energy-efficient solutions.

A concept system schematic of the heat network is presented at Appendix B and a network layout map shown on Figure 15.

5.4.3 Pipe Work Options

Outlined below (Table 13) is a summary options appraisal for the key district heating pipework material / manufacturer considering the main plastic and steel pipework options.

The twin carrier pipe steel options are known to require additional civils trenching works as the pipework is fully rigid, this option has therefore been excluded from further discussion within this report.

It is expected that the PPSL series 3 system or similar product would provide a suitable balance between installation costs and limiting pipework heat loss.

Table 13 Pipework Options Comparison

Type		PPSL Series 1 Single	PPSL Series 3 Single	PPSL Series 1 Twin	PPSL Series 3 Twin	FlexAllen Plastic
Material		Carrier Pipe = Welded Steel. Insulation to be - Polyurethane. Outer Casing - HDPE	Carrier Pipe = Welded Steel. Insulation to be - Polyurethane. Outer Casing - HDPE	Carrier Pipe = Welded Steel. Insulation to be - Polyurethane. Outer Casing - HDPE	Carrier Pipe = Welded Steel. Insulation to be - Polyurethane. Outer Casing - HDPE	Carrier Pipe - Polybutylene Insulation to be - Polyethylene extruded foam bonded to the casing or Polyurethane Outer Casing to be - Black Polyethylene (HDPE)
Pressure & Temperature Rating		25 Bar, Continuous Operation to 140 oC	25 Bar, Continuous Operation to 140 oC	25 Bar, Continuous Operation to 140 oC	25 Bar, Continuous Operation to 140 oC	8.0 Bar working pressure at 95oC, (Reduced life expectancy when temperature and pressure elevated and under 365 24/7 operation)
Heat Loss (W/m @75°C)	DN20	7.96	6.21	5.69	4.95	As per EN 15632. Manufacturer to confirm w/m
	DN25	9.77	7.26	6.26	5.24	
	DN32	9.97	7.94	6.85	5.75	
	DN40	11.52	8.89	8.49	6.78	
	DN50	12.90	9.65	8.07	6.56	
	DN65	15.27	10.87	9.98	7.85	
	DN80	15.74	11.53	11.84	8.67	
	DN100	16.46	11.94	11.72	8.54	
	DN125	19.18	13.41	10.38	7.91	
	DN150	22.88	14.82	13.43	9.61	
	DN200	28.38	17.80	17.87	9.95	
Approximate Basic Pipework Install Cost Excl. civils & trenching & commissioning		~£471/m	~£509/m	~£528/m	~£571/m	~£407/m

6.0 Costings

There are two principal components to a geothermal heating system for the Stormont site: 1) the boreholes (and borehole arrays) that provide the heat and 2) the network that distributes this to the existing buildings. Modifications to the internal systems within any of the buildings are not within the scope of this work.

6.1 Boreholes and borehole arrays

Designs and costs for the boreholes and borehole arrays have been updated based upon the outcome of the TRT. These are included at Appendix C, although there should also be further consideration of drilling techniques and analysis of the benefits of drilling deeper boreholes to access more heat per borehole. This optimisation of drilling design should be undertaken with contribution from possible drilling contractors.

6.2 Heat Network

Results of an Initial budgetary costing exercise has been undertaken for the heat network and is shown below (Table 14).

Table 14 Heat Network Approximate Cost Estimate

Location	Item	Cost	Cost Data Source
Central Heat Network Energy Centre	Pump & Inverter #1	£10,000	*Product Info £6k (Pump) plus £1k (Install) plus £3K (Inverter)*
	Pump & Inverter #1	£10,000	*Product Info £6k (Pump) plus £1k (Install) plus £3K (Inverter)*
	Pump & Inverter #1	£10,000	*Product Info £6k (Pump) plus £1k (Install) plus £3K (Inverter)*
	Plate Heat Exchanger x 2	£70,000	*Spons, 100% Duty, 100% Standby*
	DPCV / PICV Control Valve	£2,000	*Spons*
	Pressurisation Unit	£9,640	*Spons*
	Combined Deaerator & Separator	£3,700	*Spons*
	Heat Meter	£3,000	*Allowance*
	Strainers x 3	£4,500	*Spons*
	Isolation Valves x 21	£27,300	*Spons*
	Pipework & Insulation	£40,000	*Allowance*
	Sub Total	**£190,140**	
Load 1 - Parliament Building	Water to Water Heat Pump(s)	£480,000	*Spons*
	DPCV / PICV Control Valve	£2,000	*Spons*
	Strainer	£1,500	*Spons*
	Isolation Valves x 7	£9,100	*Spons*
	Heat Meter	£2,620	*Spons*
	Pipework & Insulation	£10,000	*Allowance*
	Sub Total	**£505,220**	
Load 2 - Stormont Castle	Water to Water Heat Pump(s)	£180,000	*Spons*
	DPCV / PICV Control Valve	£2,000	*Spons*
	Strainer	£1,500	*Spons*
	Isolation Valves x 7	£9,100	*Spons*
	Heat Meter	£2,620	*Spons*
	Pipework & Insulation	£10,000	*Allowance*
	Sub Total	**£205,220**	
Load 3 - Castle Buildings	Water to Water Heat Pump(s)	£800,000	*Spons*

	DPCV / PICV Control Valve	£2,000	*Spons*
	Strainer	£1,500	*Spons*
	Isolation Valves x 7	£9,100	*Spons*
	Heat Meter	£2,620	*Spons*
	Pipework & Insulation	£10,000	*Allowance*
	Sub Total	**£825,220**	
Load 4 - Massey House	Water to Water Heat Pump	£8,000	*Spons*
	DPCV / PICV Control Valve	£2,000	*Spons*
	Strainer	£1,500	*Spons*
	Isolation Valves x 7	£9,100	*Spons*
	Heat Meter	£2,620	*Spons*
	Pipework & Insulation	£10,000	*Allowance*
	Sub Total	**£33,220**	
Load 5 - Parliament Building	Water to Water Heat Pump	£180,000	*Spons*
	DPCV / PICV Control Valve	£2,000	*Spons*
	Strainer	£1,500	*Spons*
	Isolation Valves x 7	£9,100	*Spons*
	Heat Meter	£2,620	*Spons*
	Pipework & Insulation	£10,000	*Allowance*
	Sub Total	**£205,220**	
Other Items	BMS Controls	£82,000	*Allowance*
	Pipework PPSL Option Single Series 3	£966,082	*Product Information*
	Civils work, trenching and reinstatement	£379,600	*Allowance*
	NDT Testing	£45,000	*Allowance*
	Pressure Testing	£55,000	*Allowance*
	Commissioning & Balancing	£80,000	*Allowance*
	Electrical Works	£50,000	*Allowance*
	Sub Total	**£1,657,682**	
	Total	**£3,621,922**	
	Risk / Contingency	£905,481	*BSRIA BG6-2014, +/-25% at Concept Stage*
	Grand Total	**£4,527,403**	

These costs are subject to the following exclusions: - Central plant room enclosure for heat network equipment.

- Modification to building systems beyond the water-to-water heat pump.
- Borehole costs.
- Design Fees.
- VAT.

Initial allowances have been made where additional design work is required to allow more accurate costs estimates to be made at the next design stage.

Civils work, trenching and reinstatement costs have been estimated using the following - hard dig: £600/m, soft dig: £200/m, average: £400/m). Further Quantity Surveyor support would be required to determine accurate trenching costs once the proportion of hard and soft dig elements are better determined.

6.2.1 CO_2 Abatement

Energy data for the five buildings studied in this report (Parliament Buildings, Stormont Castle, Castle Buildings, Massey House and the Craigantlet Buildings) indicate that more than 7200MWh of gas are consumed each year. On the simplistic basis that this gas is replaced entirely by heat derived from a closed-loop GSHP and that the heat pump has a CoP of 3.5 then the CO_2 saving is estimated at 837 tonnes per annum. This equivalent to taking approximately 200 petrol cars off the road each year or 6000 cars over the 30-year design life.

Table 15 Simplified CO_2 Abatement Calculation

Stormont energy consumption	CO_2 from consumed gas	electricity to drive equivalent heat pumps (CoP=3.5)	$CO_2$from electricity for heat pumps	CO_2 reduction	CO_2 reduction over 30 year project life
MWh p/a	tonne p/a	MWh p/a	tonne p/a	tonne p/a	tonne
7218	1317	2062	481	837	25105
Electric Carbon (TH)	0.233	$kgCO_2/kWh$	Gas Carbon	0.1825	$kgCO_2/kWh$

7.0 Uncertainty & Risk

The geothermal ground investigation work at the Stormont Estate has significantly increased our knowledge and understanding of what an implemented geothermal heating system would look like at the site. The information gathered will also be of benefit to the wider community in terms of designing and constructing similar schemes. Subsurface uncertainty has reduced significantly with the completion of the investigation boreholes and completion of the TRT. Modelling of multiple possible borehole configurations and sensitivity analysis around these results demonstrates that the bedrock beneath the site can produce the heat required to heat the main buildings (or provide a significant proportion of that heat).

There are however some remaining uncertainties, and these generate risk for the implementation of a successful project. The residual uncertainties include:

- Groundwater Flow: Geothermal models in the main report are based upon published thermal parameters these correlate well with actual values established in the TRT but the current models are not able to build in the impact of groundwater flow. We know that groundwater flows across the site are not insignificant. This flow will improve the overall thermal conductivity (simply because the cold rock adjacent to the well bores is warmed by the passage of the water).
- Capex: Costs for the boreholes and thereby the arrays should be refined following depth/ cost optimisation.
- Scale of the heat network: Pre-TRT, the evaluation suggested that borehole arrays (as proposed and restricted to just the main car-park areas) could deliver about 80% of the required heating load or 100% of the load to some buildings. Following DfE feedback, addition of further possible areas for borehole arrays (as documented in Appendix C) will allow the full heating load to be met but this will require some future reworking of the heat network design documented here. Areas in the south around Dundonald House can be removed but others in the north and east may need to be added.

8.0 Conclusion and Recommendations

The ultimate feasibility of a geothermal solution for heating at the Stormont site is dependent upon both the technical feasibility and the cost of implementation. This study demonstrates that installation of a geothermal heating solution on the Stormont Estate is technically feasible. The results (using the TRT data) show that the full site's energy load can be met from borehole arrays developed in up to 15 arrays located in the north of the site. The arrays can be integrated with an Ambient Loop Heat Network to meet 100% of the heating demand of three of the estate's key buildings: Parliament Buildings, Stormont Castle, and Castle Buildings. The construction of a GSHP system offers the potential to reduce both energy costs and carbon emissions.

Costs for the heat network have been quantified. Cost estimates for the sub-surface systems are also indicated but would benefit from a final cost/depth optimisation analysis, informed by latest contractor rates.

Recommendations:

The economic feasibility of a geothermal heating system or systems at the Stormont site should be finalised following optimisation of the borehole design and generation of a full suite of potential costs. There will however be an element of ongoing subsurface uncertainty and risk. This combined with the significant cost of installing a system that could meet the full energy needs of the site suggests it may be prudent to proceed with an incremental build out of a geothermal solution.

A solution for Stormont Castle could be installed on the building's lawns. This would test the longer-term thermal performance of a closed loop array on this site, and help assess the impact of groundwater flow. Groundwater flow should improve efficiency and potentially provide significant savings on installation of any subsequent project stages. Based on lessons learned from this investigation, ground issues can now be better anticipated, and a suitable contract could be let for the future work. Such works would commence with installing one to two 'lead' boreholes to confirm local site-specific ground conditions further, with a TRT to refine the design and/or number of boreholes before full implementation.

Further work could also be undertaken to establish potential summer cooling loads. If such loads were identified, a combined heating/cooling system should improve the thermal efficiency of the system and reduce the number of boreholes required to meet the potential load. This could have a positive impact on the cost of the scheme.

9.0 References

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Figures

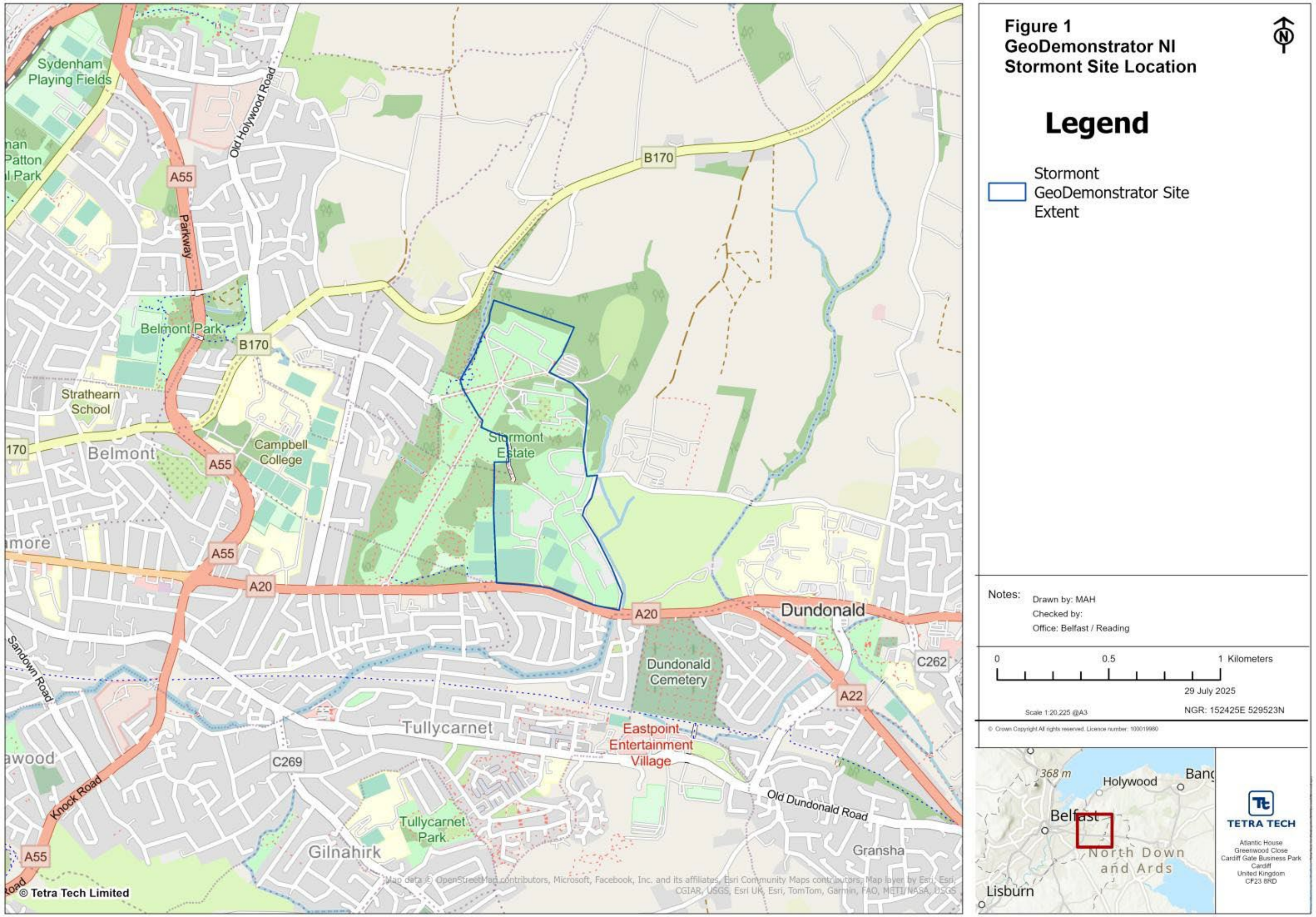


Figure 1 NI GeoEnergy Demonstrator Project : Stormont Site Location

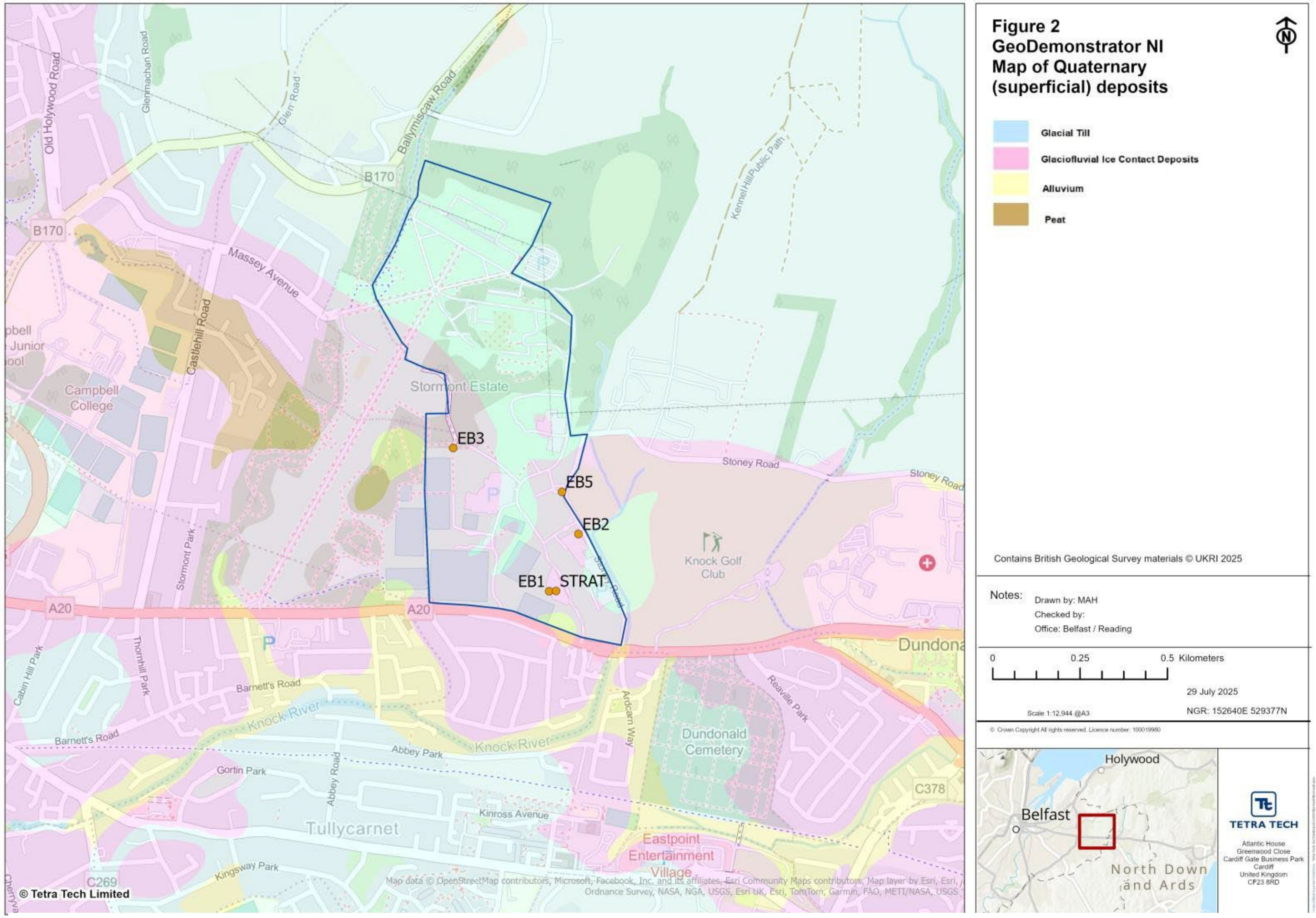
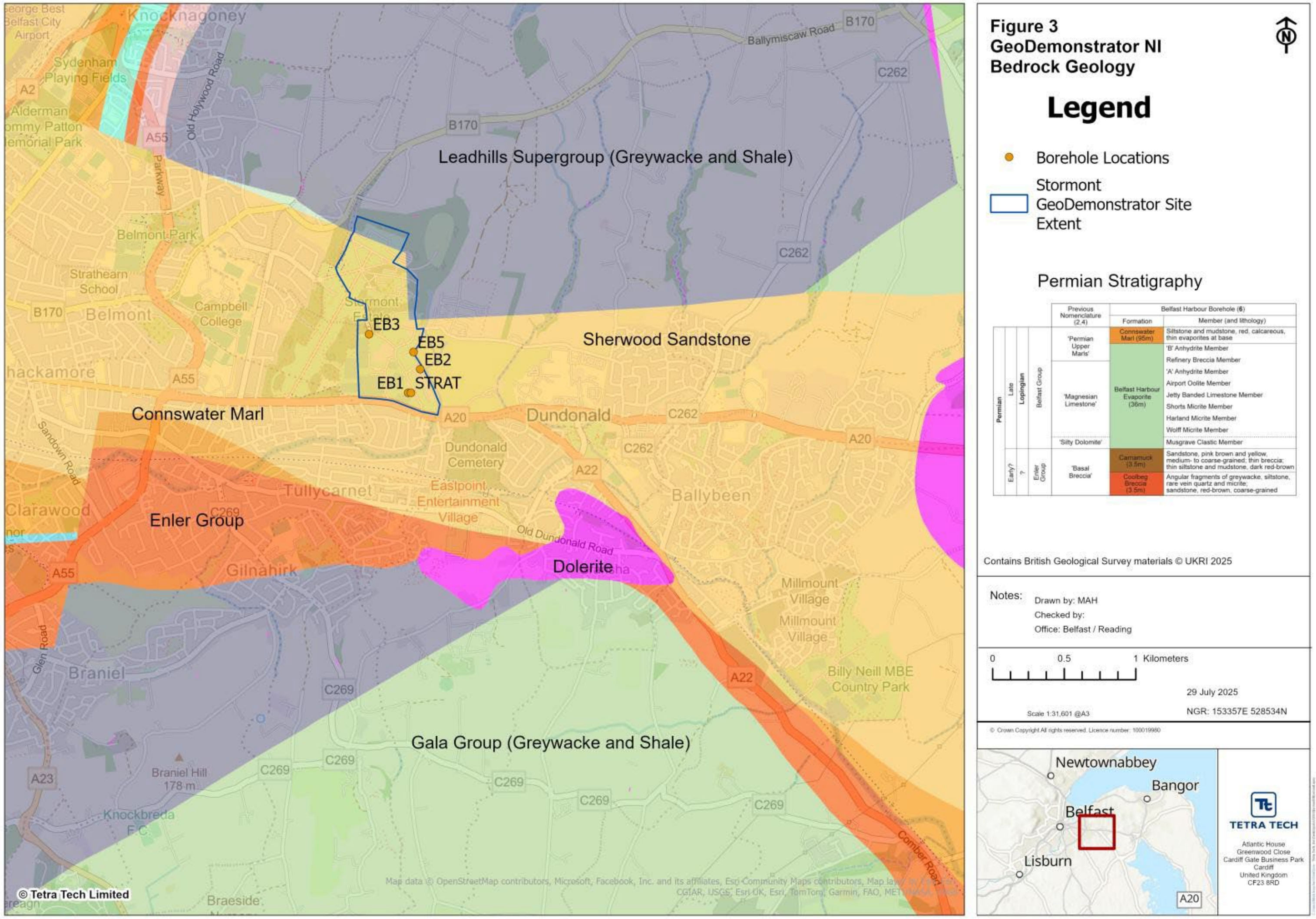


Figure 2 Quaternary Geology



				Previous Nomenclature (2,4)	Belfast Harbour Borehole (6) Formation	Member (and lithology)
Permian	Late	Lopingian	Belfast Group	'Permian Upper Marls'	Connswater Marl (95m)	Siltstone and mudstone, red, calcareous, thin evaporites at base
					Belfast Harbour Evaporite (36m)	'B' Anhydrite Member
						Refinery Breccia Member
				'Magnesian Limestone'		'A' Anhydrite Member
						Airport Oolite Member
						Jetty Banded Limestone Member
						Shorts Micrite Member
						Harland Micrite Member
						Wolff Micrite Member
				'Silty Dolomite'		Musgrave Clastic Member
	Early?	?	Enler Group	'Basal Breccia'	Carnamuck (3.5m)	Sandstone, pink brown and yellow, medium- to coarse-grained; thin breccia; thin siltstone and mudstone, dark red-brown
					Coolbeg Breccia (3.5m)	Angular fragments of greywacke, siltstone, rare vein quartz and micrite; sandstone, red-brown, coarse-grained

Figure 3 Bedrock Geology

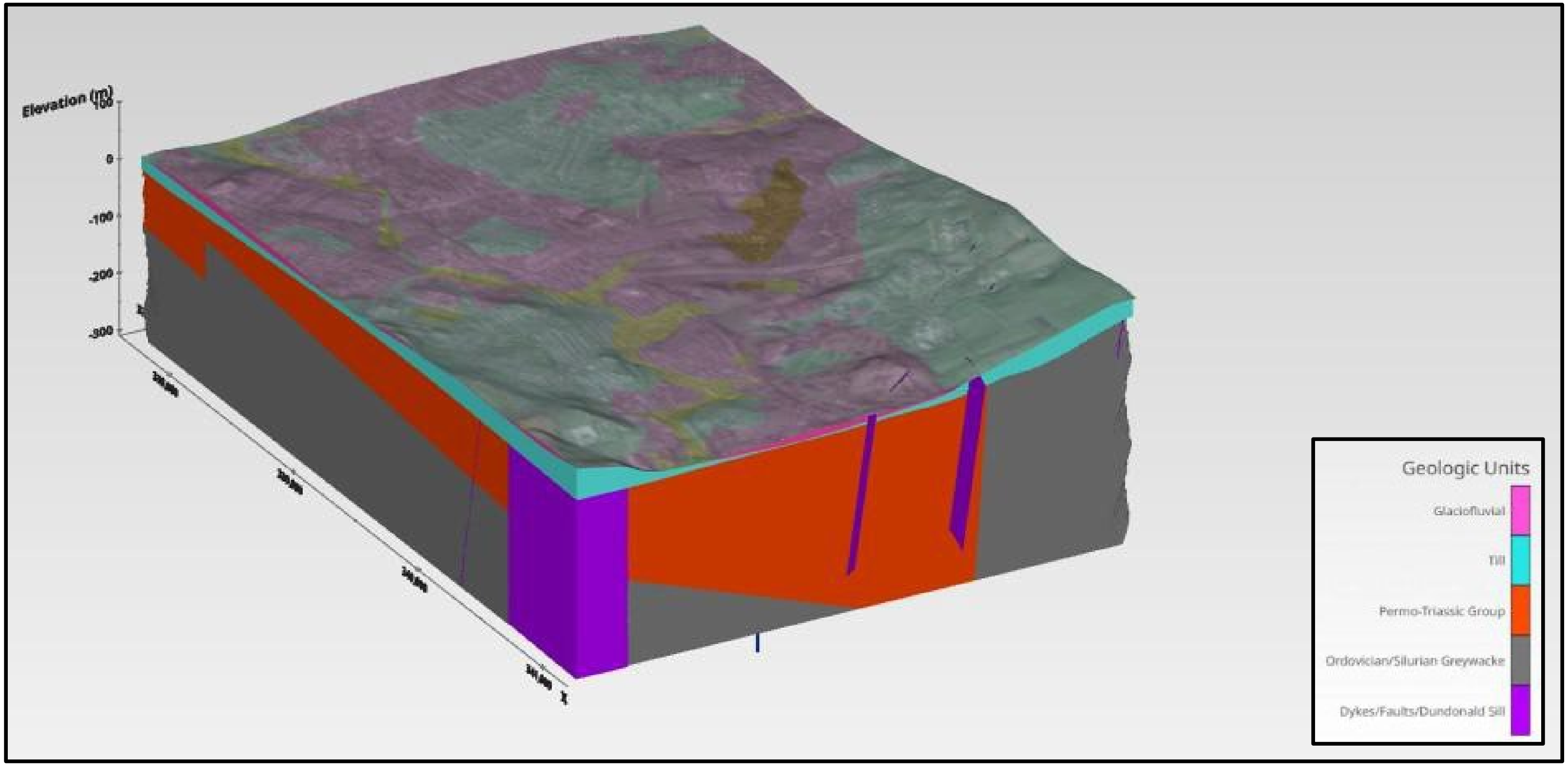


Figure 4 Updated 3D geological model showing revised and thickened Enler Group sitting beneath a fluvio glacial sequence (the structural interpretation remains the same).

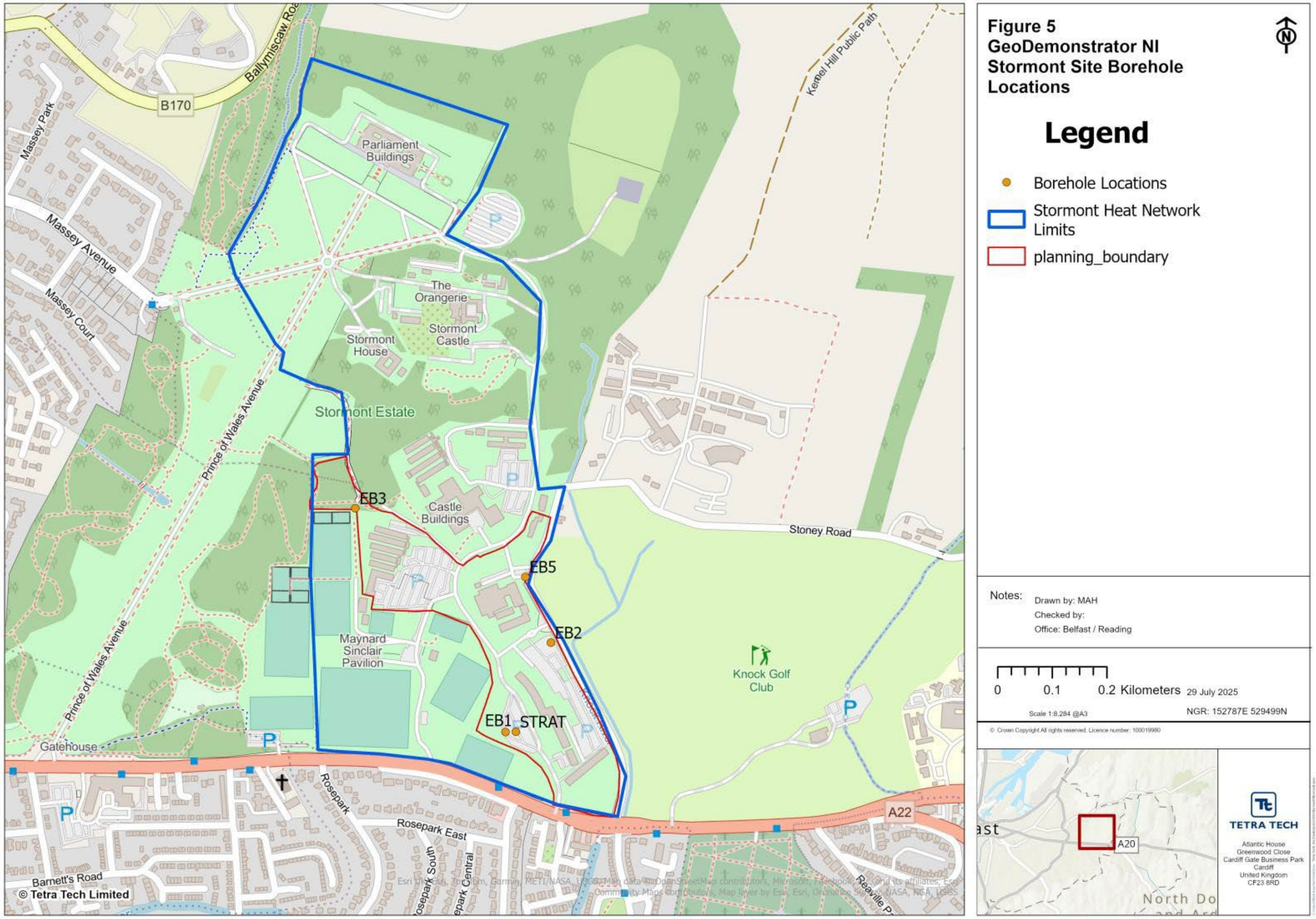


Figure 5 Borehole Locations

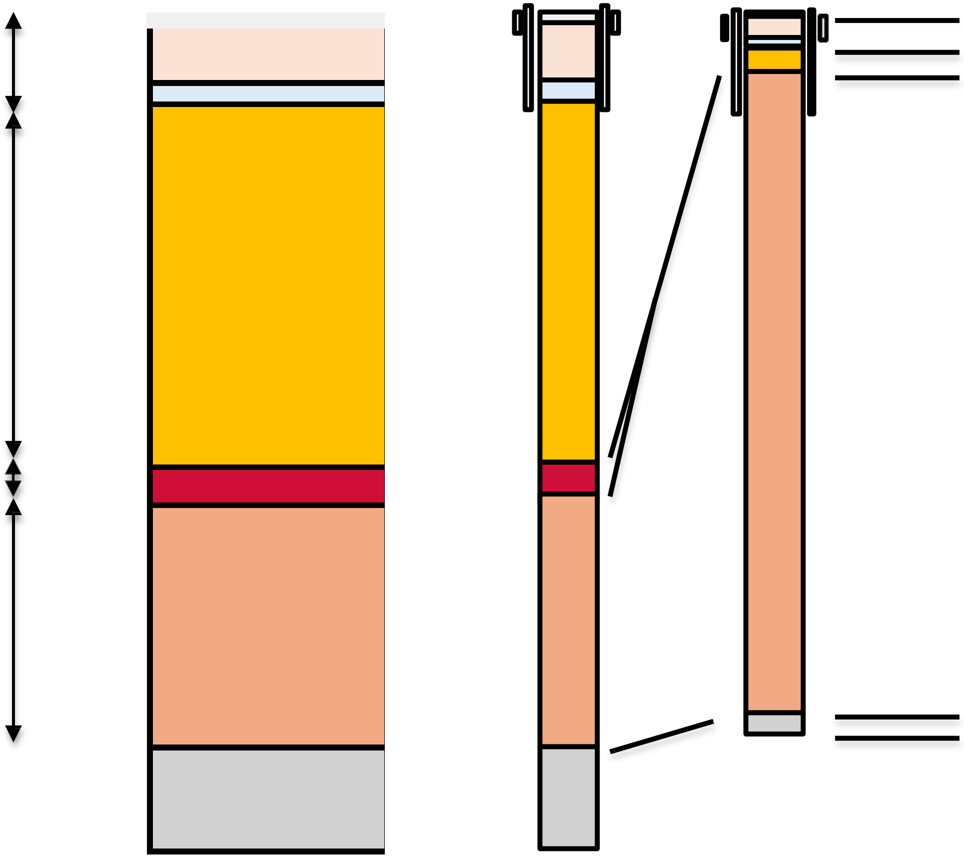


Figure 6 Prognosed versus Actual drilled section for the stratigraphic core-hole.

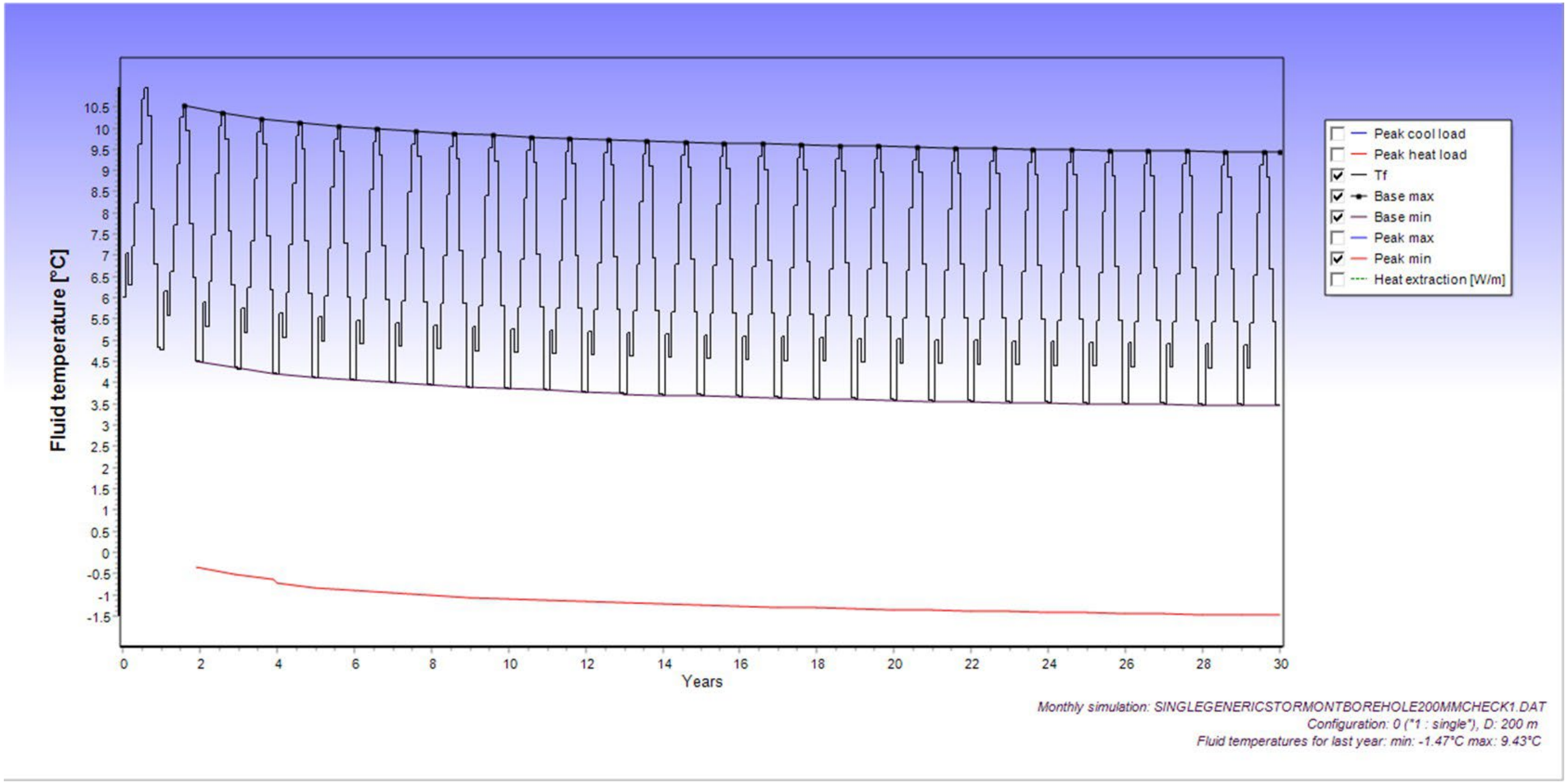
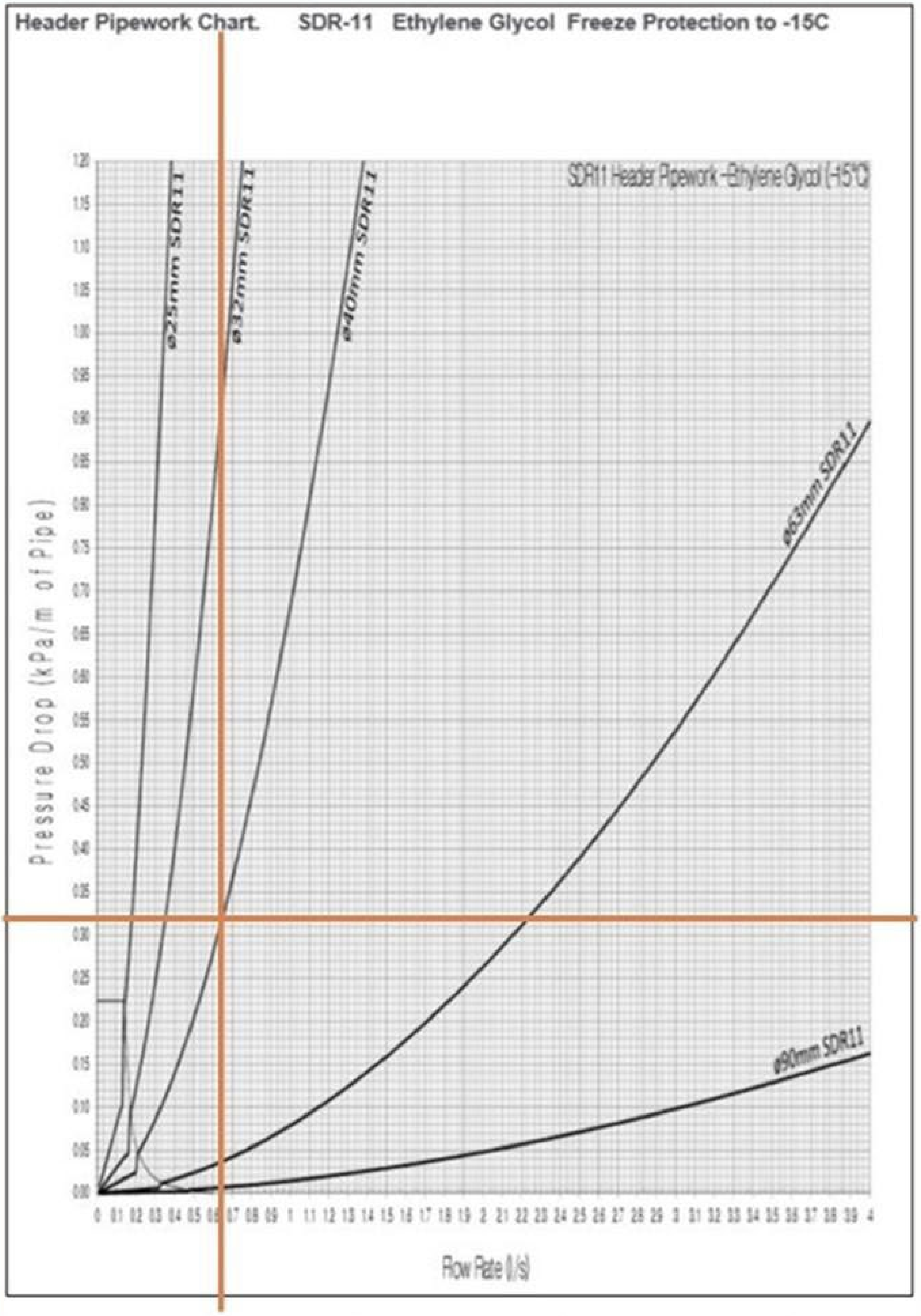


Figure 7 EED Output for single double-U 200m*200mm BHE showing evolution of average fluid temperature during a 30 year simulation of 200 m deep borehole. At the end of the simulation, the average fluid temperature under peak load conditions (10 hrs of heat delivery of 14.0 kW) reaches -1.24°C. The line shows the minimum average fluid temperature under peak load conditions, the black lines show the typical average fluid temperature under base load conditions red



Pressure drop = 0.32kPa/m = 128kPa for 400m pipe

Figure 8 MCS (2021) Header Pipe Pressure Drop Chart for SDR11 with 25% ethylene glycol fluid

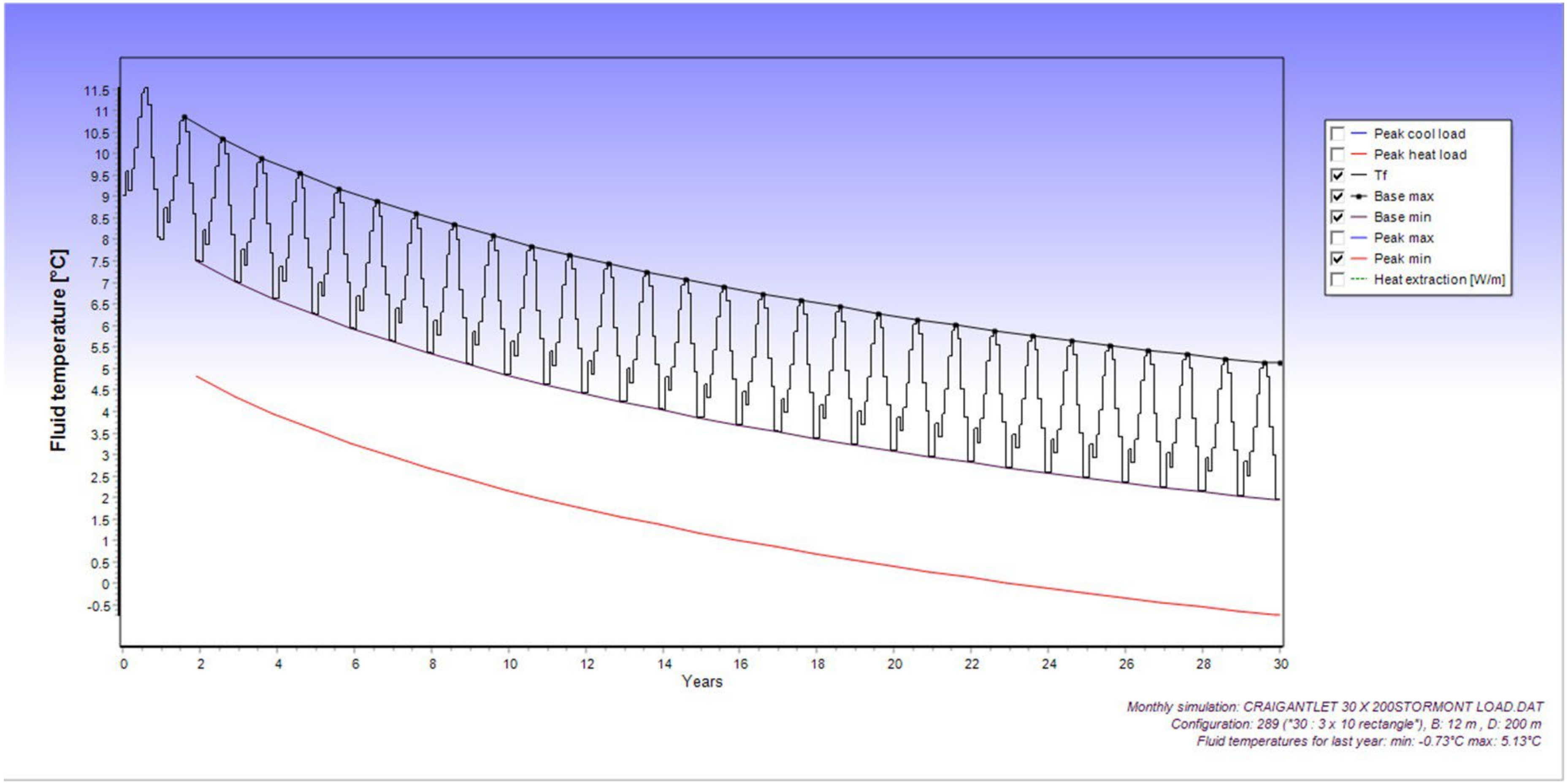


Figure 9 EED Output for 10x3 array of double-U 200m*200mm BHEs showing evolution of average fluid temperature during a 30 year simulation. At the end of the simulation, the average fluid temperature under peak load conditions (10 hrs of heat delivery of 250.0 kW) reaches -0.73°C. The red line shows the minimum average fluid temperature under peak load conditions, the black lines show the typical average fluid temperature under base load conditions

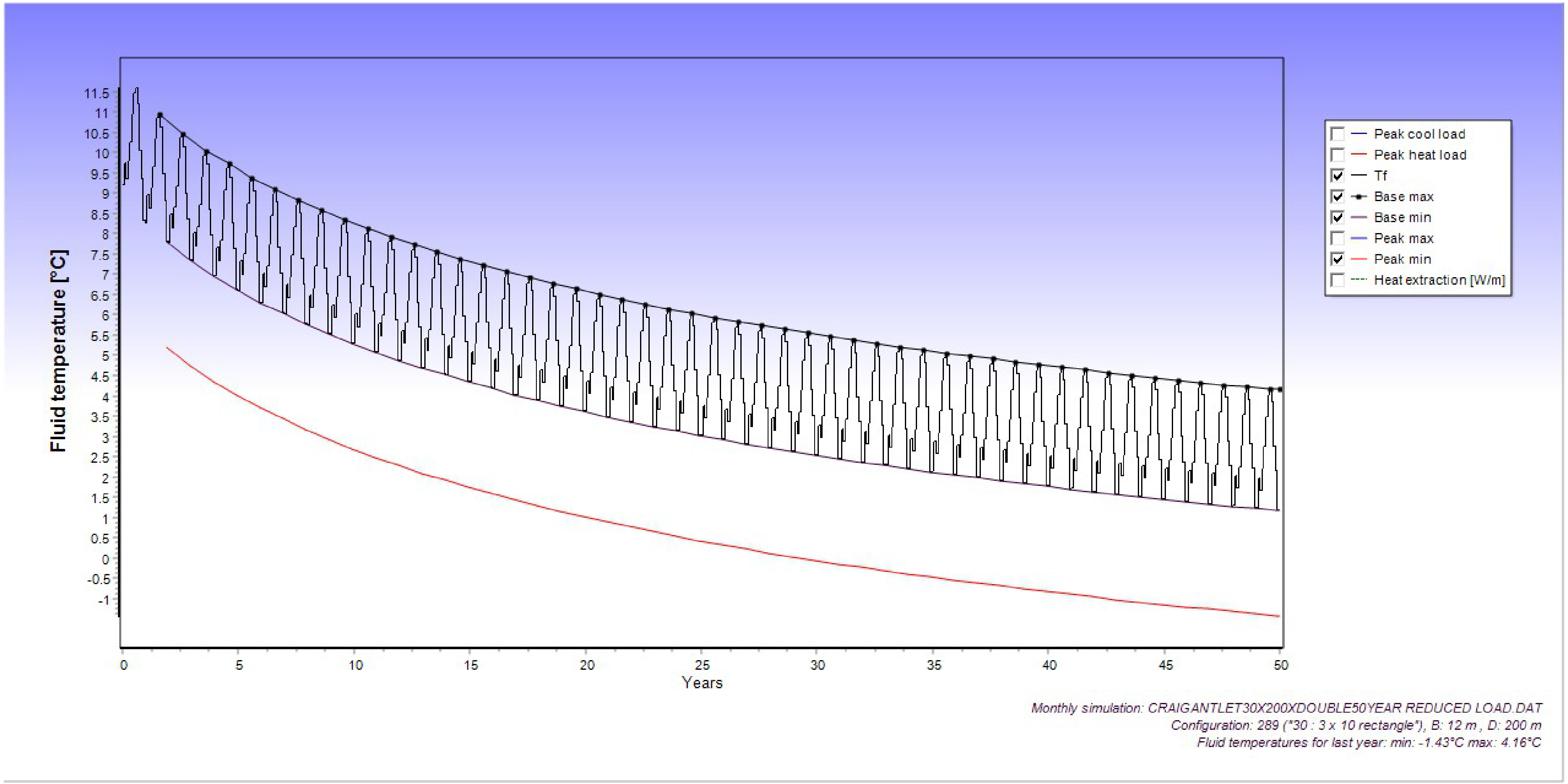


Figure 10 EED Output for 10x3 array of double-U 200m*200mm BHEs showing evolution of average fluid temperature during a 50 year simulation. At the end of the simulation, the average fluid temperature under peak load conditions (10 hrs of heat delivery of 240.0 kW) reaches -1.43°C. The red line shows the minimum average fluid temperature under peak load conditions, the black lines show the typical average fluid temperature under base load conditions

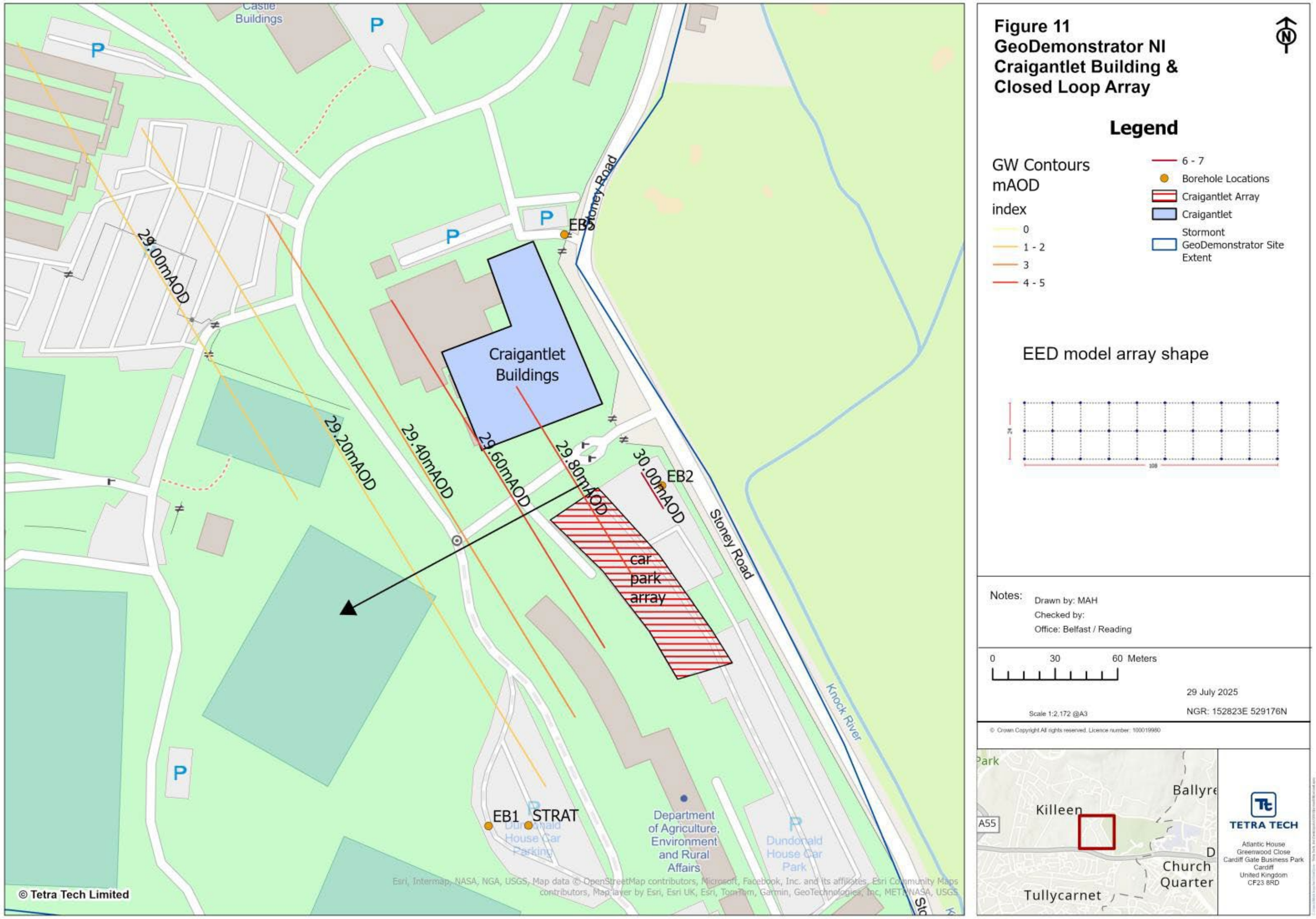
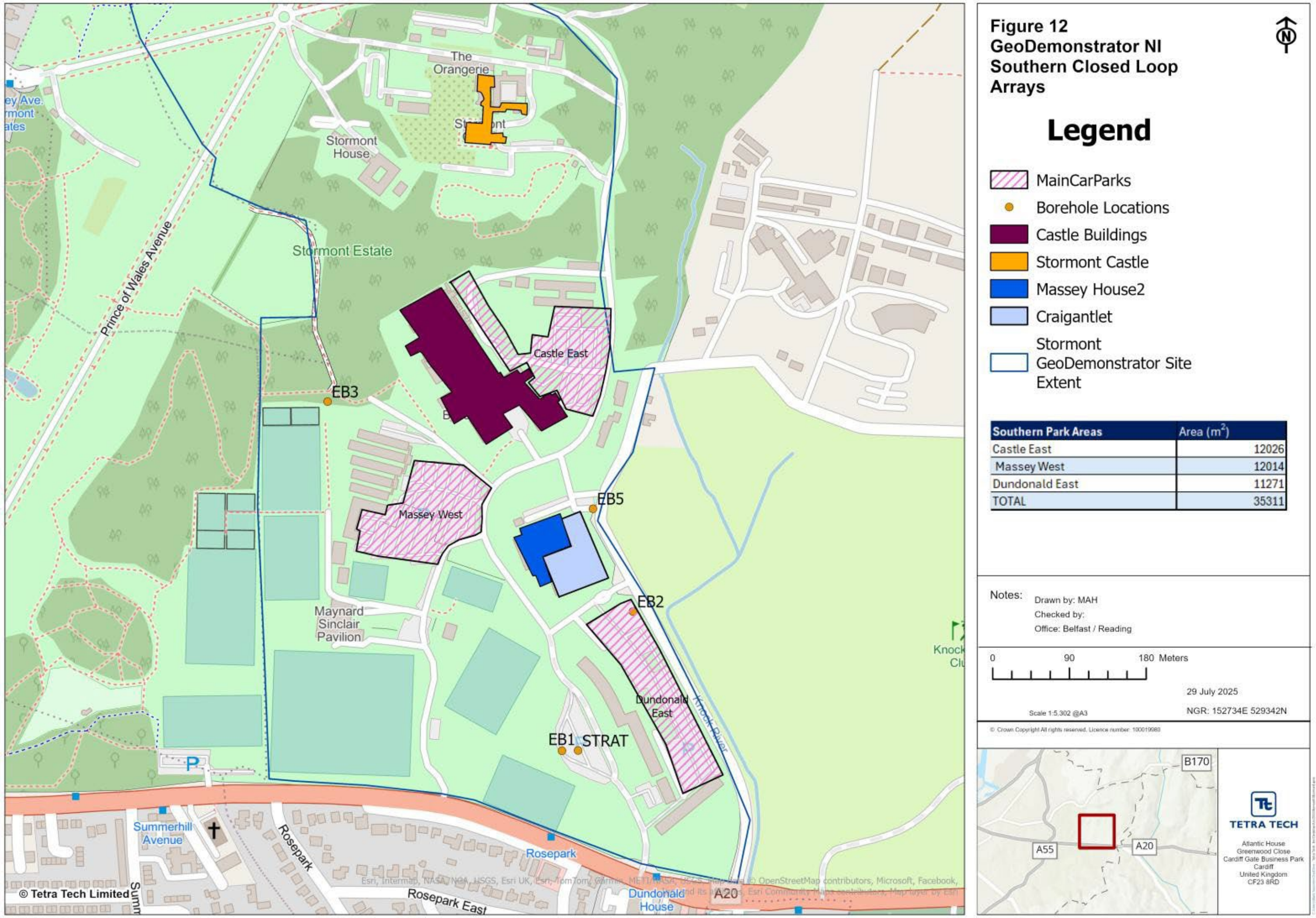


Figure 11 250kW peak capacity array to deliver 550MWh annual heat to Craigantlet Buildings with GW contours and direction of GW flow



Southern Park Areas	Area (m^2)
Castle East	12026
Massey West	12014
Dundonald East	11271
TOTAL	35311

Figure 12 2200kW peak capacity array to deliver 4800MWh annual heat to the 4 southern buildings total 342 boreholes (200m*200mm double U-tube)

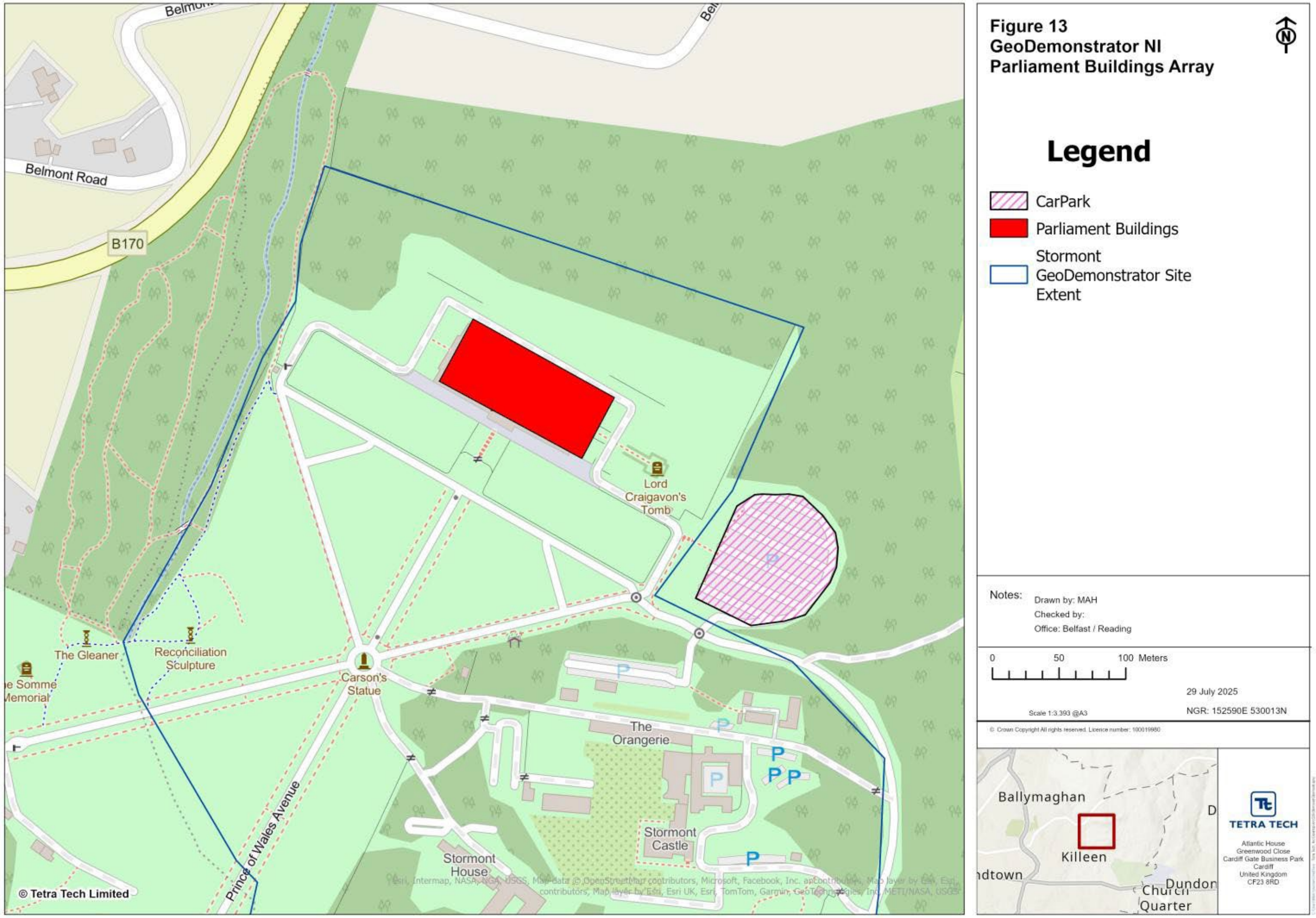
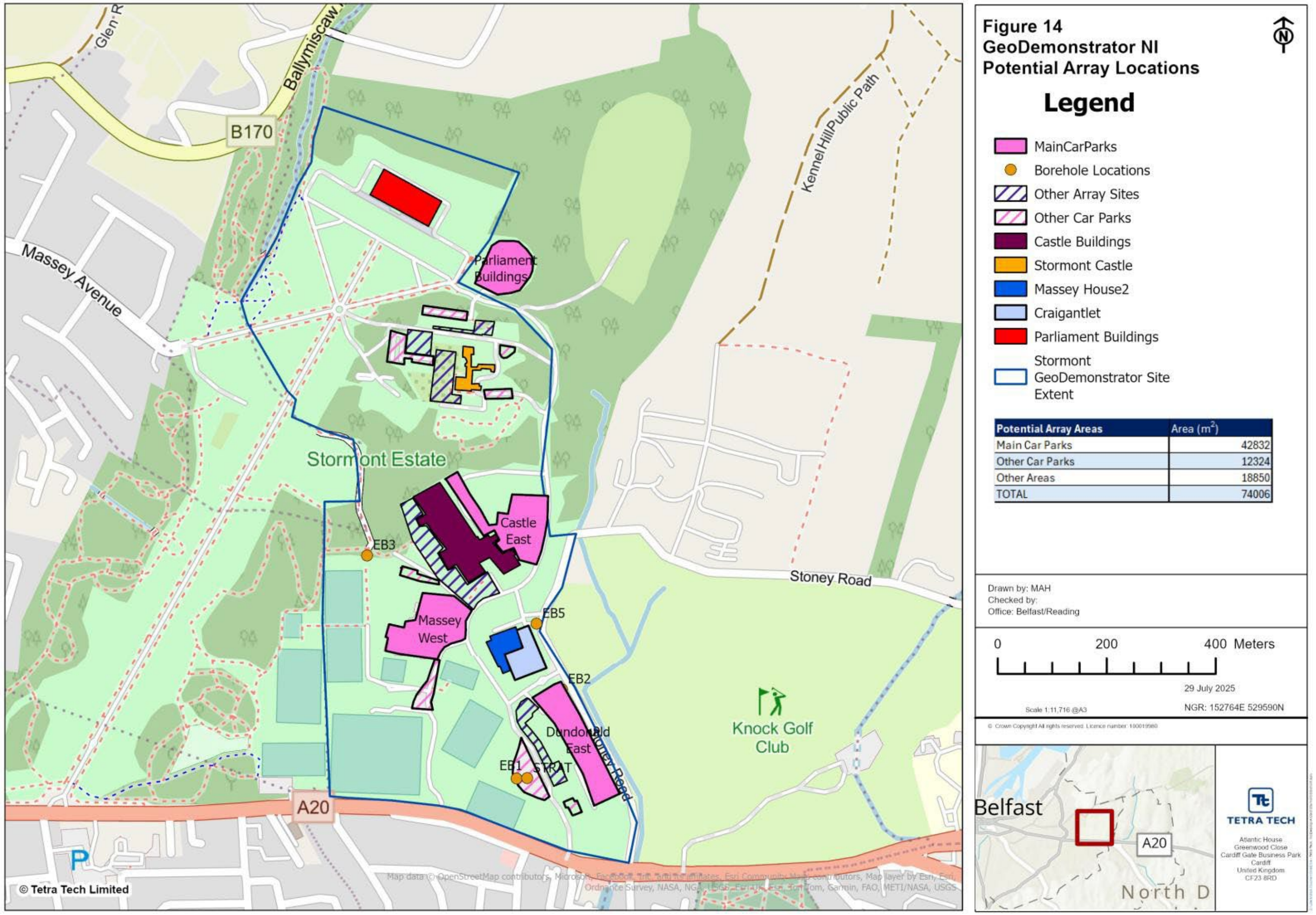


Figure 13 Parliament Buildings Array 63 boreholes (9*7) 200m*200mm double-U tube. Delivers 1000MWH/annum at 450kW peak, represents 42% of Parliament Buildings load



Potential Array Areas	Area (m^2)
Main Car Parks	42832
Other Car Parks	12324
Other Areas	18850
TOTAL	74006

Figure 14 All possible closed-loop array locations

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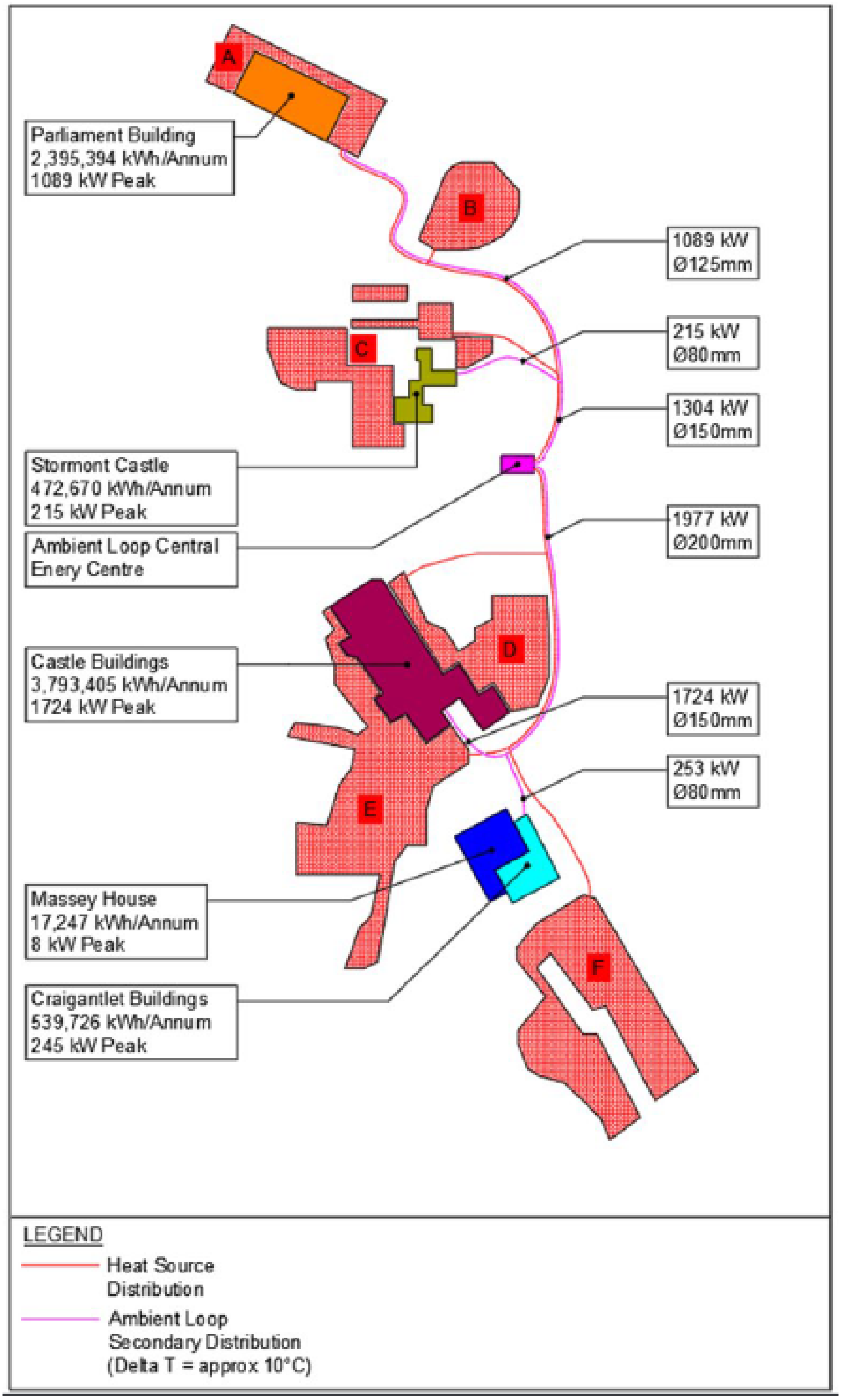


Figure 15 Proposed Heat Network

Appendix A: TRT Results

Stormont Estate – Belfast – EB5
Thermal Response Test Report

Client – TertaTech

31st March 2025

PROJECT MANAGEMENT | DESIGN | CONSULTANCY | FEASIBILITY

Executive Summary

A formation thermal conductivity test was performed at the Stormont Estate, Upper Newtownards Road, Newtownards, BT4 3ST. The vertical bore was completed on 5th March 2025 and the Geocube test unit was attached to the vertical bore on the morning of 24th March 2025 with the test terminating on 27th March 2025. The collected data was analysed using the "line source" method.

This report provides a general overview of the test and procedures that were used to perform the thermal conductivity test along with a plot of the data sats and in a form used to calculate the formation thermal conductivity. As it is understood that the borehole was grouted from the base of the borehole to surface within the inner steel casing which remained in place. The annulus of this casing was not grouted but was completely water filled to surface. This may have impacted the borehole resistance at the early stages of the test. Under normal circumstances, the data for the first 12 hours is not normally used for the analysis. With the completion details of this particular borehole, the section of data not normally used for the analysis was extended from circa 12 hours to 25 hours for the test. The data used for calculation was therefore from hour 25 to hour 72.

The following average formation thermal conductivity was found from the data analysis.

⇒ **Formation Thermal Conductivity = 2.44 W/m-K**

Due to the necessity of a thermal diffusivity value in the design calculation process, an estimate of the average thermal diffusivity was made for the encountered formation based upon the calculated thermal conductivity, anticipated formation density, specific heat capacity and moisture content.

⇒ **Formation Thermal Diffusivity ≈ 0.083 m^2/day**

An estimate of the undisturbed formation temperature was determined from the initial temperature data prior to start-up.

⇒ **Undisturbed Formation Temperature ≈ 11.7°C (auto estimated)**

An estimate of the borehole thermal resistance was determined based upon the driller's description of the borehole completion details.

⇒ **Borehole Thermal Resistance ≈ 0.14 m*k/W**

Borehole Drilling & Installation

Drilling was completed and grouting finalised on 5th March 2025. Drilling was carried out using a mixture of air and fluid flush drilling. A short length of conductor casing was installed to enable drilling to progress with air flush to approximately 27 m where a further string of casing was installed to a depth of 27 m through the Glacial Till.

Drilled diameter was 160 - 180 mm diameter and the borehole advanced to 118 m total depth. On completion of the drilling, a single 40 mm SDR11 PE100 ground loop was installed to 117 m utilising a 1m weight below the u-bend to aid installation. The borehole was then grouted with Geotherm-X thermally enhanced grout with a thermal conductivity reported to be 2.0 W/mk.

The loop was installed with water within the loop to surface and was capped off with temporary caps which were then taped in place to ensure no debris was able to enter the loop tails.

The geological succession recorded, and the installation details are shown on the schematic below.

Formation	Thickness (m)
unsaturated sand/gravel	1
Till	27
Permian	90
Total Borehole Depth	**118**

Thermal Response Test Equipment & Set Up

The thermal response test was carried out with an extended range Geocube thermal response test unit as manufactured by Precision Geothermal, capable of testing boreholes to more than 250 m in depth.

The Geocube is a self-contained fully insulated unit with external temperature sensing along with flow measuring, inlet and outlet temperatures, voltage and current and HOBOWare data logger.

The power was provided by a silenced 60 kVa generator capable of powering the unit with 63 Amp single phase power supply at circa 230 - 240 volts standard UK power supply.

Test Procedures

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) has published a set of recommended procedures for performing formation thermal conductivity tests for geothermal applications. The International Ground Source Heat Pump Association (IGSHPA) and the Ground Source Heat Pump Association (GSHPA) have also produced industry standards and guidance for such tests. GSC is committed to adhering to ASHRAE, IGSHPA and GSHPA recommendations.

On arrival for the test, the loop was found to be still full of water to within 150 mm of the loop tail ends. The by-pass pipe work was connected to the loop tails and the by-pass arrangement was filled manually to fully flood the top 50 mm of the loop and the by-pass pipe work. The by-pass pipe work was then connected to the Geocube and the stilling chamber within the Geo-cube was topped up and vented through the bleed port. The pump was then run intermittently through the loop by-pass to purge air from the heating chamber, pump and the pipe work leading to the loop but not circulated through the loop during the air purge.

Once all air had been purged from the loop, the HOBO logger was started, and the initial circulation of the fluid began for a 10-minute period without heat being applied to the loop. This initial 10-minute period is used to estimate the undisturbed ground temperature of the loop prior to heat being applied to the loop.

On completion of this 10-minute period, the heaters were engaged in quick succession to enable a nominal 7 kW of heating power to be applied to the loop which equates to 8.6 kW of power based on current draw and voltage. In turn, this then equates to 73.7 W/m applied to the borehole which is in line with industry guidance and for a borehole that is expected to have medium to thermal conductivity.

The test continued for a 72-hour heating phase after which the heaters were turned off, the pump and data logger were stopped.

The data was checked for consistency, downloaded, and extracted from the logger to a ".CSV" file for analysis. Analysis was then carried out based upon the Line Source methods, in line with standard industry practice and guidance.

Data Analysis

The "line source" method of data analysis was used. The line source equation used is not valid for early test times. Also, the line source method assumes an infinitely thin line source of heat in a continuous medium. If a u-bend grouted in a borehole is used to inject heat into the ground at a constant rate, to determine the average formation thermal conductivity, the test must be run long enough to allow the finite dimensions of the u-bend pipes and the grout to become insignificant. Experience has shown that the amount of time required to allow early test time error and finite borehole dimension effects to become insignificant is approximately ten to twelve hours.

To analyse real data from a formation thermal conductivity test, the average temperature of the water entering and exiting the u-bend heat exchanger is plotted versus the natural log of time.

Using the Method of Least Squares, the linear equation coefficients are then calculated that produce a line that fits the data.

Formation Thermal Conductivity Test Report

Date of Testing	24th – 27th March 2025
Location	EB5 – Stormont Estate
Undisturbed Formation Temperature	Approx. 11.7°C (auto estimated by Geocube unit)

Borehole Data

Borehole Diameter	150 - 180 mm, GL - 118 m

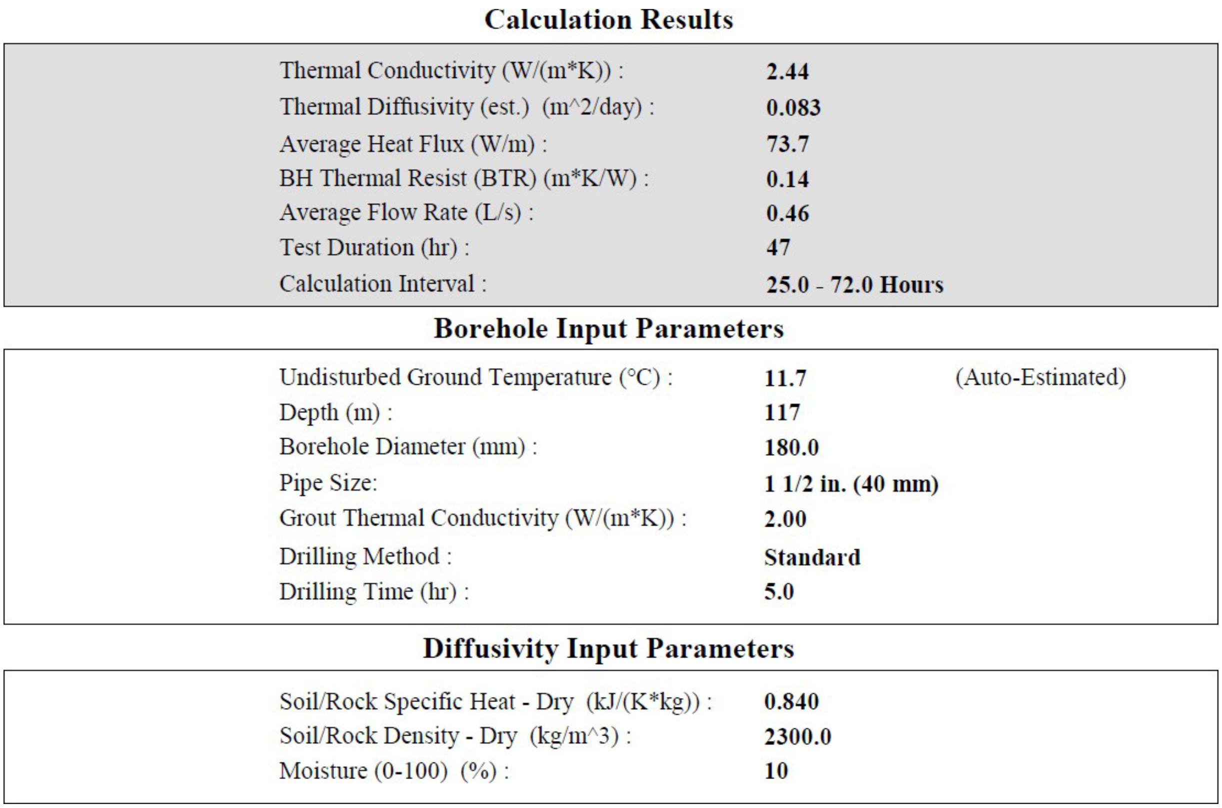
Formation	Thickness(m)
unsaturated sand/gravel	1
Till	27
Permian	90
Weighted mean	**118**

U-bend Size ………………………………………..	40 mm
U-Bend Length ..……………………………………	117 m
Grout Type ...……………………………………….	Geotherm-X Cement Based
Grouted Portion ………..…………………………….	Entire bore

Test Power Parameters

Test Duration	72 hrs		
Average Voltage	237.9 V		
Average Heat Input Rate	8,628 W		
Standard Deviation of Power	0.30% Pass	Default	1.5%
Variation in Power	1.62% Pass	Default	10%
Temperature	0.20% Pass	Default	5%
Flow Rate	3.40% Pass	Default	5%
Slope Stability	1.41% Pass	Default	25%
Water Flow Test	0.03% Pass	Default	20%

Line Source Data Analysis



Calculation Results

Thermal Conductivity (W/(m*K)) :	**2.44**	
Thermal Diffusivity (est.) (m^2/day) :	**0.083**	
Average Heat Flux (W/m) :	**73.7**	
BH Thermal Resist (BTR) (m*K/W) :	**0.14**	
Average Flow Rate (L/s) :	**0.46**	
Test Duration (hr) :	**47**	
Calculation Interval :	**25.0 - 72.0 Hours**	

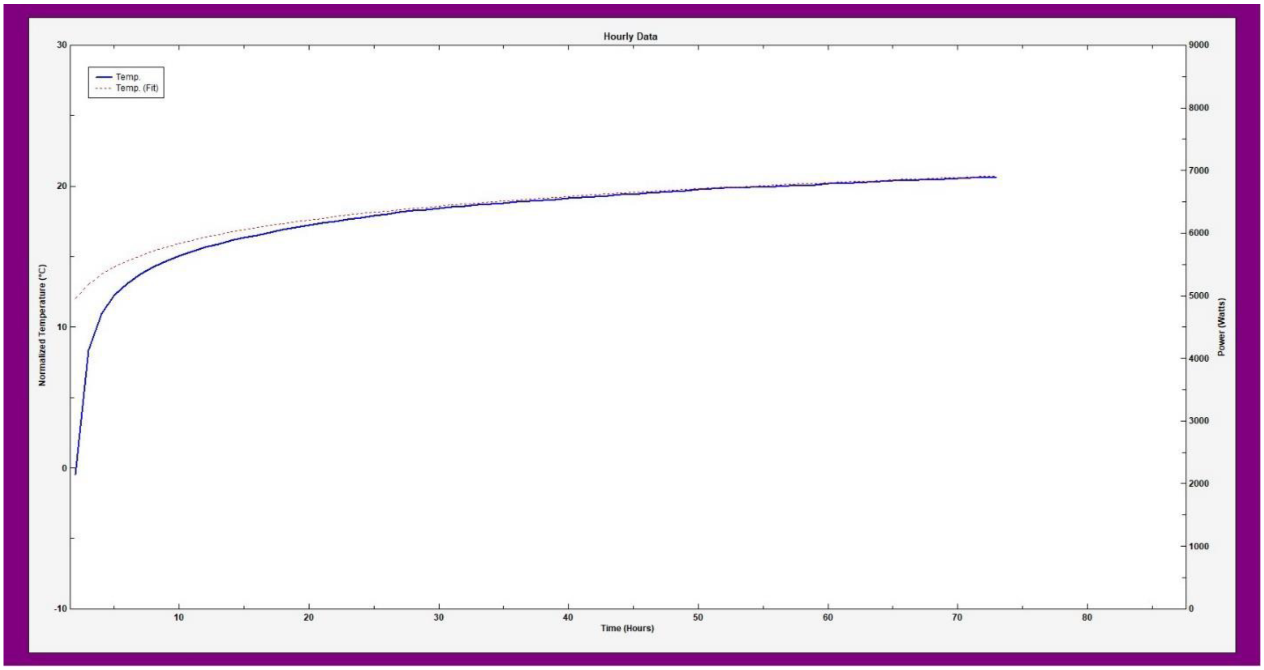
Borehole Input Parameters

Undisturbed Ground Temperature (°C) :	**11.7**	(Auto-Estimated)
Depth (m) :	**117**	
Borehole Diameter (mm) :	**180.0**	
Pipe Size:	**1 1/2 in. (40 mm)**	
Grout Thermal Conductivity (W/(m*K)) :	**2.00**	
Drilling Method :	**Standard**	
Drilling Time (hr) :	**5.0**	

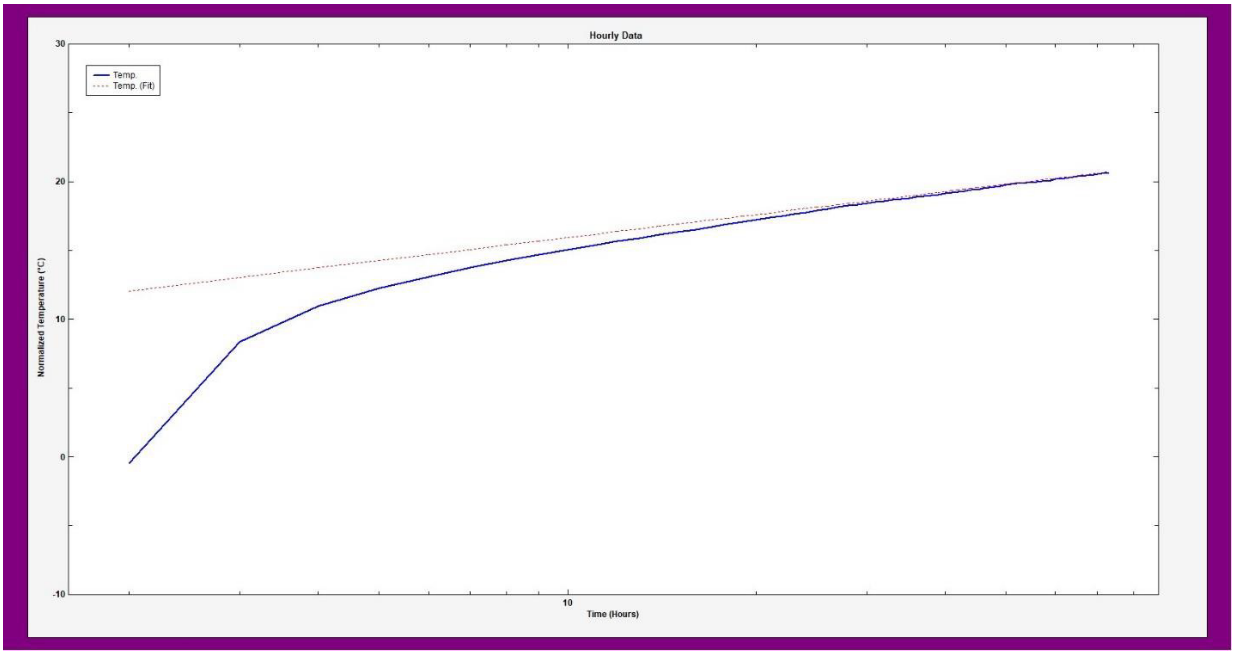
Diffusivity Input Parameters

Soil/Rock Specific Heat - Dry (kJ/(K*kg)) :	**0.840**
Soil/Rock Density - Dry (kg/m^3) :	**2300.0**
Moisture (0-100) (%) :	**10**

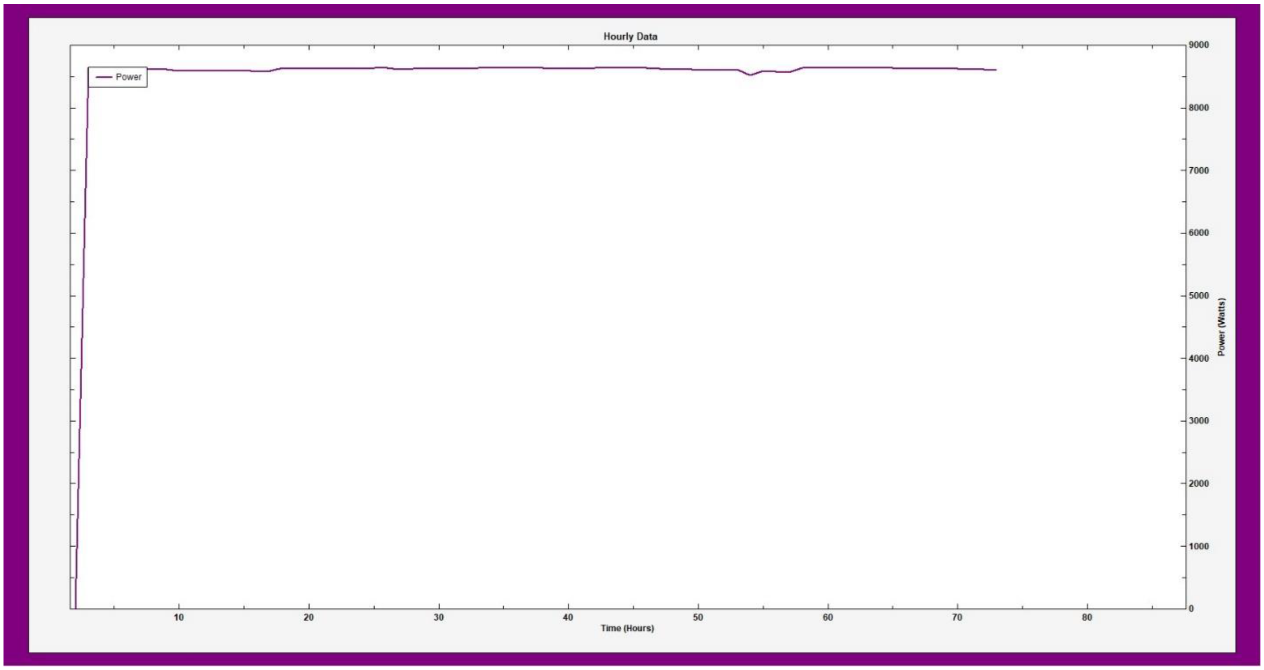
Temperature vs Time



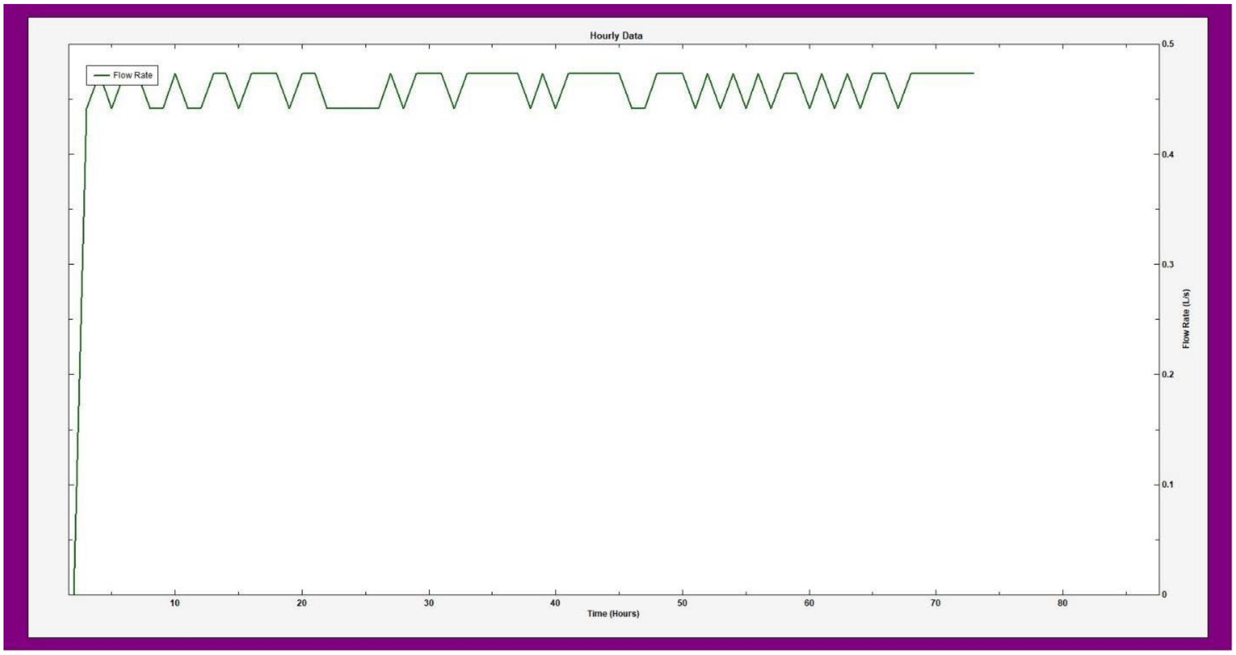
Temperature vs Time (Log Scale)



Power vs Time

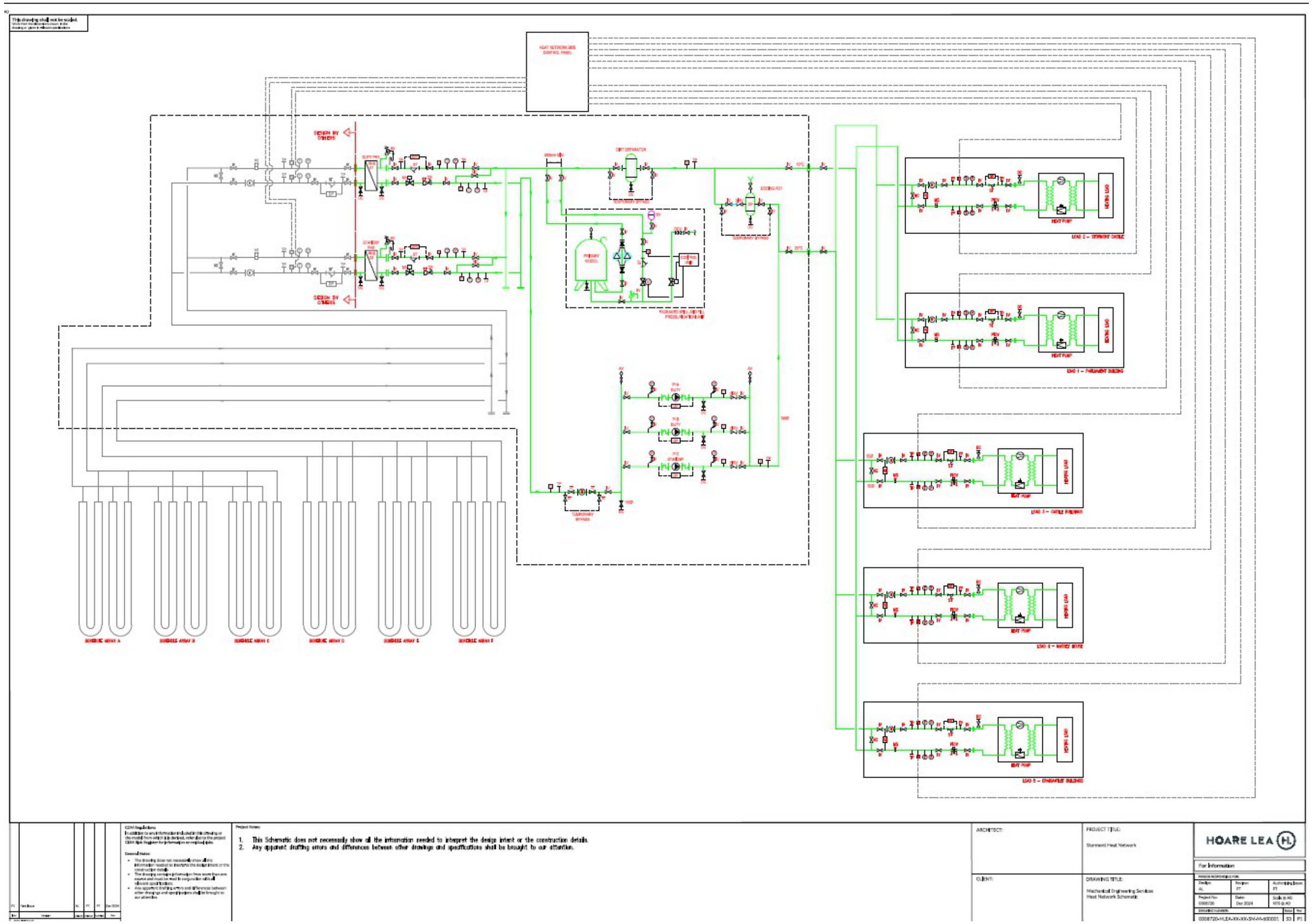


Flow Rate vs Time



Project: Stormont Estate EB5 Revision - 0	
Author: Andy Howley	**Review:**
Date: 31th March 2025	Date:
A.H	

Appendix B: Stormont Estate Heating Network Feasibility Study (system schematic).

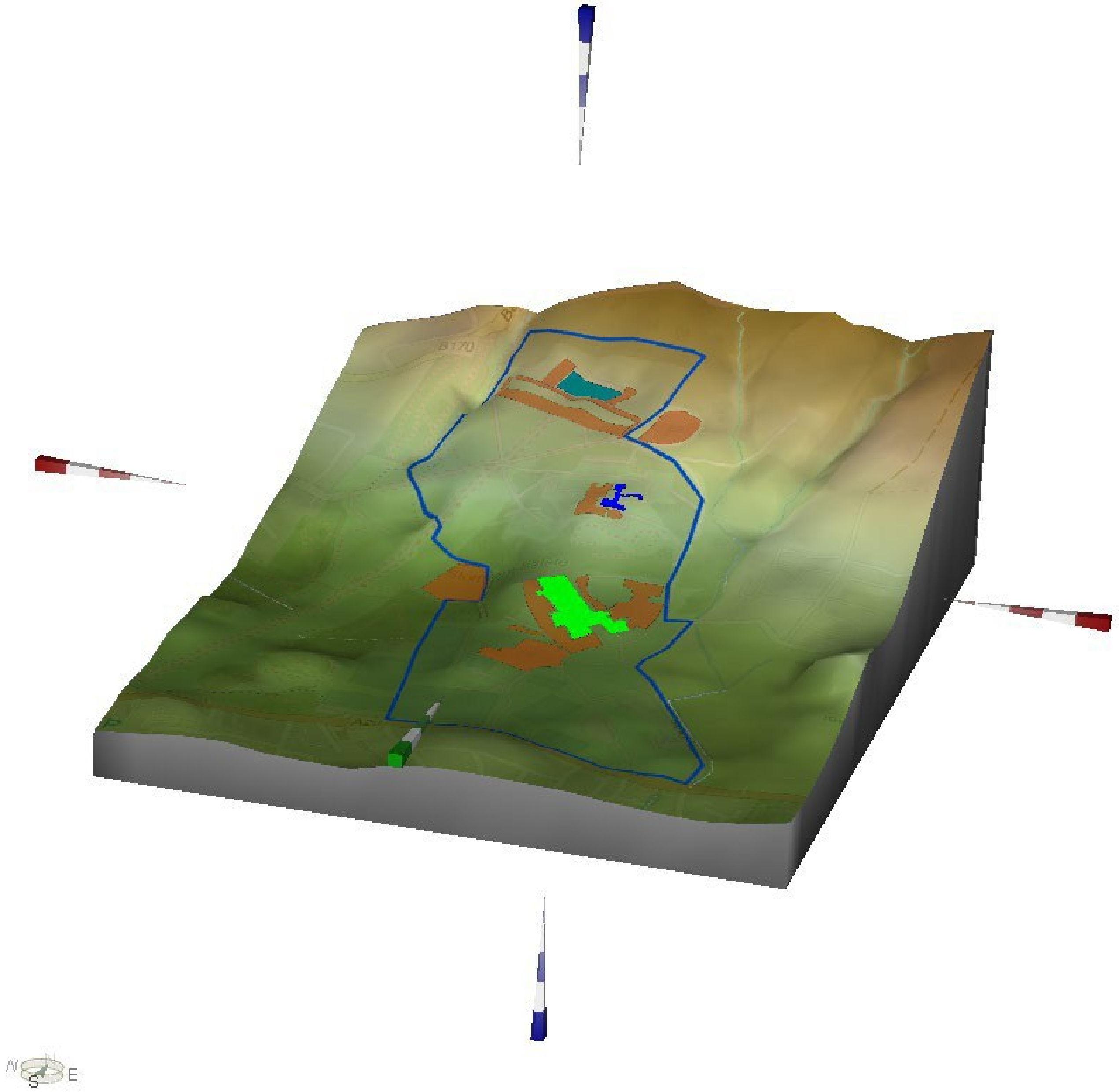


Project Notes:

1. This Schematic does not necessarily show all the information needed to interpret the design intent or the construction details.
2. Any apparent drafting errors and differences between other drawings and specifications shall be brought to our attention.

Stormont Estate, Belfast Concept System Schematic (Hoare Lea 2025)

Appendix C:
Stormont Closed Loop Array Design Modifications incorporating TRT Results



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Executive Summary

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Acronyms/Abbreviations

Acronyms/Abbreviations	Definition
BHE	Borehole Heat Exchanger
EED	Earth Energy Designer
GSHP	Ground Source Heat Pump
FLEQ	Full Load Equivalent Hours
mBGL	metres below ground level
MCS	Microgeneration Certification Scheme
TRT	Thermal Response Test

1.0 Introduction

This Appendix describes revisions to the initially modelled closed-loop borehole arrays described in the main report It incorporates the results of the Thermal Response Testing (TRT) completed in March 2025, further work on preferred borehole depths and feedback on preferred solutions received from DfE in June 2025.

2.0 Thermogeological Parameters

Following on from the preliminary modelling which used published literature values for strata thermal properties, site specific data became available from a TRT completed at borehole EB5 at the end of March 2025. This returned a value of 2.44 W/m/K for thermal conductivity and 0.083m^2/day for thermal diffusivity allowing calculation of volumetric heat capacity at 2.54 MJ/m^3/K. This test data showed a higher thermal diffusivity[1] compared to that used in the initial modelling and is thus more positive with respect to developing a closed loop scheme at Stormont. Parameters for the individual stratigraphic units derived from the test are illustrated in Table 1.

Table 1: Thermal parameters derived from EB5 TRT

Formation	Thickness (m)	Thermal Conductivity (W/m/K)	Volumetric Heat (MJ/m3/K)
Unsaturated sand/gravel	1	1.00	1.60
Till	27	2.00	2.20
Permian Enler Group	90	2.59	2.65
Weighted mean	**118**	**2.44**	**2.54**

The EB5 well is likely too shallow to represent an optimised depth for all the boreholes required at the Stormont site. The 200m depth used in modelling to date has been reduced to 150m in the revised models described below as likely to be less challenging from a drilling perspective and therefore more predictable in terms of cost estimating. The TRT data were therefore used to calculate a new set of thermal parameters for this drill depth (Table 2).

---

[1] Thermal Diffusivity is equal to thermal conductivity divided by the product of volumetric heat capacity and rock density

Table 2: modelled thermal parameters for a 150m borehole post TRT

Formation	Thickness (m)	Thermal Conductivity (W/m/K)	Volumetric Heat Capacity (MJ/m3/K)
Unsaturated sand/gravel	1	1.00	1.60
Till	27	2.00	2.20
Permian Enler Group	122	2.59	2.65
Weighted mean	**150**	**2.47**	**2.56**

The simulation makes the following assumptions

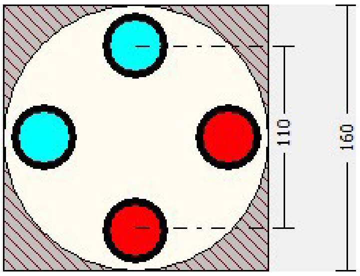
- Ground surface temperature 10.2°C – Section 4.2.2
- Geothermal heat flux 0.062 W/m² - Section 4.2.3
- Ground thermal conductivity 2.47W/m/K - Section 4.2.4
- Ground heat capacity 2.56 MJ/(m³·K) – Section 4.2.5
- Borehole depth 150m
- Borehole diameter 160mm
- Grout thermal conductivity 1.5W/m/K
- Double U-tube 40mm, SDR 11 HDPE pipe
- Shank spacing 110mm
- Fluid flow rate 0.65L/s per borehole[2]
- Heat transfer fluid: 25% monoethylene glycol[3]
- Contact resistance grout-to-pipe 0.01Km/W (recommended by EED manual)
- Coefficient of performance COPH 3.5 (in heating mode)[4]

---

[2] sufficient to give a Reynolds Number > 2500 – i.e. transient turbulent flow

[3] This should not be construed as a recommendation. The final selection of the heat transfer fluid should be based on considerations of viscosity, density, necessary frost protection, cost and – importantly – toxicity and acceptability to NIEA. The 25% glycol gives a nominal frost protection to -14°C

[4] EED only allows a single COPH to be entered, which also functions as a the seasonal performance factor (SPFH), which is a slight weakness in the EED program. A moderately conservative (high) value has been assumed for a closed loop system.



EED-generated section of borehole, showing assumed 160 mm diameter and double U-tube with 110 mm shank spacing (blue = downflow, red = upflow).

Model simulation period has been set to 30 years, starting in January.

3.0 Borehole Array Locations

DfE advised on 11th June 2025 that the focus for the heat networks should be Parliament Buildings, Stormont Castle, and Castle Buildings and that lawn areas as well as the Dog Park could be considered as possible array sites. Figure A shows a map of the revised locations (based on a LiDAR image which was used to exclude some steep areas which would be inaccessible to drill rigs).

4.0 Thermal Modelling

Separate EED models were constructed for each of the borehole arrays illustrated on Figure A. Each array was modelled as an initially rectangular grid of boreholes at 11m borehole spacing and modified to reflect the actual mapped geometry. It was assumed that required heating load would be met at FLEQ 2200hrs with maximum continuous peak load duration of 10 hr/day. Average fluid temperature under peak load conditions after 30 years was kept between 1.0°C and -1.5°C

Thermal outputs are summarised in Table 3.

Table 3: Thermal output for revised Stormont closed loop borehole arrays

	area m^2	borehole	base load	peak load
			MWh/annum	kW
Parliament Building South Lawn	9379	78	975	448
Parliament Building - Roadway	2481	25	415	207
Parliament Building - West Car Park	2005	19	258	120
Parliament Building - East Car Park	1589	17	238	105
Parliament Building Main Car Park	7244	63	712	324
Parliament Building West Road	485	5	118	49
Parliament Building East Road	391	5	113	47
Stormont Castle Lawn	4037	39	492	226
Stormont Castle 1	478	6	97	41
Castle Buildings West 3	8319	76	830	379
Castle Buildings West 1	11942	102	1065	486
Castle Buildings West 2	930	9	143	64
Castle Buildings East 1	1920	19	262	116
Castle Buildings East 2	9510	88	920	421
Dog Park	10605	95	1013	463
TOTAL		646	7558	3460

The EED outputs for each model are included as Figures B to O and the capacity of each array is also shown on Figure P.

The newly modelled arrays have the capacity to match heating energy demand for each of the three targeted buildings (Table 4). The designs carry a small over capacity which allows some margin to allow for future design changes.

Table 4: Heating demand and array heating capacity

	Heat Demand		Heat Supply from		Excess capacity	
	Total Annual	Peak kW	Total Annual	Peak kW	Total Annual	Peak kW
Parliament Buildings	2395	1090	2829	1300	18%	19%
Stormont Castle	473	220	588	267	24%	22%
Castle Buildings	3793	1720	4233	1930	12%	12%
	6661	3030	7650	3497	15%	15%

5.0 Borehole Array Costing Estimate

The 4No geothermal boreholes drilled at the Stormont site in 2024-205 cost £50,000-£60,000 each and were drilled to an average depth of 105mBGL. These were the initial investigation boreholes and rock section was not as anticipated. Drilling efficiency should improve with learnings gained from multiple well sets and Tetra Tech expect that it will also be possible to leverage the expertise in the wider UK market where larger scheme geothermal drilling is a more developed practice. It is anticipated that it should be possible to reduce prices for multiple borehole arrays of 150m deep boreholes with installed ground loops to approximately £18,000-£20,000 per well. With additional costs for the array surface pipework, manifolds and the required ground-works/trenching expected to add approximately £7500 per well, this results in an estimated cost range of £25000-£27000 per borehole.

Costs per array are outlined below in Table 5

Table 5: Geothermal Closed Loop Array Cost Estimates

	borehole number	cost estimate
		£million
Parliament Building South Lawn	78	2.01
Parliament Building - Roadway	25	0.64
Parliament Building - West Car Park	19	0.49
Parliament Building - East Car Park	17	0.44
Parliament Building Main Car Park	63	1.62
Parliament Building West Road	5	0.13
Parliament Building East Road	5	0.13
Stormont Castle Lawn	39	1.00
Stormont Castle 1	6	0.15
Castle Buildings West 3	76	1.96
Castle Buildings West 1	102	2.63
Castle Buildings West 2	9	0.23
Castle Buildings East 1	19	0.49
Castle Buildings East 2	88	2.27
Dog Park	95	2.45
TOTAL	646	17

6.0 Summary and Recommendations:

As described in the main report, this study demonstrates that installation of a geothermal heating solution on the Stormont Estate is technically feasible. The (amended) results show that the full site’s energy load can be met from borehole arrays developed in up to 15 arrays located in the north of the site. The arrays can be integrated with an Ambient Loop Heat Network to meet 100% of the heating demand of three of the estate's key buildings: Parliament Buildings, Stormont Castle, and Castle Buildings. The construction of a GSHP system offers the potential to reduce both energy costs and carbon emissions.

Recommendations:

The economic feasibility of a geothermal heating system or systems at the Stormont site should be finalised following optimisation of the borehole design and generation of a full suite of potential costs. There will however be an element of ongoing subsurface uncertainty and risk. This combined with the significant cost of installing a system that could meet the full energy needs of the site suggests it may be prudent to proceed with an incremental build out of a geothermal solution.

A solution for Stormont Castle Buildings could be installed on the buildings lawns and would test the thermal performance of a closed loop array on this site and help assess the influence of groundwater flow which should improve operational efficiency and potentially provide significant savings by reducing the number/depth of boreholes required for installation of any subsequent project stages. Based on lessons learned from this investigation, ground issues can now be better anticipated, and a suitable contract could be let for the future work. Such work would commence with installing one to two 'lead' boreholes to confirm local site-specific ground conditions further with a TRT to refine the design and/or number of boreholes before full implementation.

Further work could also be undertaken to establish potential summer cooling loads. If such loads were identified, a combined heating/cooling system should improve the thermal efficiency of the system and reduce the number of boreholes required to meet the potential load. This could have a positive impact on the cost of the scheme

Figures

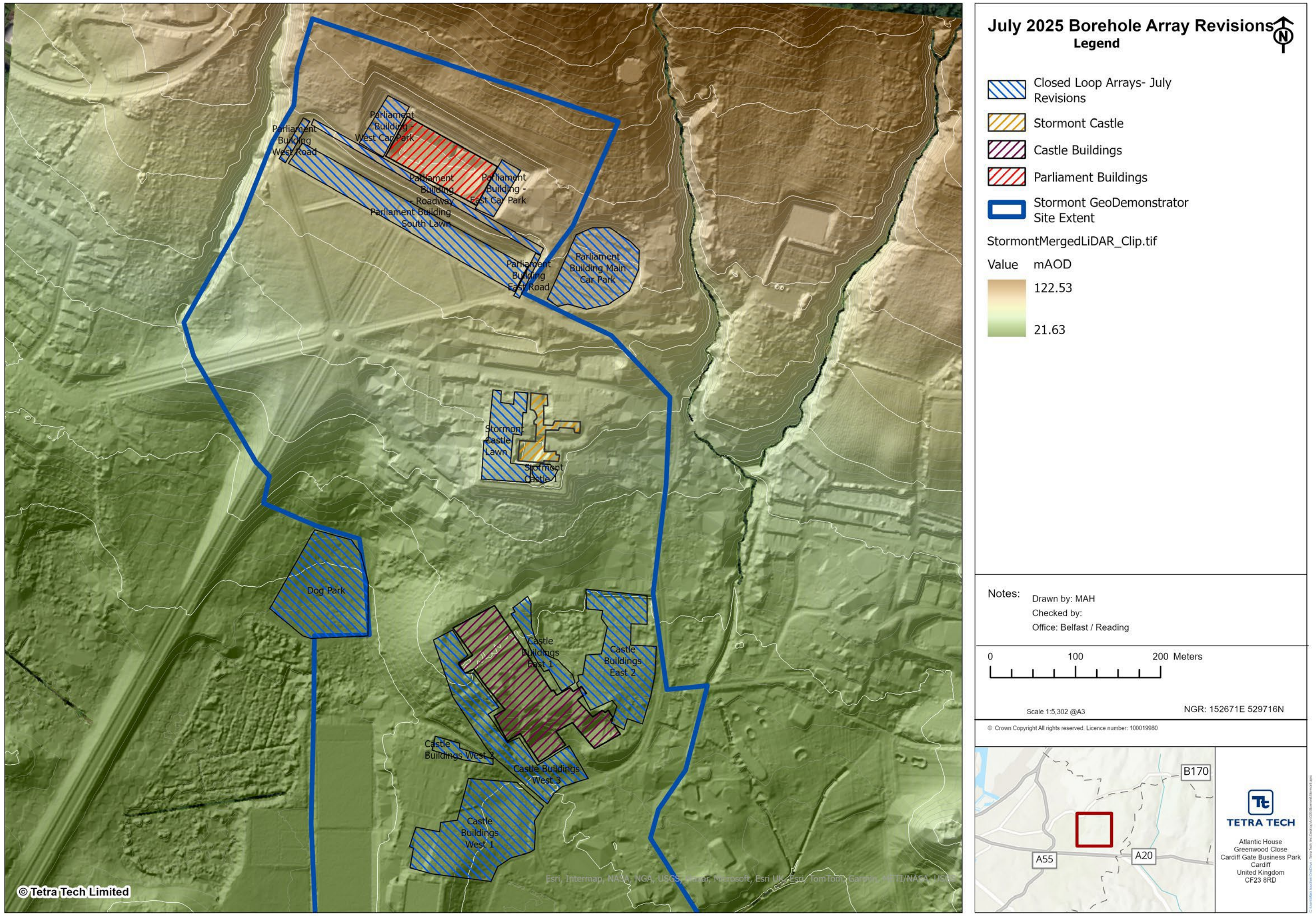
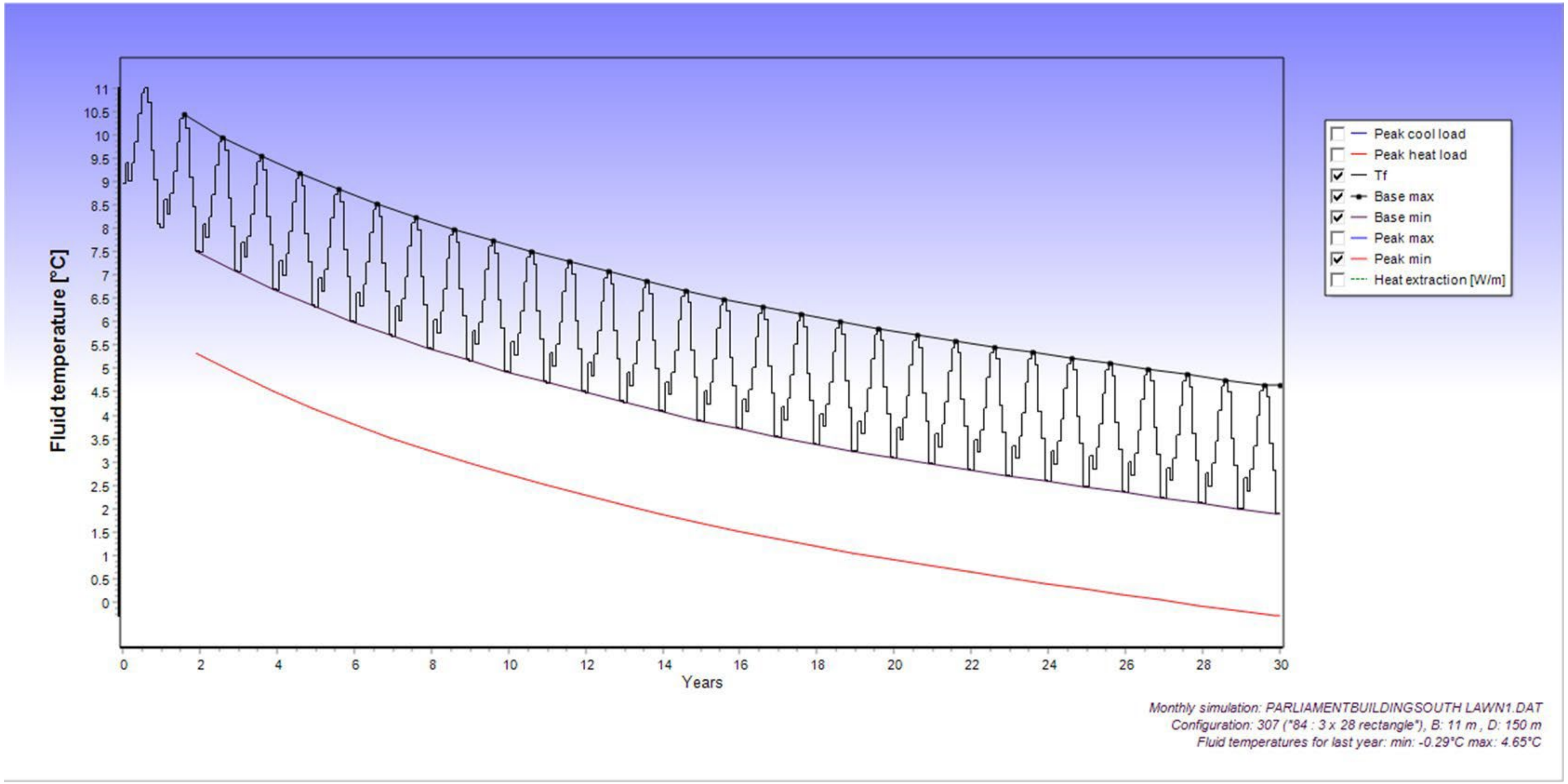


Figure A: Revised Stormont Closed Loop Array Locations



Monthly simulation: PARLIAMENTBUILDINGSOUTH LAWN1.DAT
Configuration: 307 ("84 : 3 x 28 rectangle"), B: 11 m , D: 150 m
Fluid temperatures for last year: min: -0.29°C max: 4.65°C

Figure B: EED output for Parliament Building South Lawn

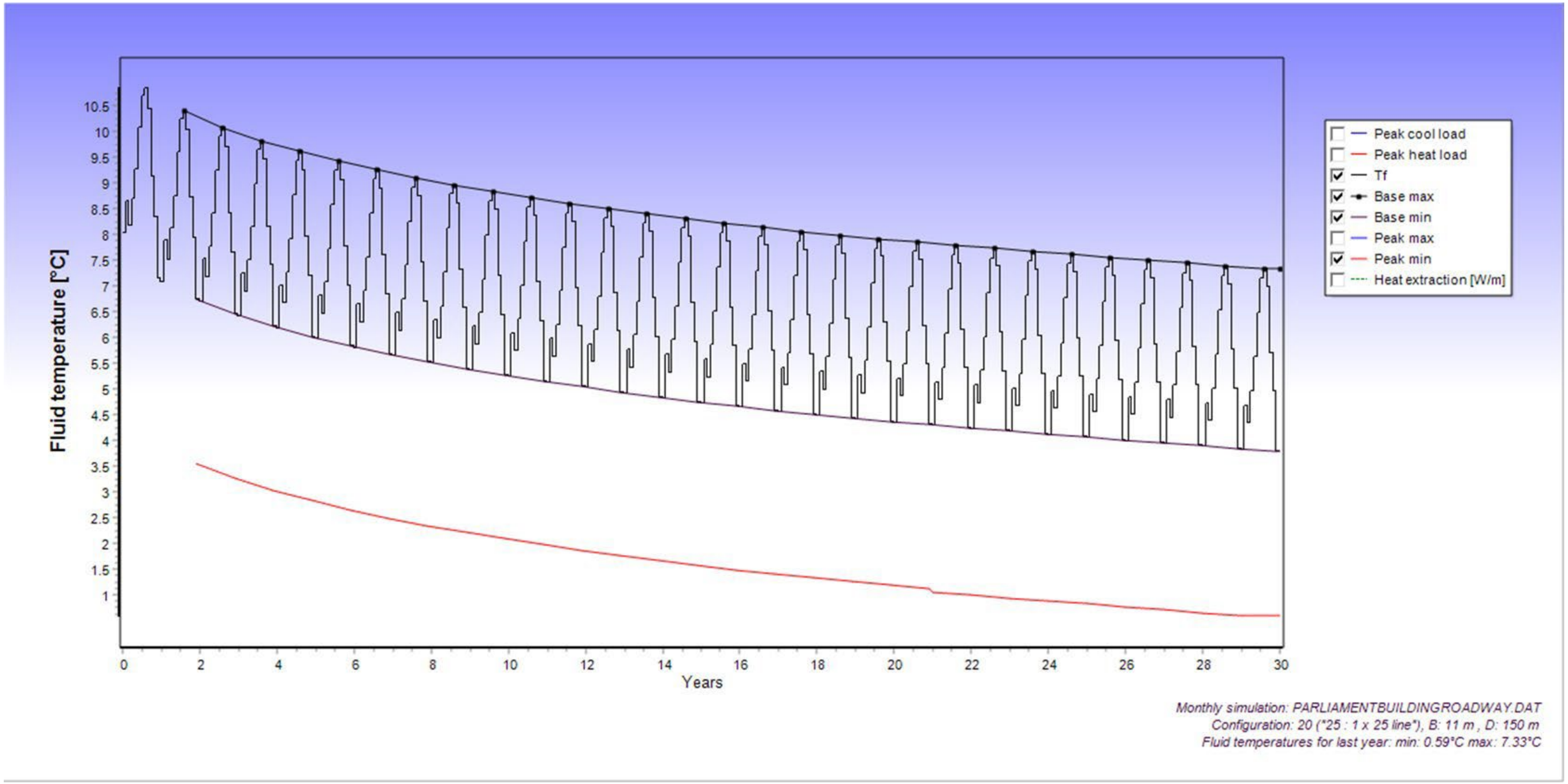


Figure C: EED output for Parliament Building Roadway[5]

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[5] Note that this has been run for a 25*1 array versus 29*1 array as EED is not set up to do the latter. Output has been scaled appropriately

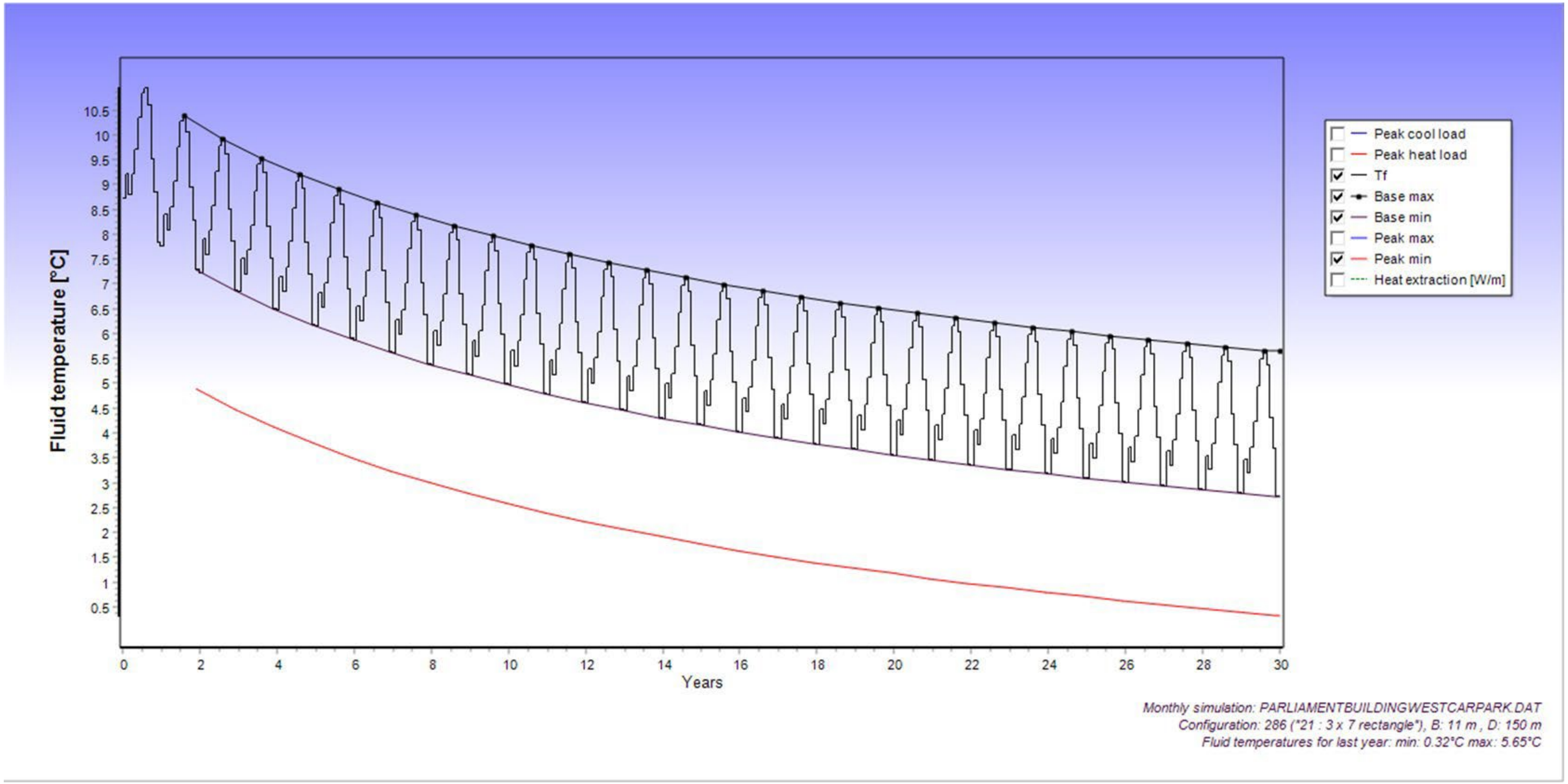
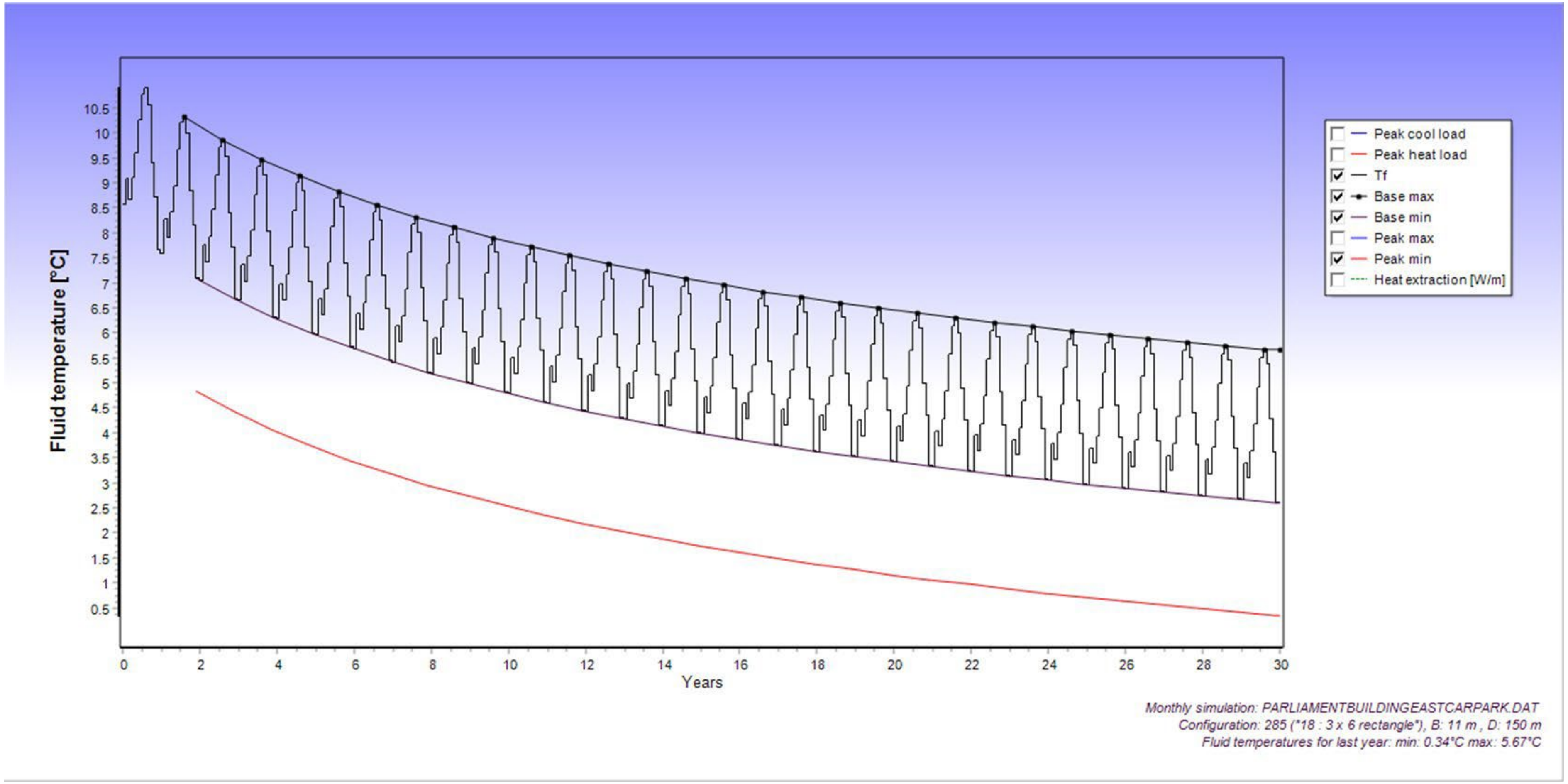


Figure D: EED Output for Parliament Building West Car Park



Monthly simulation: PARLIAMENTBUILDINGEASTCARPARK.DAT
Configuration: 285 ("18 : 3 x 6 rectangle"), B: 11 m , D: 150 m
Fluid temperatures for last year: min: 0.34°C max: 5.67°C

Figure E: EED Output for Parliament Building East Car Park

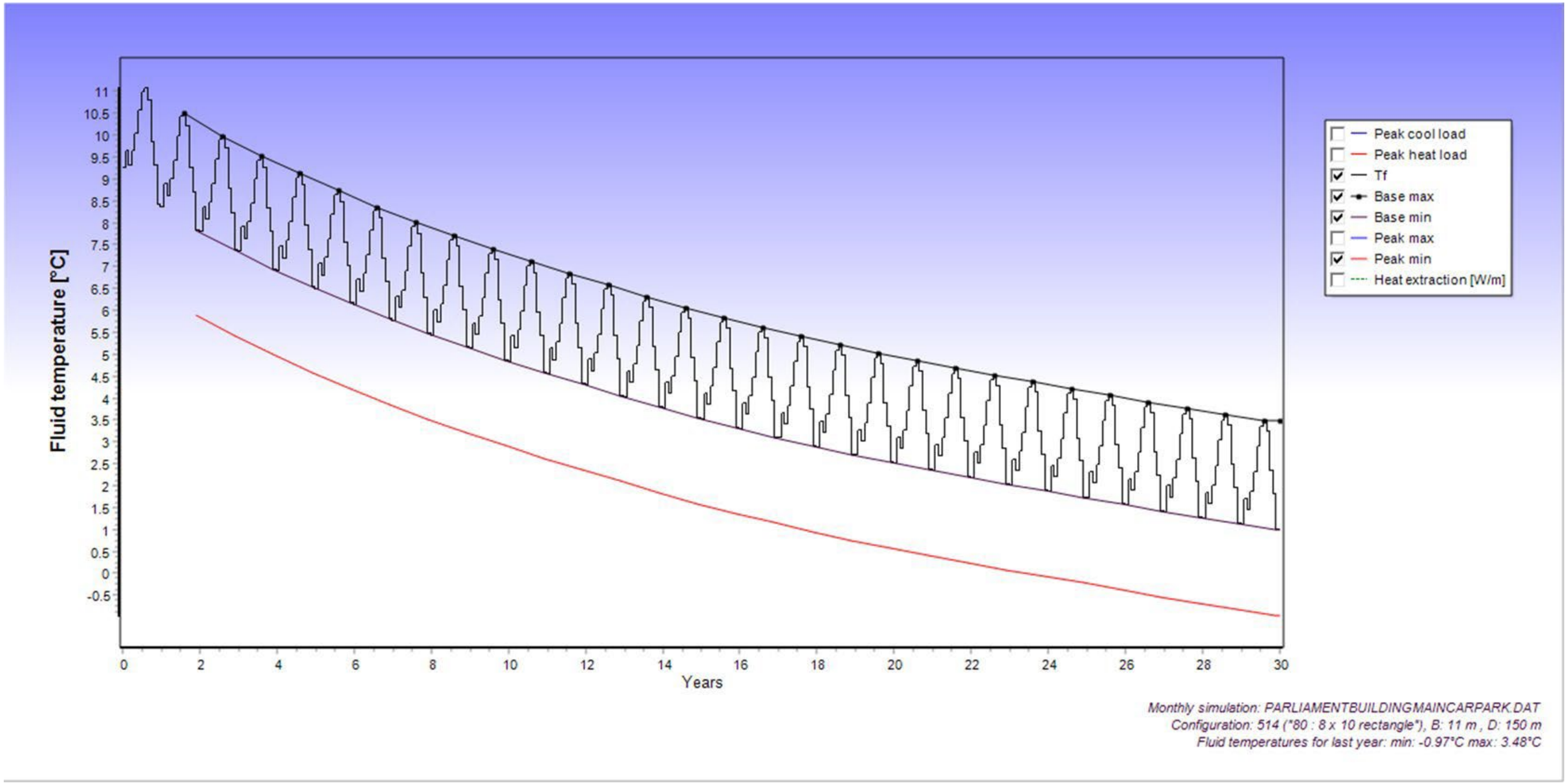
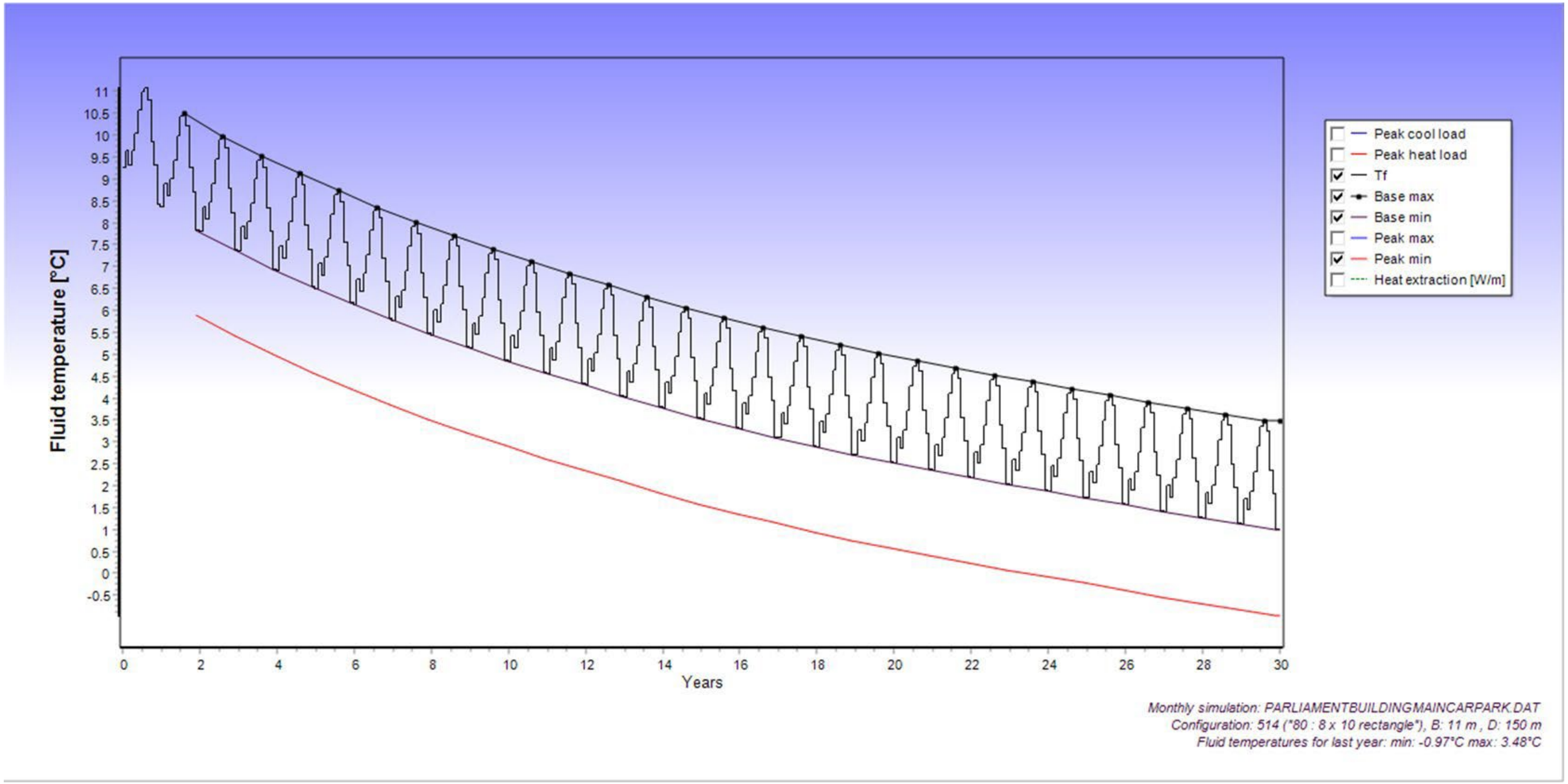
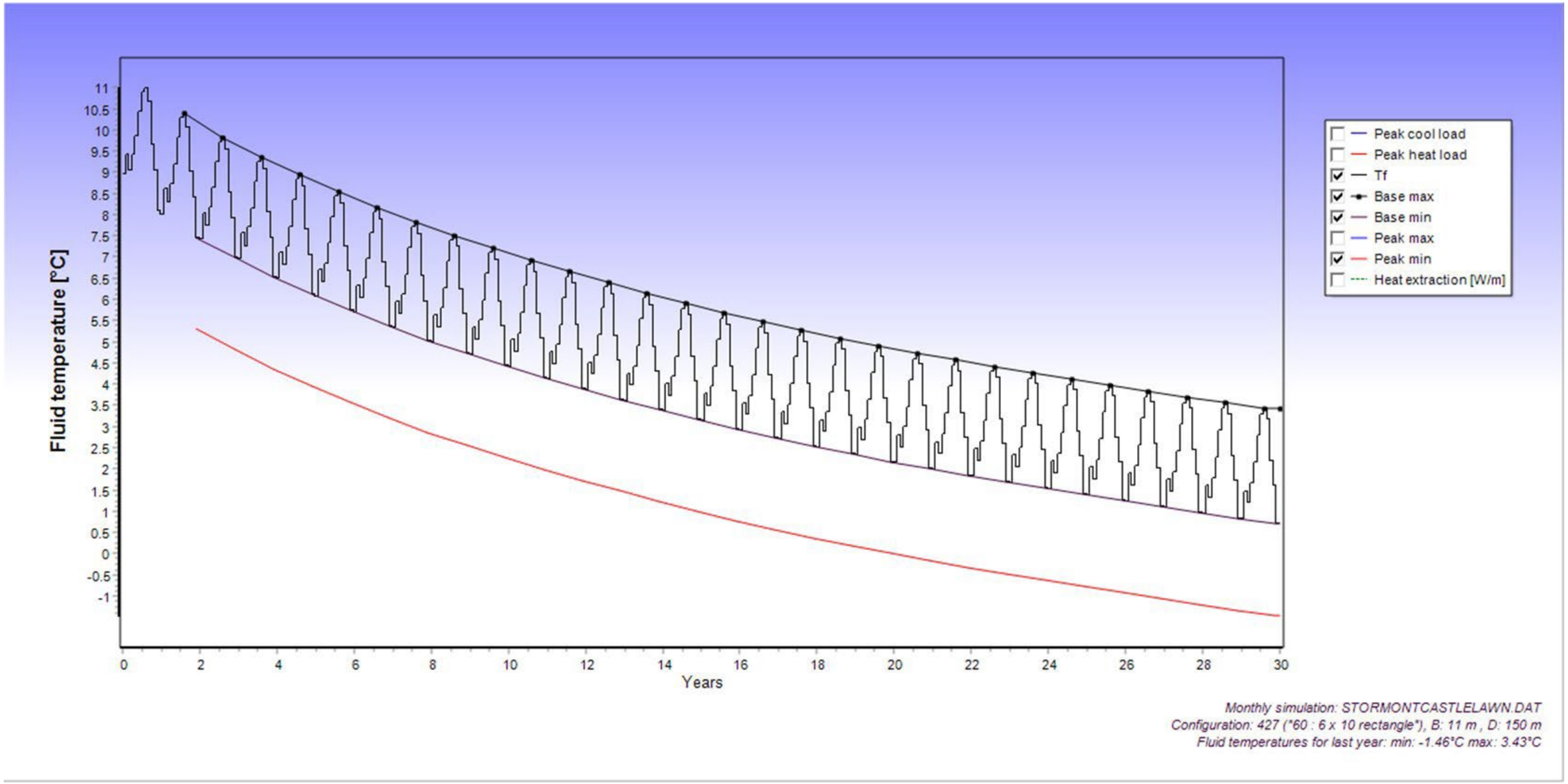


Figure F: EED Output for Parliament Building Main Car Park



Monthly simulation: PARLIAMENTBUILDINGMAINCARPARK.DAT
Configuration: 514 ("80 : 8 x 10 rectangle"), B: 11 m , D: 150 m
Fluid temperatures for last year: min: -0.97°C max: 3.48°C

Figure G: EED Output for Parliament Building East and West Roads



Monthly simulation: STORMONTCASTLELAWN.DAT
Configuration: 427 ("60 : 6 x 10 rectangle"), B: 11 m , D: 150 m
Fluid temperatures for last year: min: -1.46°C max: 3.43°C

Figure H: EED Output for Stormont Castle Lawn

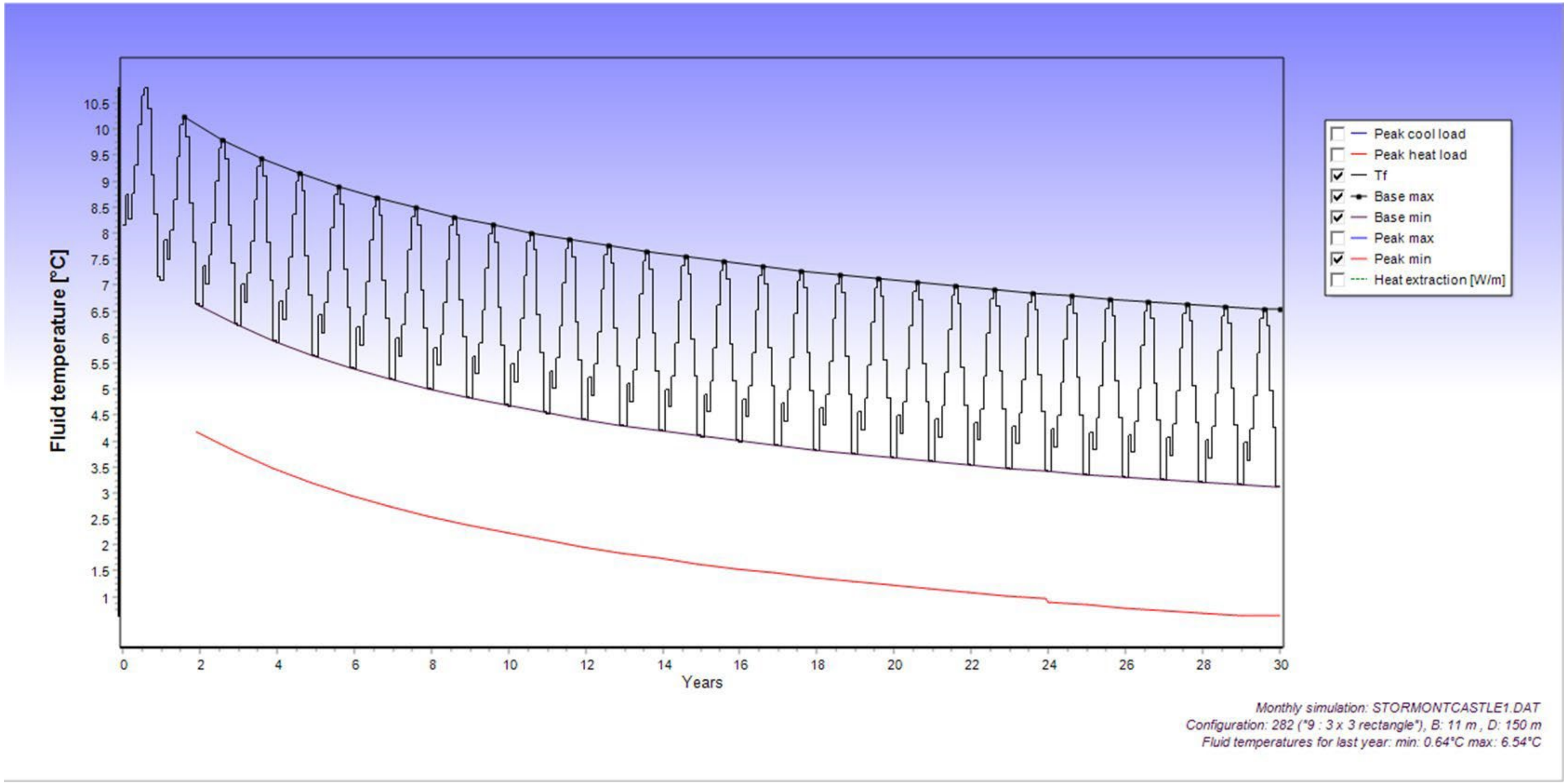
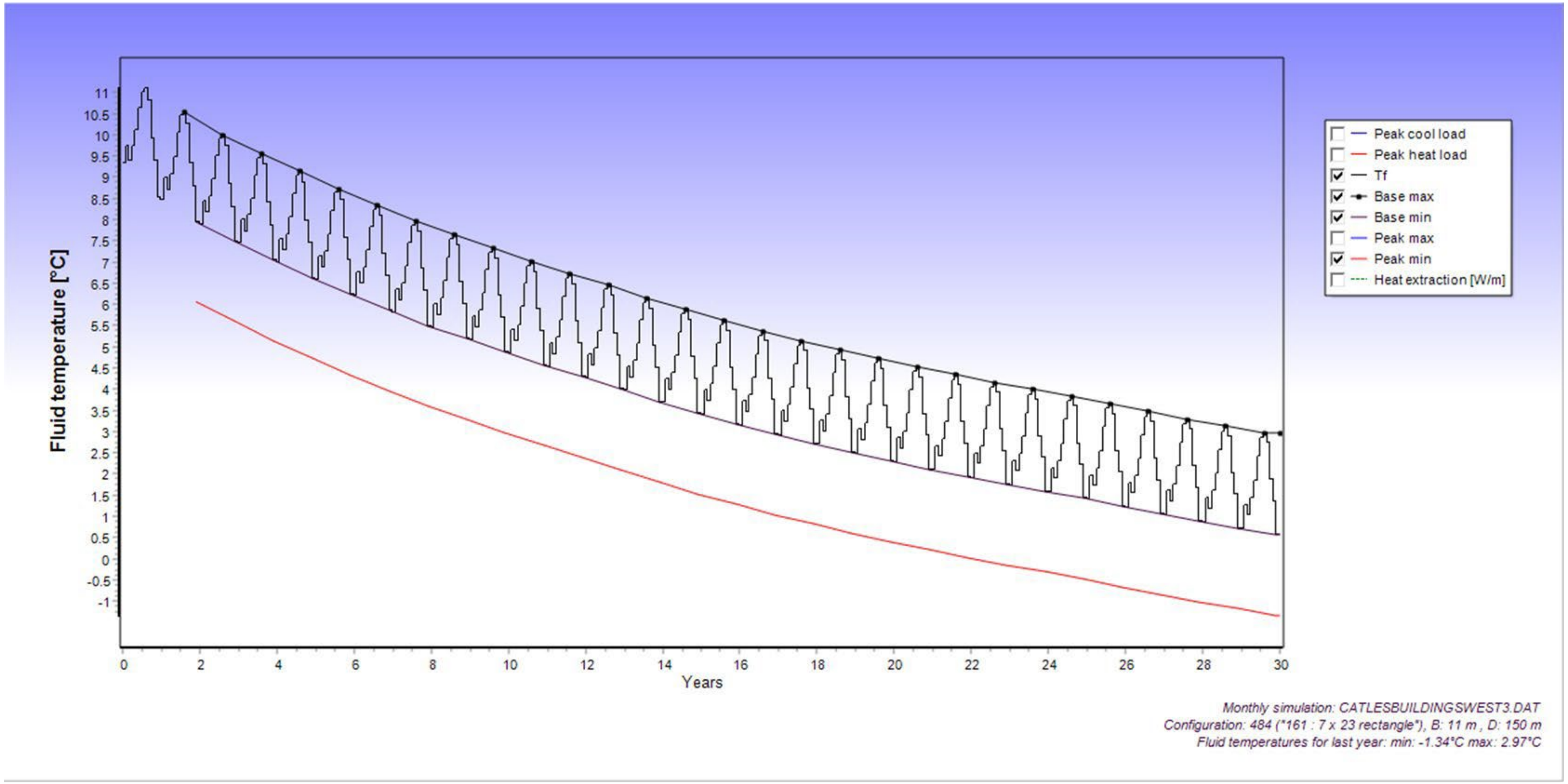
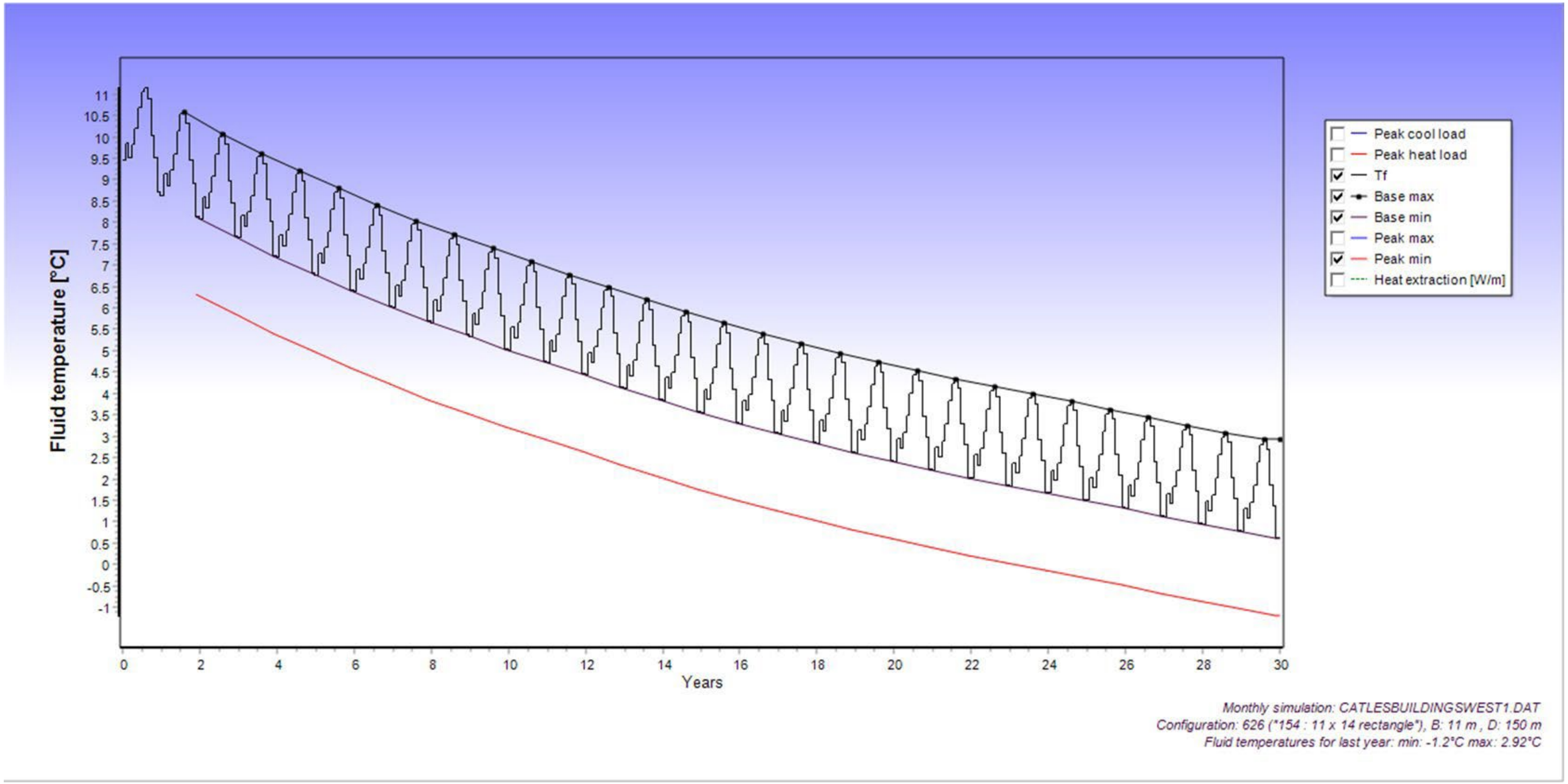


Figure I: EED Output for Stormont Castle 1



Monthly simulation: CATLESBUILDINGSWEST3.DAT
Configuration: 484 ("161 : 7 x 23 rectangle"), B: 11 m , D: 150 m
Fluid temperatures for last year: min: -1.34°C max: 2.97°C

Figure J: EED Output for Castle Buildings West3



Monthly simulation: CATLESBUILDINGSWEST1.DAT
Configuration: 626 ("154 : 11 x 14 rectangle"), B: 11 m , D: 150 m
Fluid temperatures for last year: min: -1.2°C max: 2.92°C

Figure K: EED Output for Castle Buildings West1

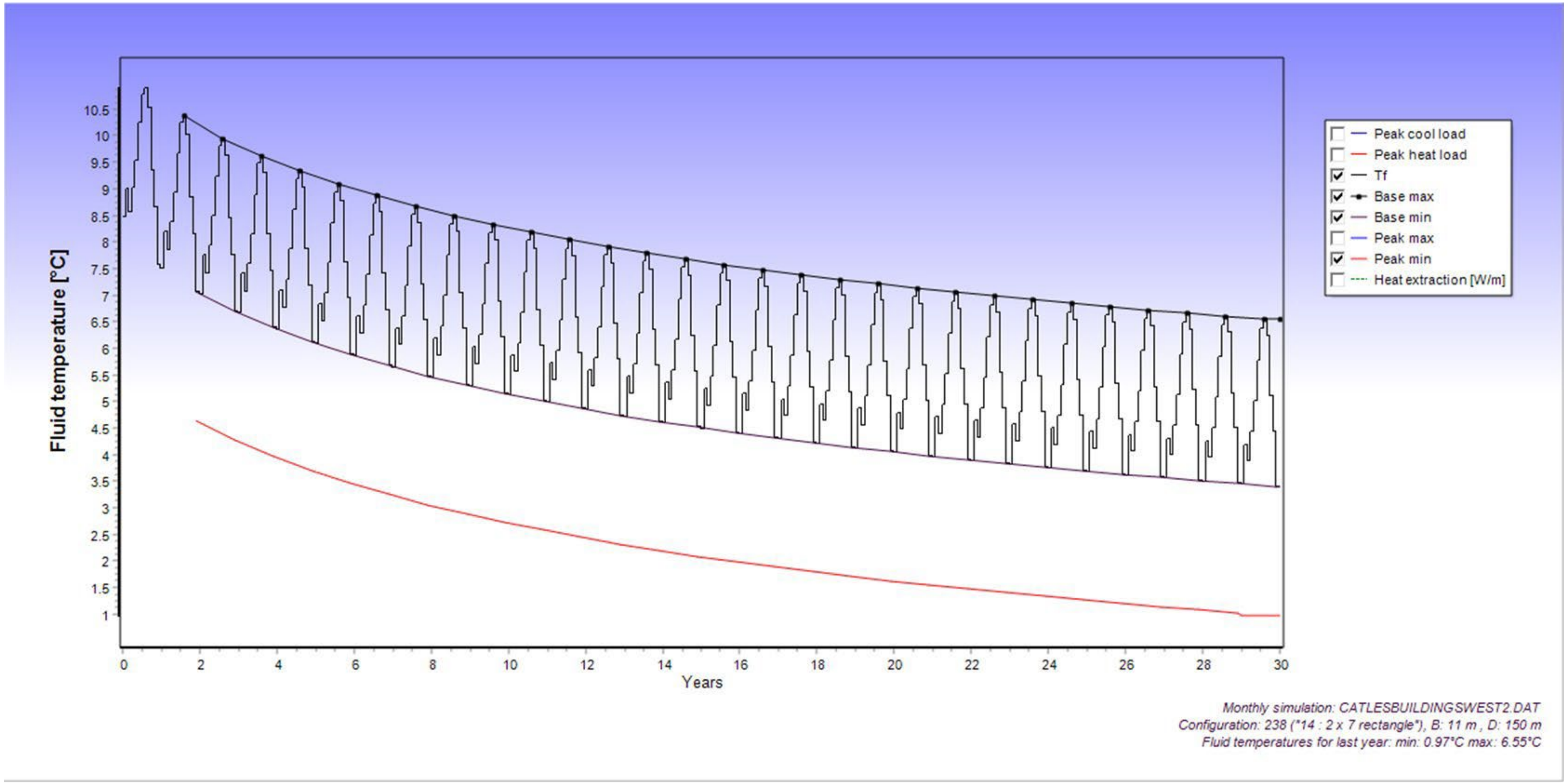


Figure L: EED Output for Castle Buildings West2

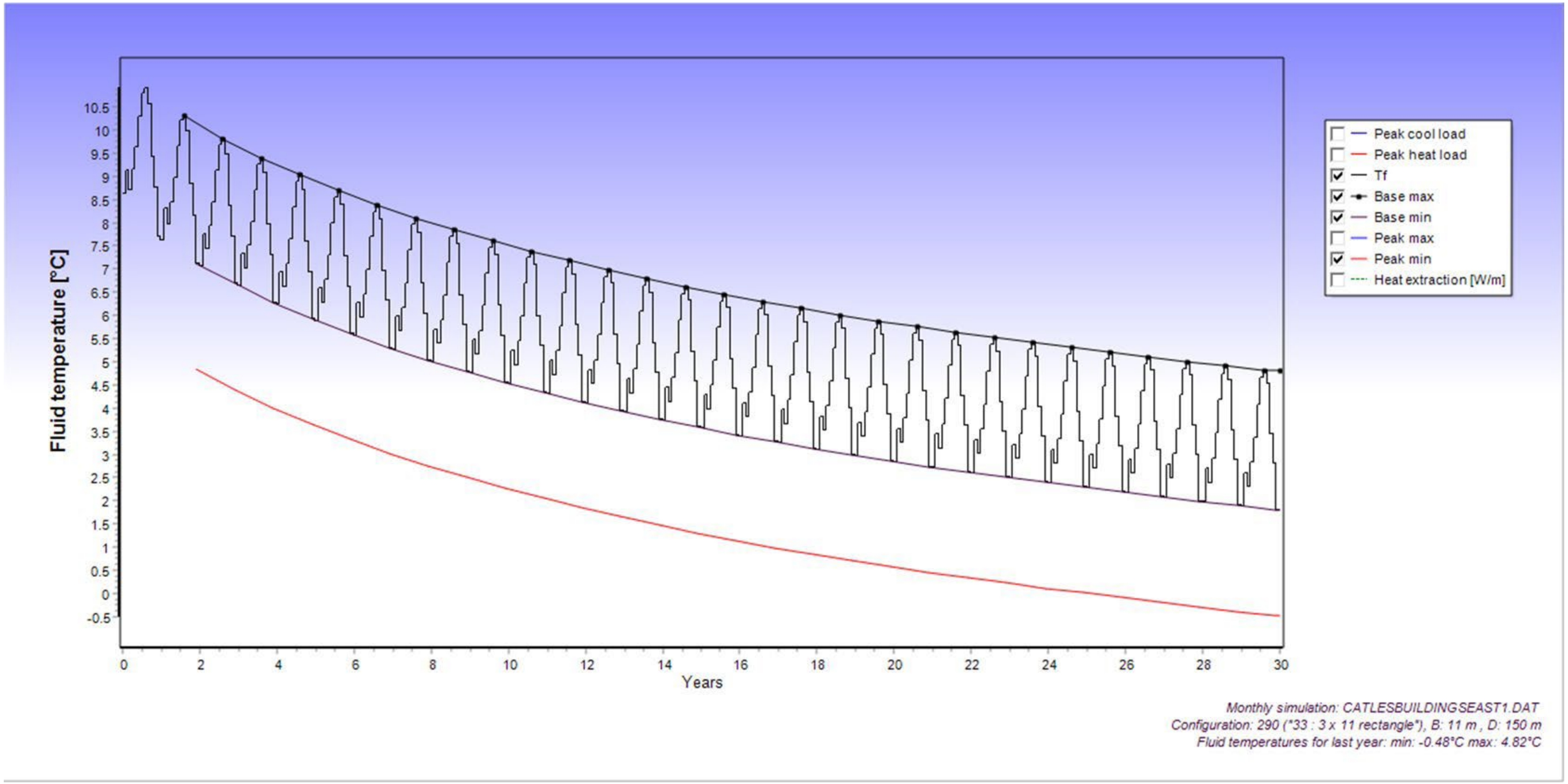


Figure M: EED Output for Castle Buildings East1

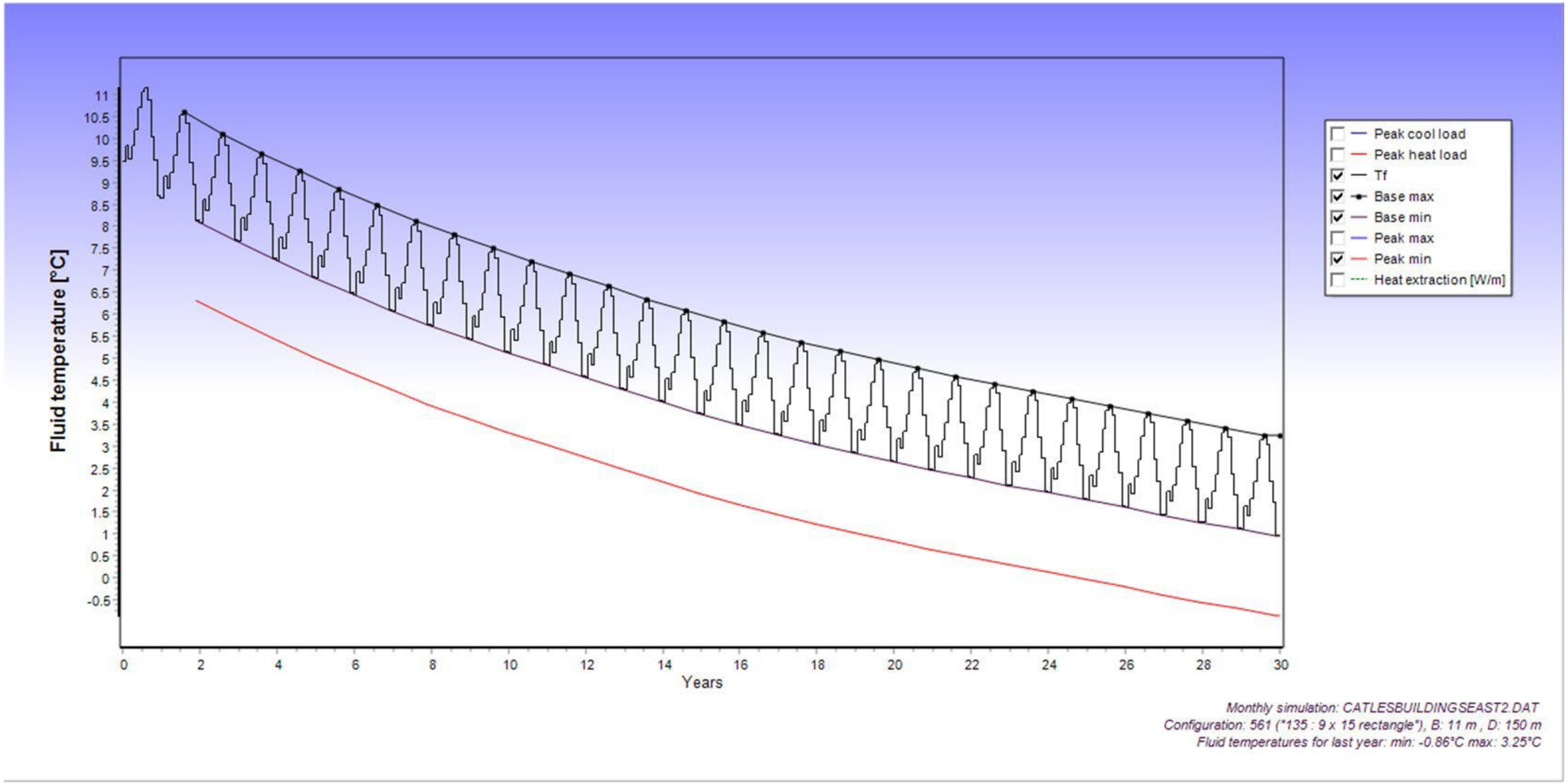
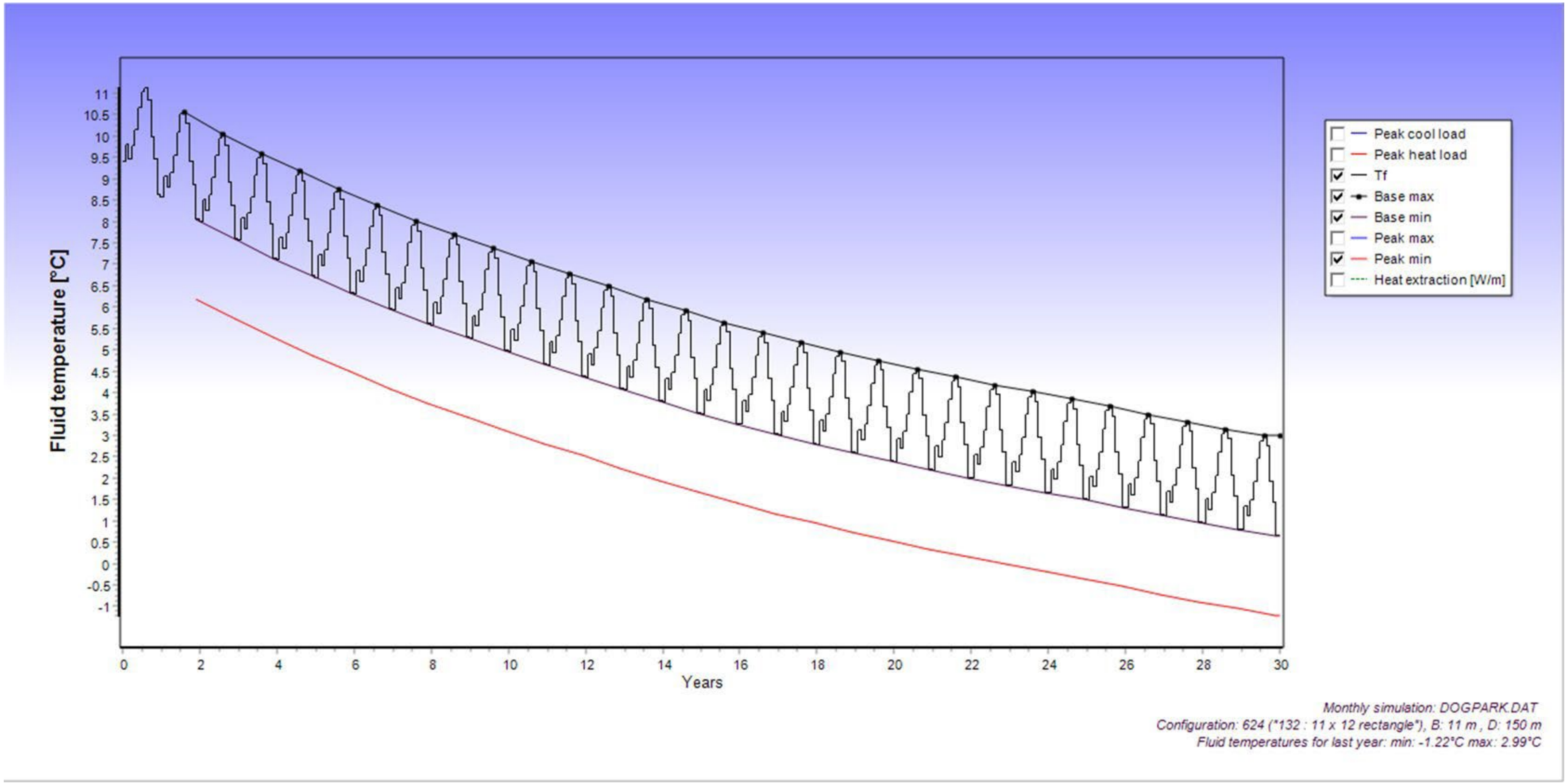


Figure N: EED Output for Castle Buildings East2



Monthly simulation: DOGPARK.DAT
Configuration: 624 ("132 : 11 x 12 rectangle"), B: 11 m , D: 150 m
Fluid temperatures for last year: min: -1.22°C max: 2.99°C

Figure O: EED Output for Dog Park

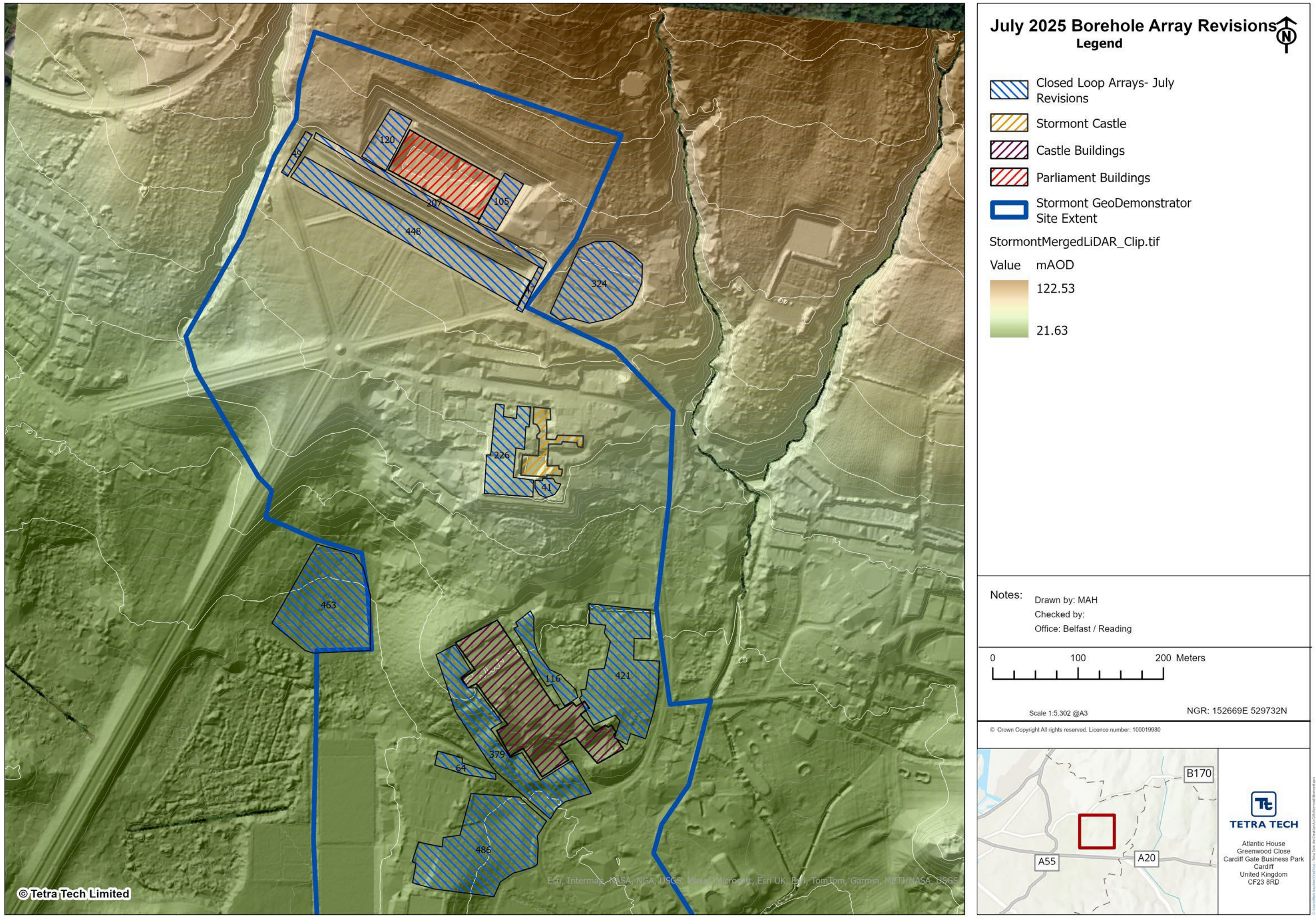


Figure P: Peak capacity (kW) of proposed closed-loop ground arrays at Stormont