United Kingdom Holocaust Memorial and Learning Centre

Energy Statement
December 2018

The Secretary of State for Housing Communities and Local Government

CONTENTS

TABLES

FIGURES

APPENDICES

APPENDIX B

TOPIC PAPER

APPENDIX C

MODELLING INPUT DATA

APPENDIX D

BRUKL DOCUMENTS

APPENDIX D.1

LEAN

APPENDIX D.2

CLEAN

APPENDIX D.3

GREEN

EXECUTIVE SUMMARY

The United Kingdom Holocaust Memorial and Learning Centre is a new building of significant national and international importance, located adjacent to the Palace of Westminster within the grounds of the Victoria Tower Gardens. The Memorial is dedicated to the memory of those who lived and died in the Holocaust. It will be a public attraction, intended to house a wide range of exhibits and articles relating to the persecution of minorities, designed, architecturally and sculpturally by Adjaye Associates and Ron Arad Associates. Their design is embodied as an atmospheric subterranean building with a series of subdivided rooms, corridors and spaces.

As an engineering design team, we understand that the memorial should be a place for quiet reflection, learning and understanding. The ventilation, heating, cooling and humidity control, lighting and the few visible elements of the building services systems have all been designed to contribute towards this.

This document is the Energy Statement for Planning. It has been prepared to demonstrate at the point of the submission of the Planning Application that the Memorial will meet all requisite UK Building Regulations standards and additional standards imposed on new buildings in Greater London. This Energy Statement has been produced with reference and to meet the requirements of The London Plan (the Spatial Development Strategy for London Consolidated with Alterations Since 2011, March 2016), Energy Planning (Greater London Authority guidance on preparing energy assessments, March 2016) and Sustainable Design and Construction (Supplementary Planning Guidance, London Plan 2011, Implementation Framework, April 2014).

The following description of the energy strategy is aligned with the London Plan's Lean, Clean, Green Energy Hierarchy; all design decisions were rigorously tested against alternatives during the feasibility stage with the support of a dynamic simulation model to inform on the effect on energy consumption and carbon emissions.

LEAN MEASURES

Thermal mass - The building is situated underground with the roof of the occupied spaces being at ground level for visitors to Victoria Tower Gardens. All floors, walls and soffits will concrete, providing high thermal mass. This will reduce internal temperature fluctuation, providing a stable / comfortable internal environment and free cooling during periods of warm weather, and free heating during cold weather, improving comfort and saving energy and carbon.

Optimised insulation – By maintaining a thermally massive internal concrete layer and surrounding this with a layer of insulation and isolating the building from the ground, net carbon emissions will be minimised and the risk of condensation eliminated. The solution uses 100 mm rigid insulation in the floor and walls and 125 mm in the roof.

Thermal labyrinth – Fresh air will be supplied to the occupied spaces via a concrete labyrinth located underneath the floor of the building. This will be 'charged' using cool air overnight when the building is not occupied. During the day, fresh air will be supplied from air handling plant and the labyrinth will pre-cool the air due to the coolth retained in its thermal mass, reducing the requirement for energy for cooling energy.

Displacement ventilation system - Will supply fresh tempered air at floor level and extract stale air at high level. This is the best technical solution to partner the labyrinth, allowing year-round heat storage and recovery to maximise efficiency in operation. The air handling plant and the distribution system, including the design of the distribution ducts were selected to minimise specific fan powers and the system will be 'demand controlled' using CO_2 sensors concealed within the extract air outlet. Refer to Ventilation Statement for Planning for further details.

Optimised lighting – All lighting in the building will utilise extremely high efficiency lamps and luminaires with optimised controls, including auto on/off sensor controls to minimise energy use when the building is not occupied. The lighting levels will be low compared with other building types, which will significantly reduce energy consumption.

Underfloor cooling system - Supplied with chilled water from the ground source heat pumps, the system will be zoned, using a series of manifolds which are thermostatically-controlled to maintain comfort conditions in the space.

Hydronic heating coils – Heating will be provided to the space using heating coils built into the low-level supply grilles. Using an air system ensures a faster heat-up time than an underfloor system, so comfort conditions can be maintained during occupied hours.

CLEAN MEASURES

The design does not incorporate any CHP equipment or have connections to any district heat networks due to project, site and locational constraints (see energy strategy constraints below).

GREEN MEASURES

Open loop ground source heat pumps - Uses the ground as a heat source and heat sink, for both heating and cooling. The system will be powered by mains electricity with the potential to utilise renewably-generated electricity (generated off-site, arranged with utility supplier) and would have a high efficiency, with a COP of around 5.

The building does not incorporate any additional renewable energy technologies due to building and site constraints, nor did it need additional renewables to meet the requisite performance standards.

RESULTS

ENERGY AND CARBON

It was demonstrated through modelling that the building would be compliant with UK Building Regulations Part L2A with a **BER of 27.0 $kgCO_2/m^2$** against a **TER of 32.6 $kgCO_2/m^2$** (a **17.2%** improvement).

It was shown that this would provide an estimated EPC rating of 31B, indicating a very high level of energy efficiency in the proposed design.

It was also shown that the performance was commensurate with a BREEAM Excellent mandatory credit score in Ene01 of **8 credits** (against a minimum standard of 5).

The following tables and graphs demonstrate the performance of the building at each stage of the London Plan Energy Hierarchy, as per the GLA guidance on producing energy assessments.

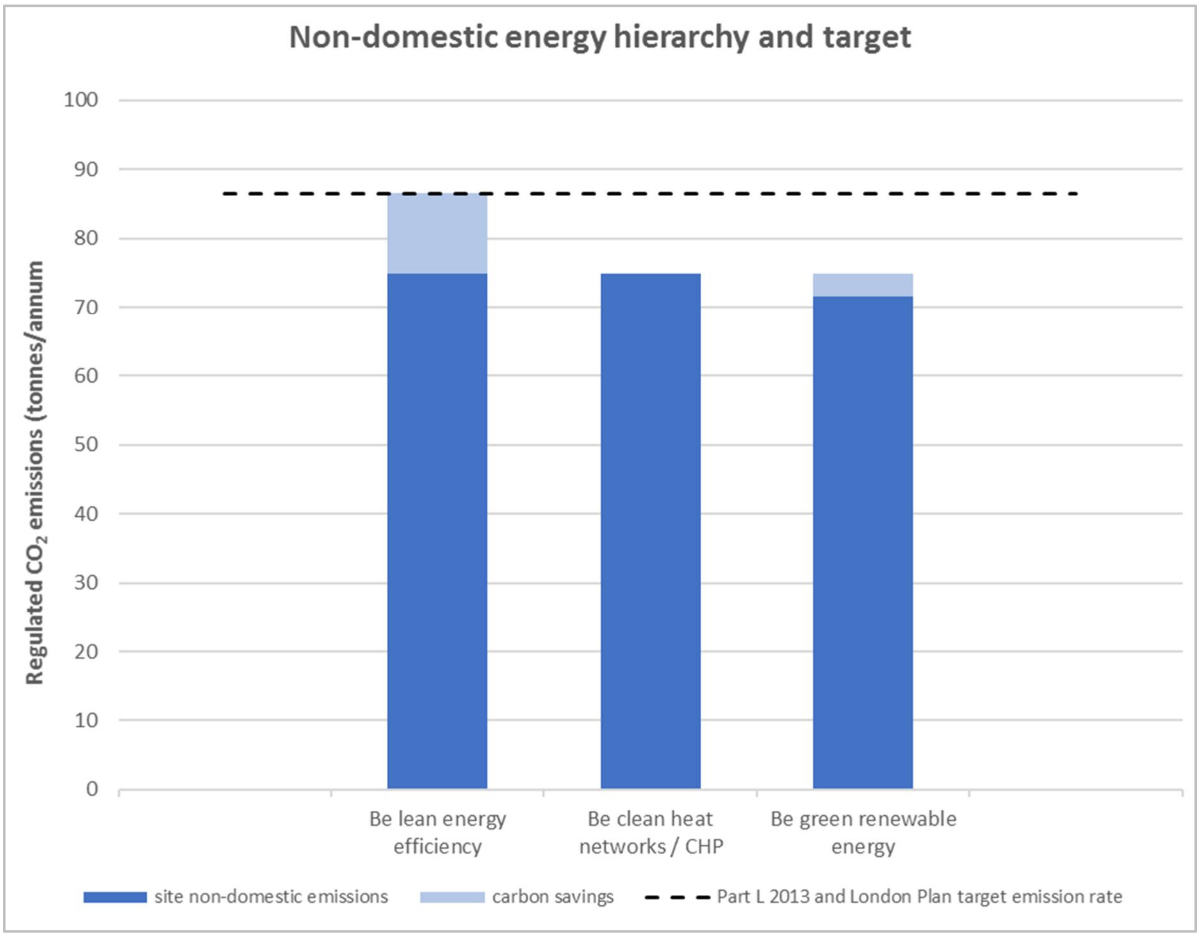
Carbon Dioxide Emissions after each stage of the Energy Hierarchy for non-domestic buildings (main memorial building only)

	Carbon dioxide emissions for domestic buildings (Tonnes CO_2 per annum)	
	Regulated	Unregulated
Baseline: Part L 2013 of the Building Regulations Compliant Development	86.5	139.4
After energy demand reduction	74.8	139.4
After heat network / CHP	74.8	139.4
After renewable energy	71.6	139.4

Regulated carbon dioxide savings from each stage of the Energy Hierarchy for non-domestic buildings (main memorial building only)

	Regulated non-domestic carbon dioxide savings	
	(Tonnes CO_2 per annum)	(%)
Savings from energy demand reduction	11.7	13.5
Savings from heat network / CHP	0.0	0.0
Savings from renewable energy	3.2	3.7
Total Cumulative Savings	**14.9**	**17.2**

Non-domestic energy hierarchy and target (main memorial building only)



OVERHEATING

The results showed that a comfortable and reasonable temperature profile is anticipated within the completed building, and demonstrates compliance with the BREEAM Hea04 first credit (thermal modelling). Further work will be carried out to evidence the second credit (climate change adaption) and this will be detailed in the WSP report entitled ‘BREEAM Low Carbon Design Study’.

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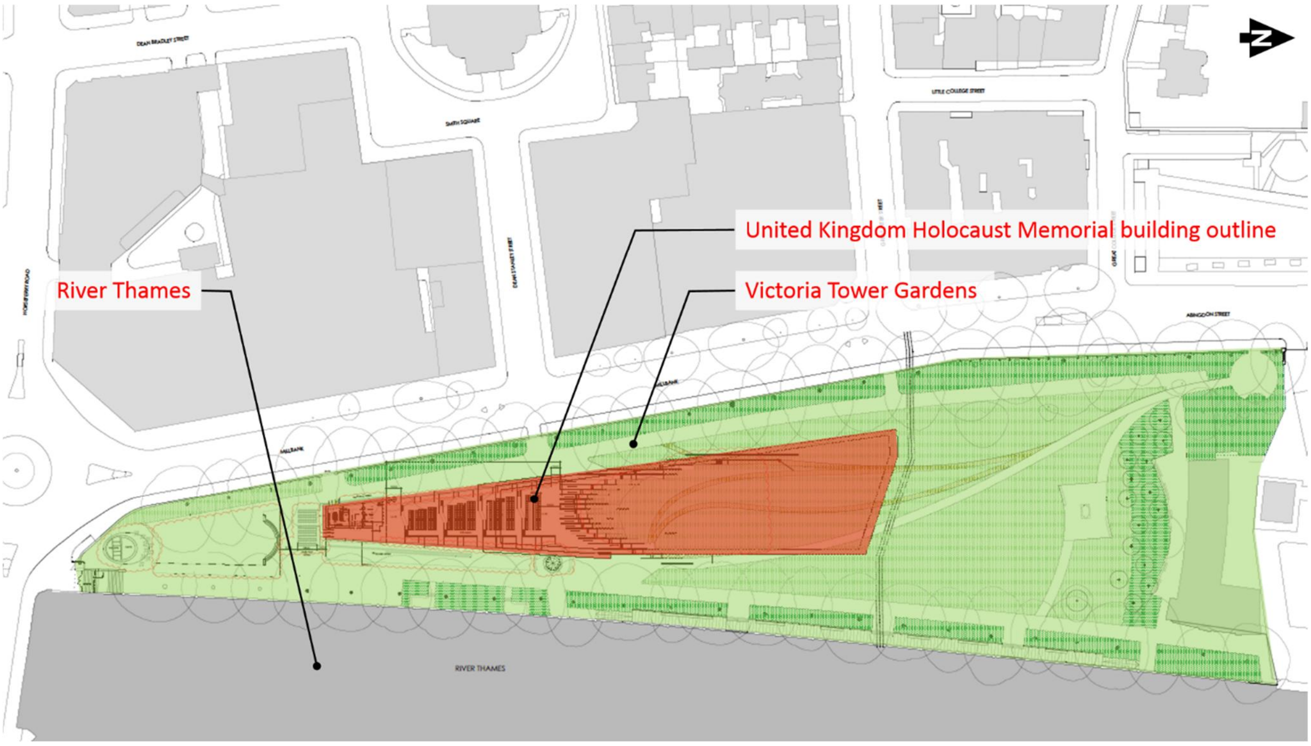
1 INTRODUCTION

1.1 OUTLINE OF THE DEVELOPMENT

The United Kingdom Holocaust Memorial and Learning Centre is a new building of significant national and international importance, located adjacent to the Palace of Westminster within the grounds of the Victoria Tower Gardens. The Memorial and is dedicated to the memory of those who lived and died in the Holocaust. It will be a public attraction, intended to house a wide range of exhibits and articles relating to the persecution of minorities, designed, architecturally and sculpturally by Adjaye Associates and Ron Arad Associates. Their design is embodied as an atmospheric subterranean building with a series of subdivided rooms, corridors and spaces.

As an engineering design team, we understand that the memorial should be a place for quiet reflection, learning and understanding. The ventilation, heating, cooling and humidity control, lighting and the few visible elements of the building services systems have all been designed to contribute towards this. Figure 1 shows the proposed site location of United Kingdom Holocaust Memorial.

Figure 1: Proposed site location of United Kingdom Holocaust Memorial



1.2 PURPOSE OF THIS DOCUMENT

This document is the Energy Statement for Planning. It has been prepared to demonstrate at the point of the submission of the Planning Application that the Memorial will meet all requisite UK Building Regulations standards and additional standards imposed on new buildings in Greater London. To this end, the Energy Statement has been produced with reference and to meet the requirements of the following publications:

The London Plan, the Spatial Development Strategy for London Consolidated with Alterations Since 2011, March 2016

Energy Planning, Greater London Authority guidance on preparing energy assessments, March 2016

Sustainable Design and Construction, Supplementary Planning Guidance, London Plan 2011, Implementation Framework, April 2014

The Energy Statement also addresses UK Building Regulations Part L2A performance (as compliance with the London Plan targets is based on this), BREEAM energy performance (Ene01 minimum mandatory credits required for BREEAM Excellent to be achieved) and overheating.

1.3 AREAS OF GLA POLICY ADDRESSED IN THIS STATEMENT

The specific London Plan policies addressed in this Energy Statement are listed in 1.3.1.

1.3.1 LONDON'S RESPONSE TO CLIMATE CHANGE

- Policy 5.1 Climate change mitigation
- Policy 5.2 Minimising carbon dioxide emissions
- Policy 5.3 Sustainable design and construction
- Policy 5.6 Decentralised energy in development proposals
- Policy 5.7 Renewable energy
- Policy 5.8 Innovative energy technologies
- Policy 5.9 Overheating and cooling

2 ENERGY STRATEGY

2.1 DESCRIPTION OF STRATEGY

The description of the energy strategy is split into the London Plan's Lean, Clean, Green categories. Furthermore, all design decisions were tested against alternatives during the feasibility stage with the support of a dynamic simulation model to report back on the effect on energy consumption and carbon emissions.

2.1.1 LEAN

Thermal mass - The building is situated underground with the roof of the occupied spaces being at ground level for visitors to Victoria Tower Gardens. All floors, walls and soffits will concrete, providing high thermal mass. This will reduce internal temperature fluctuation, providing a stable / comfortable internal environment and free cooling during periods of warm weather, and free heating during warm weather, improving comfort and saving energy and carbon.

Optimised insulation – By maintaining a thermally massive internal concrete layer and surrounding this with a layer of insulation and isolating the building from the ground, net carbon emissions will be minimised and the risk of condensation eliminated. The solution uses 100 mm rigid insulation in the floor and walls and 125 mm in the roof.

Thermal labyrinth – Fresh air will be supplied to the occupied spaces via a concrete labyrinth located underneath the floor of the building. This will be 'charged' using cool air overnight when the building is not occupied. During the day, fresh air will be supplied from air handling plant and the labyrinth will pre-heat or pre-cool the air due to the coolth retained in its thermal mass, reducing the requirement for energy for heating and cooling energy.

Displacement ventilation system - Will supply fresh tempered air at floor level and extract stale air at high level. This is the best technical solution to partner the labyrinth, allowing year-round heat storage and recovery to maximise efficiency in operation. The air handling plant and the distribution system, including the design of the distribution ducts were selected to minimise specific fan powers and the system will be 'demand controlled' using CO2 sensors concealed within the extract air outlet. Refer to Ventilation Statement for Planning for further details.

Optimised lighting – All lighting in the building will utilise extremely high efficiency lamps and luminaires with optimised controls, including auto on/off sensor controls to minimise energy use when the building is not occupied. The lighting levels will be low compared with other building types, which will significantly reduce energy consumption.

Underfloor cooling system - Supplied with chilled water from the heating ground source heat pumps, the system will be zoned, using a series of manifolds which are thermostatically-controlled and will operate under more extreme climatic conditions to maintain comfort conditions in the space.

Hydronic heating coils – Heating will be provided to the space using heating coils built into the low-level supply grilles. Using an air system ensures a faster heat-up time than an underfloor system, so comfort conditions can be maintained during occupied hours.

2.1.2 CLEAN

The design does not incorporate any CHP (combined heat and power) equipment or have connections to any district heat networks due to the project, site and locational constraints (see energy strategy constraints below).

2.1.3 GREEN

Open loop ground source heat pumps - this technology uses the ground as a heat source and heat sink, meaning that the same system can be utilised for both heating and cooling, as and when dictated by the building's requirements. The system will be powered by mains electricity with the potential to utilise renewably-generated electricity and would have a high efficiency, with a coefficient of performance (COP) of around 5. The system components will be discrete, with no parts of the system visible to the public.

A summary of the feasibility study is included below:

Description: Ground source heat pumps using open loop abstraction from chalk or Thames gravel

Technical details:

- It is estimated that two boreholes will be required for heat rejection & recovery (can provide up to 400 kW per borehole (fewer potential points of failure compared to closed loop)
- The boreholes are both considered as abstraction and discharge points and as such are interchangeable
- A minimum separation distance of 150 m is recommended by the guidance - this is easily achievable within the site spatial constraints, although, these will be outside of building footprint
- No manifold room required, so there will be a circa 10 m^2 space saving over closed loop option within the plant area of the building
- An Environment Agency license will be required for this system - this can take circa 6 months to obtain
- An additional heat rejection coil can be provided in the ventilation AHU to guard against the unlikely event that the ground could become thermally saturated if the load is unbalanced
- There will be a 150 m separation distance between boreholes (not under building footprint, so trenching will be required) and larger thermal capacity of the system compared to closed loop option
- No pollutants will be used (glycol, for example, which is used in closed-loop ground source systems) in designated principal aquifer

Figure 2 shows a layout plan for the open loop boreholes.

Figure 2: Open loop borehole provisional layout plan

SITE PLAN

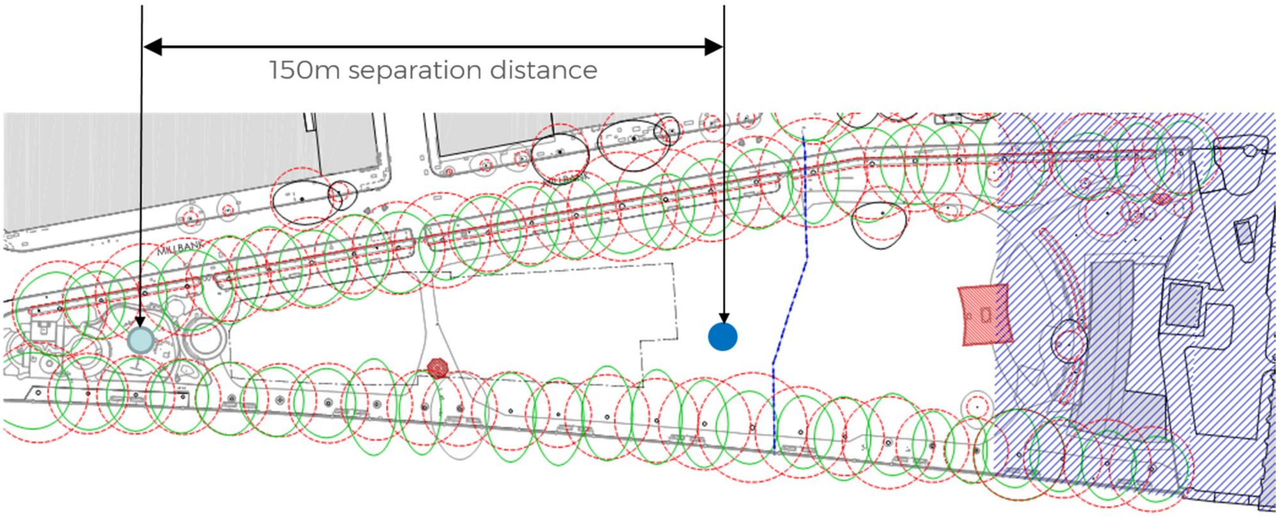
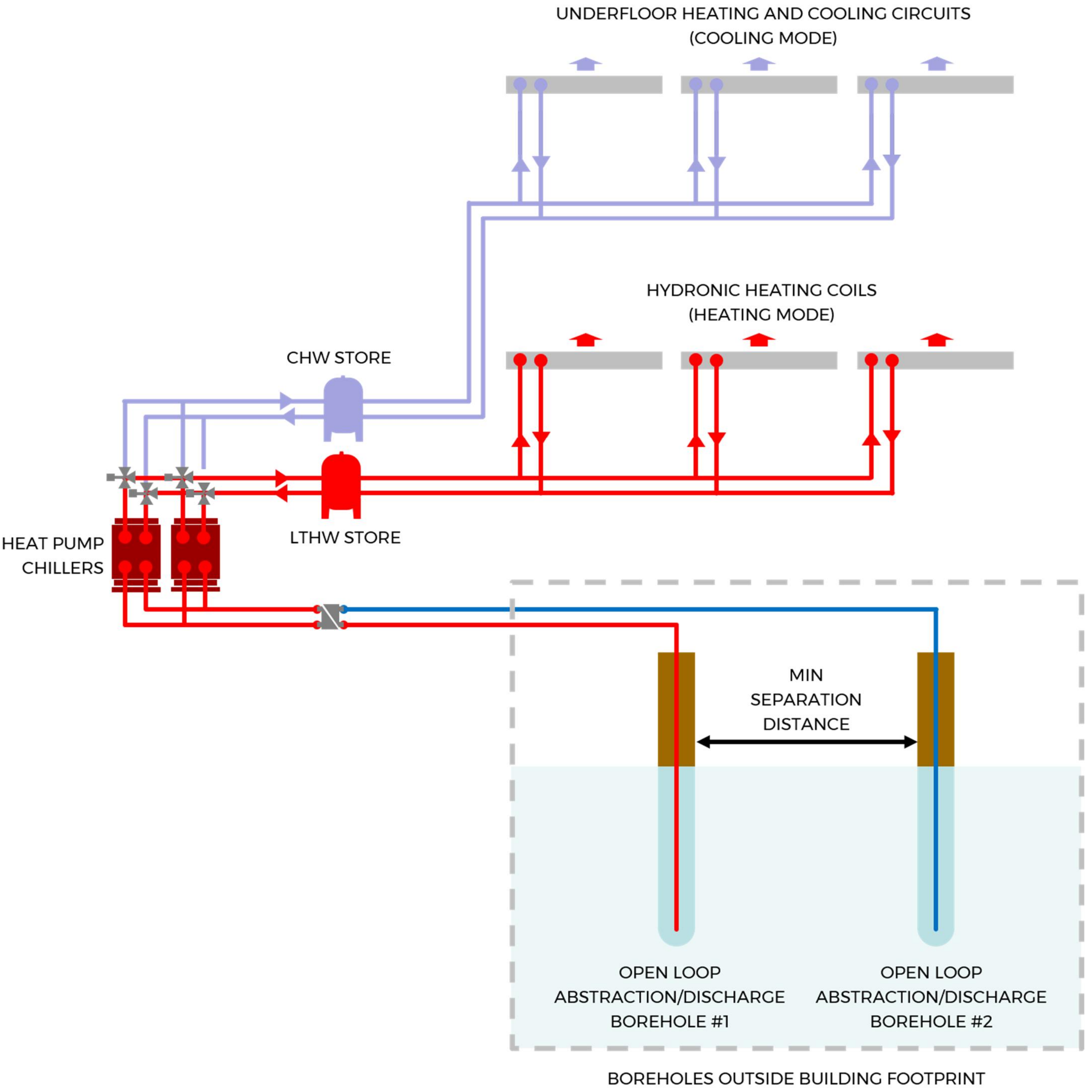


Figure 3 shows a schematic representation of the main system components.

Figure 3: Ground source heat pumps using open loop abstraction from chalk or Thames gravel



The pros and cons of using the open loop ground source option are summarised in Table 1.

Table 1: Pros and cons of using the open loop ground source option

Pros	Cons
• Second most efficient heating and cooling solution (first being a closed loop system) • Good chance of meeting the Westminster and GLA energy and carbon emissions performance standards • Possible to meet all space heating and cooling demands with a single system • Back-up system could also be electric • No flues required, no vapours/chimneys • No gas supply to site necessary • All HVAC services could be hidden • Fins could remain structural/ sculptural - no need to integrate services • Number of boreholes would be considerably fewer • The system components will be discrete, with no parts of the system visible to the public	• Likely to be an expensive option compared with traditional heating and cooling methods (similar cost to closed loop) • Abstraction/ discharge licences are required which have a long lead time (c. 6 months) • Required more annual maintenance than closed loop solution • Higher life cycle cost associated with pump replacement

The Hydrogeological Study

A separate hydrogeological study was subsequently carried out to assess the feasibility of using groundwater for heating and cooling at the proposed development (see Appendix A for the full report). The study concluded the following:

- *This report assesses the feasibility Holocaust Museum, Westminster and, specifically, provides an indicative cost estimate, programme and assessment of risk.*

- *The groundwater system under consideration is designed to provide a close balance between heating and cooling and the estimated loads are small compared to similar applications of the technology in the near vicinity of the site and elsewhere in other established schemes. This has a bearing on project risk (considered low due to the small heating and cooling loads) and also on the economics.*

- *In the context of other established and emerging low carbon heating and cooling technologies the cost of developing a groundwater heating and cooling system is likely to be considerably higher. However, the authors of this report understand that there are other drivers, including an aspiration not to use fossil fuels (for heating) and aesthetic considerations (minimal/negligible surface expression). Justification of the anticipated higher* *cost of developing the groundwater heating and cooling system described in this report should be considered in the context of these and other drivers.*

And recommended the following:

This report should be used as a basis comparing the commercial case for a groundwater heating and cooling system with other viable technologies. If the case for a groundwater heating and cooling system is favourable then further development should be undertaken in accordance with the route map outlined in Section 9 of this report.

From the model results, it was found that the heating and cooling loads of the building will be almost balanced over the course of the year (with a tendency to be cooling-led). This presents a good situation by minimising the possibility of eventual thermal saturation of the ground. Our design incorporates a means of rejecting excess heat to the atmosphere during times when it is not beneficial to reject heat to the ground. This also provides a key climate change adaption measure, allowing the building to adapt to progressively warmer environmental temperatures.

2.2 ENERGY STRATEGY CONSTRAINTS

2.2.1 THE BUILDING

The building is located underground - while presenting a wide range of energy-saving opportunities and benefits, this also presents some limitations. These include:

- There are no exposed external walls - meaning no windows, which means that there will be no (or very little) natural daylight in the space. This in turn means that the energy consumption from artificial lighting will generally be higher.
- There is an absence of windows - means that no beneficial solar gain is possible during the winter months.
- There is no opportunity for natural ventilation - meaning that all fresh air for respiration and odour control will have to be mechanical. This comes with an energy cost.

2.2.2 THE SERVICES

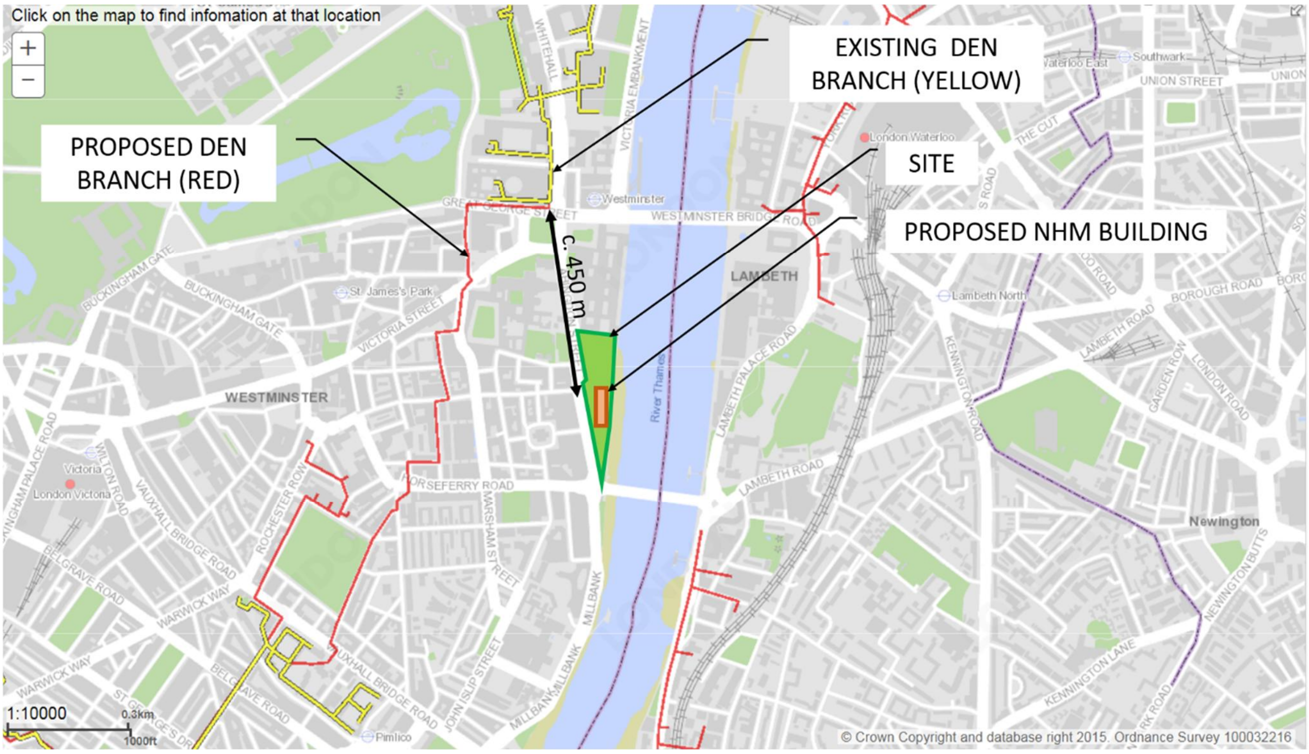
No opportunity to incorporate CHP or district heat network connection - Whilst CHP or a connection to a local heat network might be sensible ways of serving the heating demands of the building, it was found that neither would be possible here.

- **CHP** - This project is subject to significant cultural sensitivities relating to the persecution of minorities during the Holocaust. These have been discussed at length with the client and within the design team and the consensus was that we should aim to avoid all combustion equipment. The rationale for this is that combustion equipment requires a flue/chimney which, under certain atmospheric conditions would produce a vapour, which could have extreme negative connotations in this context. CHP equipment was discounted and alternative heating solutions were investigated.
- **Heat Network** - Using the London Heat map interactive tool, it was identified that there is no district heat network branch within reach of the site (see Figure 4). The map showed that the

closest branch for an existing buried heat main is the corner of Whitehall and Great George Street c. 450 m away from site.

It was also shown that potential future network branches do not pass adjacent to the site, with the closest being St Anne's Street to the West of the site, although the timescales for implementation of this branch is unknown.

Figure 4: Location of the site superimposed on the interactive London Heat Map with district heat network layers (existing and proposed) activated



– **Additional reasons for discounting CHP and heat network** - In addition to the feasibility study on CHP implementation and connections to district heat networks, other reasons for not implementing these technologies were identified. Chief among these were that the building has both heating and cooling demands and the cooling demand is dominant. Because of site constraints, there is no outside space to locate an air-cooled chiller or dry coolers (which need to be open to atmosphere), so cooling would have to be ground source. It was reasoned that if cooling was ground source, then heating might as well be too (they would use the same system, operated in reverse). This would negate the requirement for any CHP or district energy connections, which would be superfluous in this situation.

  Further to this, it does not make any sense to provide blanked-off connections for future connection to a district network, as the heat pump would still be a more efficient system with lower carbon emissions in operation, especially as the carbon emission factor for electricity being reduced in 2019 to 0.233 $kgCO_2/kWh$ in the recently released 'SAP 10'. Finally, the current system is designed for a flow temperature of 45°C (typical for heat pump installations), which would not be compatible with heat derived from alternative sources.

- **Photovoltaics/other renewable energy technology** – The building is underground and one of the key project requirements is to preserve the use of the Victoria Tower Gardens beneath which the building is situated. Because of this, the building effectively has no roof upon which to install any photovoltaics or solar thermal hot water systems, so these technologies were discounted. The technologies: wind, biomass, anaerobic digestion were quickly identified as options to discount.

3 MODELLING

3.1 METHODOLOGY

3.1.1 GENERAL

1. This modelling statement should be read in conjunction with the Energy and Sustainable Construction Topic Paper, produced in March 2018 during RIBA Stage 2 of the project (see Appendix B).

Since the topic paper was produced, the design has developed both architecturally and in terms of the building services and building fabric design

3.1.2 METHODOLOGY NOTES

1. The building was modelled in IES Virtual Environment dynamic simulation modelling software by a CIBSE (Chartered Institution for Building Services Engineers) Level 5 LCEA (Low Carbon Energy Assessor)

IES is accredited under CIBSE AM 10 (Building Performance Modelling)

The model was based on the Architectural Revit model which was issued on 14/09/18 by Adjaye Associates

The model was created in VE Compliance, which is the IES UK Building Regulations compliance software module

The overall carbon dioxide emissions from the development design were minimised through the implementation of the energy hierarchy set out in London Plan policy 5.2

As the main building is predominantly underground, the building was modelled with an 'adjacent condition' representing the ground (12°C year-round average ground temperature taken from data)

The London Plan Energy Hierarchy was followed during the modelling process, which means:

a) All sensible means of reducing energy demand were investigated and sensitivity tested to identify what would be possible, economic, practicable and would minimise energy demand and carbon emissions. The measures tested/considered included:

   - Insulation levels (U-value of ground floor, external walls, roof)
   - Glazing performance (U-value, g-value, daylight transmittance)
   - Opportunities for passive solar gain
   - Air permeability
   - Thermal bridging
   - Thermal massing (or admittance)
   - Lighting efficacy and controls (including daylight dimming/switching)
   - Ventilation - methodology, rates, distribution, fan power, controls (demand, on/off), opportunities for natural ventilation

- Heating – source, distribution, emitters, controls, heat recovery, opportunities for ‘free-heating’
- Cooling – source, distribution, emitters, controls, coolth recovery, opportunities for ‘free-cooling’
- Humidity control

b) Clean energy measures were then considered, including:

- On or off-site CHP (combined heat and power) systems
- Opportunities to connect to a district heat network, using the London Heat Map Interactive Tool

c) Finally, renewable energy technologies were considered, including:

- Heat pumps (air source, ground source, water source)
- Micro-hydro
- Anaerobic digestion
- Solar technologies (photovoltaics, solar thermal, hybrid systems, innovative forms)
- Wind turbines
- Biomass

3.1.3 THE MODEL

Figure 5 to Figure 6 show the model geometry built in the DSM software (Memorial Building and Ticketing Pavilion shown). Please note that the ground plane is not shown in these images.

Figure 5: UK Holocaust Memorial model geometry (looking from South West)

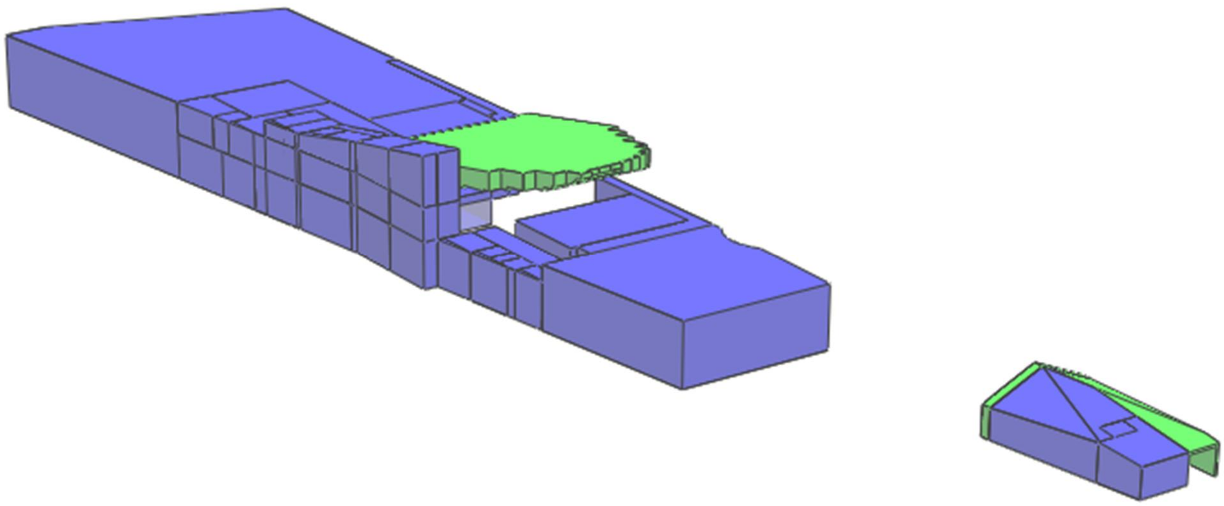


Figure 6: UK Holocaust Memorial model geometry (looking from South East)

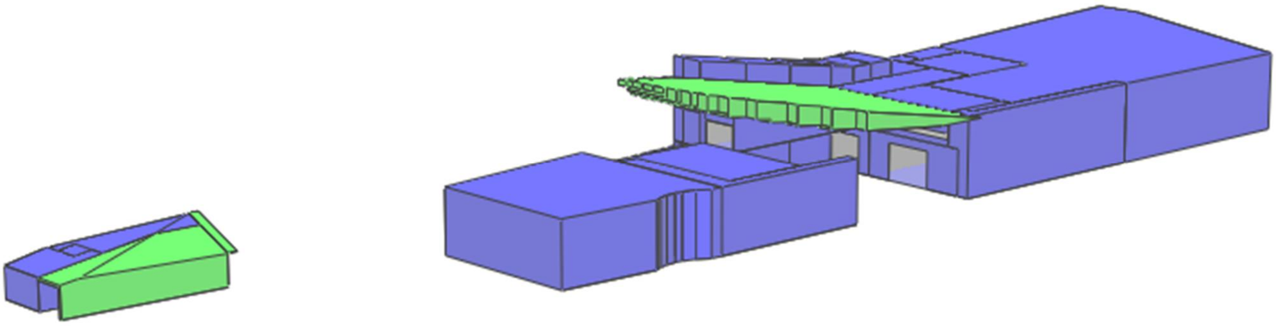
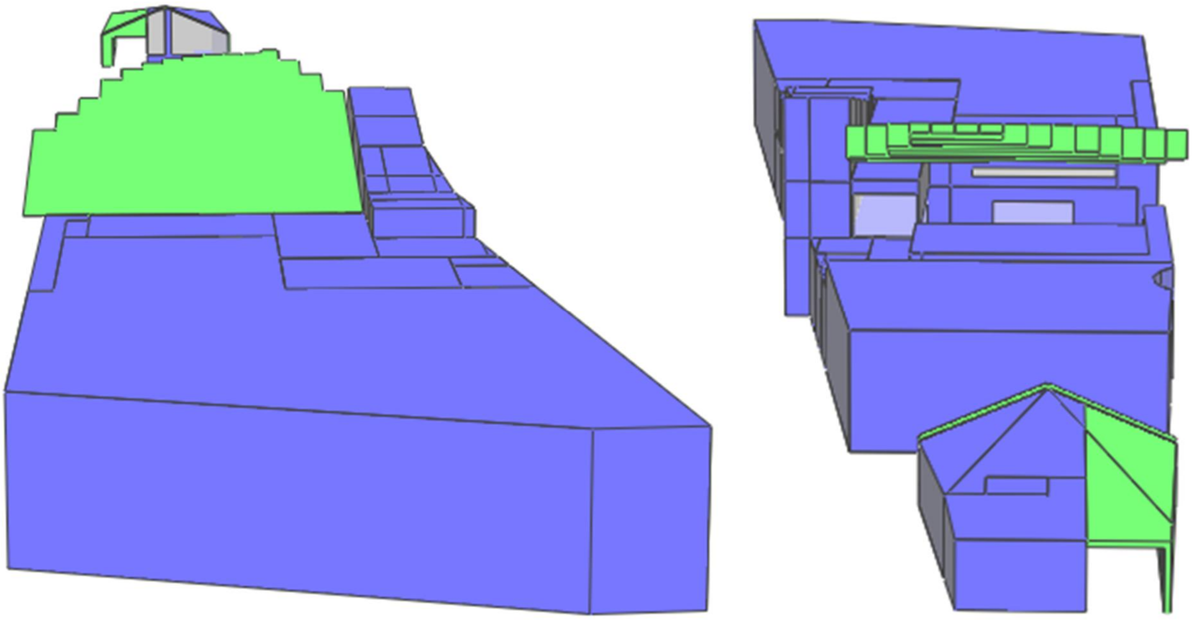


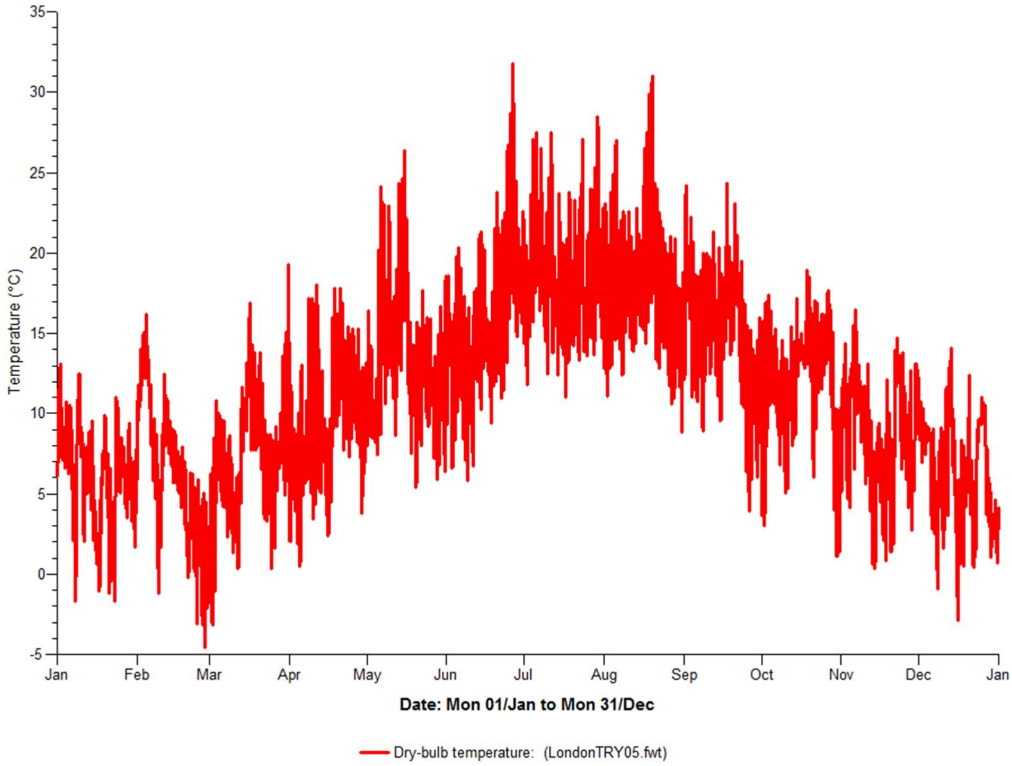
Figure 7: UK Holocaust Memorial model geometry (looking from North (left) and South (right))



3.1.4 THE WEATHER FILE / CLIMATE DATA

The London TRY05 (Test Reference Year 05) weather file was used for UK Building Regulations compliance calculations and to evaluate performance against the London Plan requirements (see Figure 8).

Figure 8: London TRY05 weather file



3.1.5 INPUT DATA

All modelling input data for the Part L compliance modelling is detailed in Appendix C1.

3.2 OVERHEATING ANALYSIS

The building is fully conditioned (both upper and lower temperature limits are controlled), therefore TM52 is not valid as a methodology for assessing the comfort profile. Instead the ‘peak operative temperature’, ‘max PPD (percentage persons dissatisfied)’ and ‘PMV (predicted mean vote)’ are used in compliance with the BREEAM Hea04 credit requirements.

3.2.1 INPUT DATA

Table 2 shows the comfort criteria for the space types contained, Table 3 lists the steady state cooling loads per room and Table 4/Table 5 provide a breakdown of the internal gains – all based on CIBSE Guide A recommendations, where applicable.

Table 2: Comfort Criteria, based on CIBSE Guide A recommendations

Occupied Areas	Room Type	Heating Setpoint	Cooling Setpoint
B1_Learning Centre	Exhibition Area	19	25
B2_Learning Centre	Exhibition Area	19	25

Occupied Areas	Room Type	Heating Setpoint	Cooling Setpoint
B2_Meeting Room 1	Meeting Room	21	25
B2_Meeting Room 2	Meeting Room	21	25
B2_CCTV	Office	21	25
B2_Office	Office	21	25
B2_Info Desk	Reception	21	25
B1_Cafe and Retail	Retail	21	25

Table 3: Steady state cooling loads

Room	Conduction gain (kW)	Solar gain (kW)	Internal gain (kW)	Infiltration gain (kW)	Cooling load (kW)
B1_Cafe and Retail	0.10	0.00	3.48	0.10	**3.67**
B1_Learning Centre	0.09	0.16	8.31	0.11	**8.67**
B2_CCTV	0.01	0.00	0.36	0.01	**0.38**
B2_Info Desk	0.03	0.00	0.28	0.01	**0.32**
B2_Learning Centre	0.37	0.56	40.56	3.18	**44.67**
B2_Meeting Room 1	0.00	0.00	0.74	0.01	**0.75**
B2_Meeting Room 2	0.01	0.00	0.42	0.01	**0.44**
B2_Office	0.04	0.00	2.99	0.07	**3.10**

Table 4: Internal gains breakdown for each of the spaces (a)

Room	Lighting Gain (W/m²)	Lighting Gain (W)	Lighting Profile	No. People	Sensible Gain (W/person)	Latent Gain (W/person)	Occupancy Sensible Gain (W)
B1_Cafe and Retail	10	868.8	8AM-8PM	29	75	66	2172

B1_Learning Centre	5	447.359	8AM-8PM	100	75	66	7500
B2_CCTV	10	114.66	8AM-8PM	1	74	56	74
B2_Info Desk	10	81.328	8AM-8PM	1	74	56	74
B2_Learning Centre	5	5864.513	8AM-8PM	400	75	66	30000
B2_Meeting Room 1	10	118.26	8AM-8PM	6	74	56	444
B2_Meeting Room 2	10	80.73	8AM-8PM	3	74	56	222
B2_Office	10	721.23	8AM-8PM	16	74	56	1184

Table 5: Internal gains breakdown for each of the spaces (b)

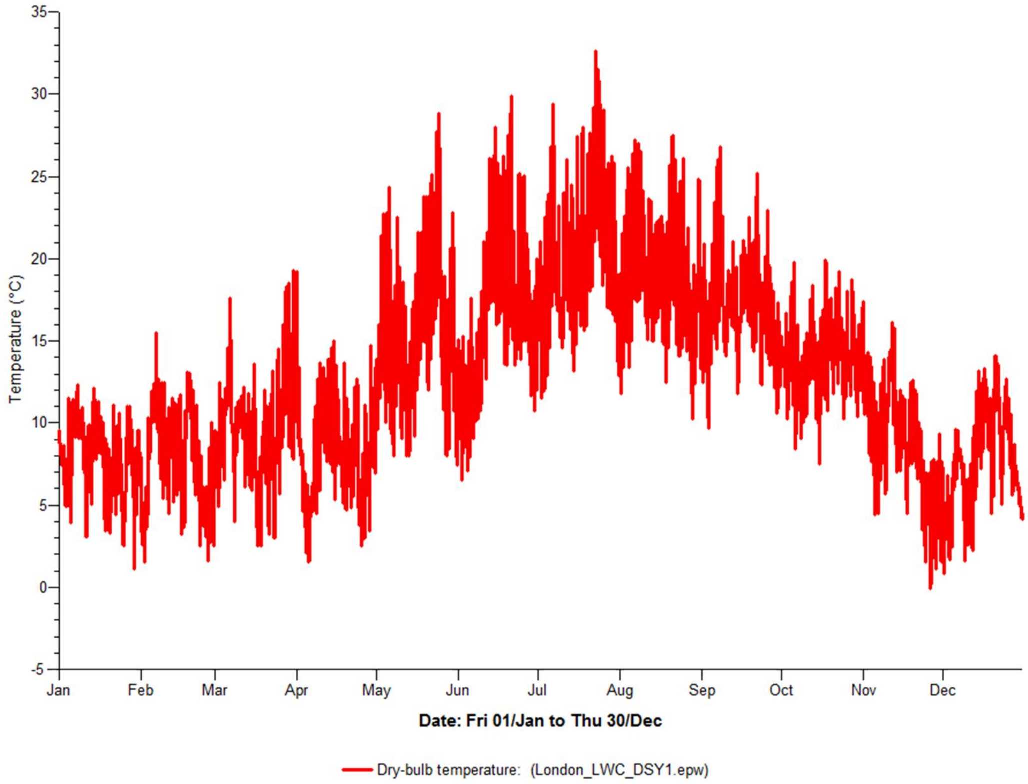
Room	Occupancy Latent Gain (W)	Occupancy Profile	Equipment Gain (W/m²)	Equipment Gain (W)	Equipment Gain Profile	Total Internal Gain (W)
B1_Cafe and Retail	1911	8AM-8PM	5	434	8AM-8PM	3.48
B1_Learning Centre	6600	8AM-8PM Learning area	4	358	8AM-8PM	8.31
B2_CCTV	56	8AM-8PM	15	172	8AM-8PM	0.36
B2_Info Desk	56	8AM-8PM	15	122	8AM-8PM	0.28
B2_Learning Centre	26400	8AM-8PM Learning area	4	4692	8AM-8PM	40.56
B2_Meeting Room 1	336	8AM-8PM	15	177	8AM-8PM	0.74
B2_Meeting Room 2	168	8AM-8PM	15	121	8AM-8PM	0.42
B2_Office	896	8AM-8PM	15	1082	8AM-8PM	2.99

All further input data for the overheating analysis is detailed in Appendix C2.

3.2.2 THE WEATHER FILE / CLIMATE DATA

For the overheating analysis, the London LWC DSY1 (London Weather Centre – Design Summer Year 1) weather file was used (see Figure 9).

Figure 9: London LWC DSY1 weather file



4 RESULTS TABLES AND GRAPHS

In this section, we have presented a range of tables and graphs which summarise the performance of the proposed design at RIBA Stage 3. These include the tables and graphs prescribed in the GLA guidance on preparing energy assessments, demonstrating compliance with the energy hierarchy approach. We have also included the Part L analysis graphs which show a breakdown of the energy demand and carbon emissions by use, to help the reader understand how the building consumes energy and how this in turn contributes to carbon emissions. Finally, we have presented the results of an assessment to identify the number of BREEAM credits available in the Energy (Ene) section.

4.1 GLA GUIDANCE ON PREPARING ENERGY ASSESSMENTS

Table 6: Carbon Dioxide Emissions after each stage of the Energy Hierarchy for non-domestic buildings (main memorial building only)

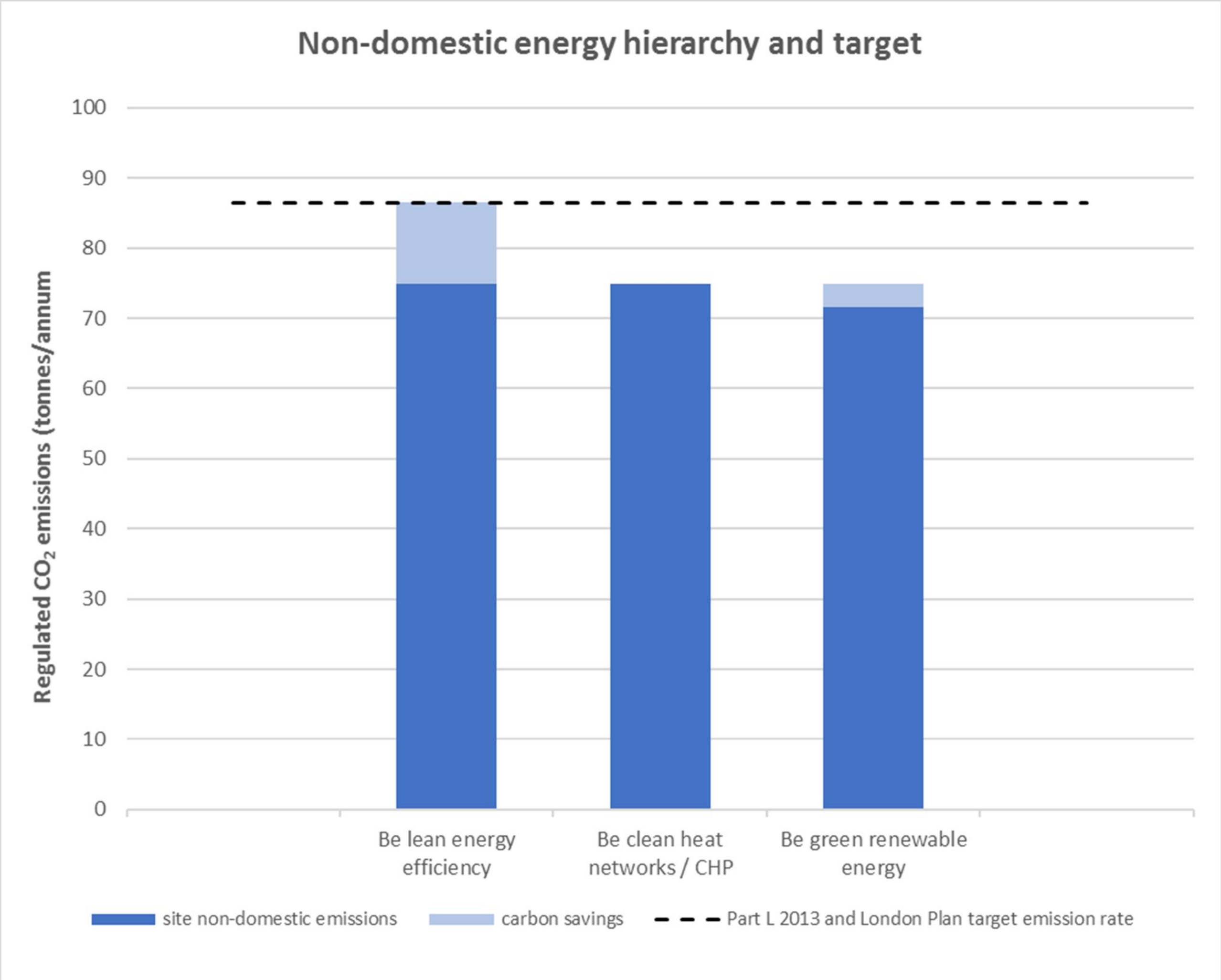
	Carbon dioxide emissions for domestic buildings (Tonnes CO_2 per annum)	
	Regulated	Unregulated
Baseline: Part L 2013 of the Building Regulations Compliant Development	86.5	139.4
After energy demand reduction	74.8	139.4
After heat network / CHP	74.8	139.4
After renewable energy	71.6	139.4

Table 7: Regulated carbon dioxide savings from each stage of the Energy Hierarchy for non-domestic buildings (main memorial building only)

	Regulated non-domestic carbon dioxide savings	
	(Tonnes CO_2 per annum)	(%)
Savings from energy demand reduction	11.7	13.5
Savings from heat network / CHP	0.0	0.0
Savings from renewable energy	3.2	3.7

Total Cumulative Savings	**14.9**	**17.2**

Figure 10: Non-domestic energy hierarchy and target (main memorial building only)



4.1.1 DISCUSSION

- Figure 10 has been adjusted from the current GLA guidance on preparing energy assessments to account for the London Plan changes to the minimum standard (the requirement to be 35% better than the Part L 2013 TER has been removed for the current period, 2016-2019)
- Figure 10 does not show any improvement in the 'Be Clean' section of the Hierarchy, as the design does not incorporate and CHP or connections to district heat networks (discussed in Section 2.2.2)
- All savings in the 'Be Green' section of the Hierarchy are from the open loop ground source heat pump system which will serve the building's heating and cooling demands

4.2 PART L 2013 ANALYSIS

Figure 11 and Figure 12 show the Part L compliance results for the final stage of the London Plan Energy Hierarchy (the proposed design), displayed as stacked bar graphs. In each case the 'actual building' is compared against the 'notional building' (this comparison is how the National Calculation Methodology evaluates compliance with UK Building Regulations Part L). The graphs demonstrate how each component of regulated energy contributes to the total, in terms of energy consumption and carbon emissions, respectively.

Figure 11: Part L2A regulated carbon emissions (proposed design) (main memorial building only)

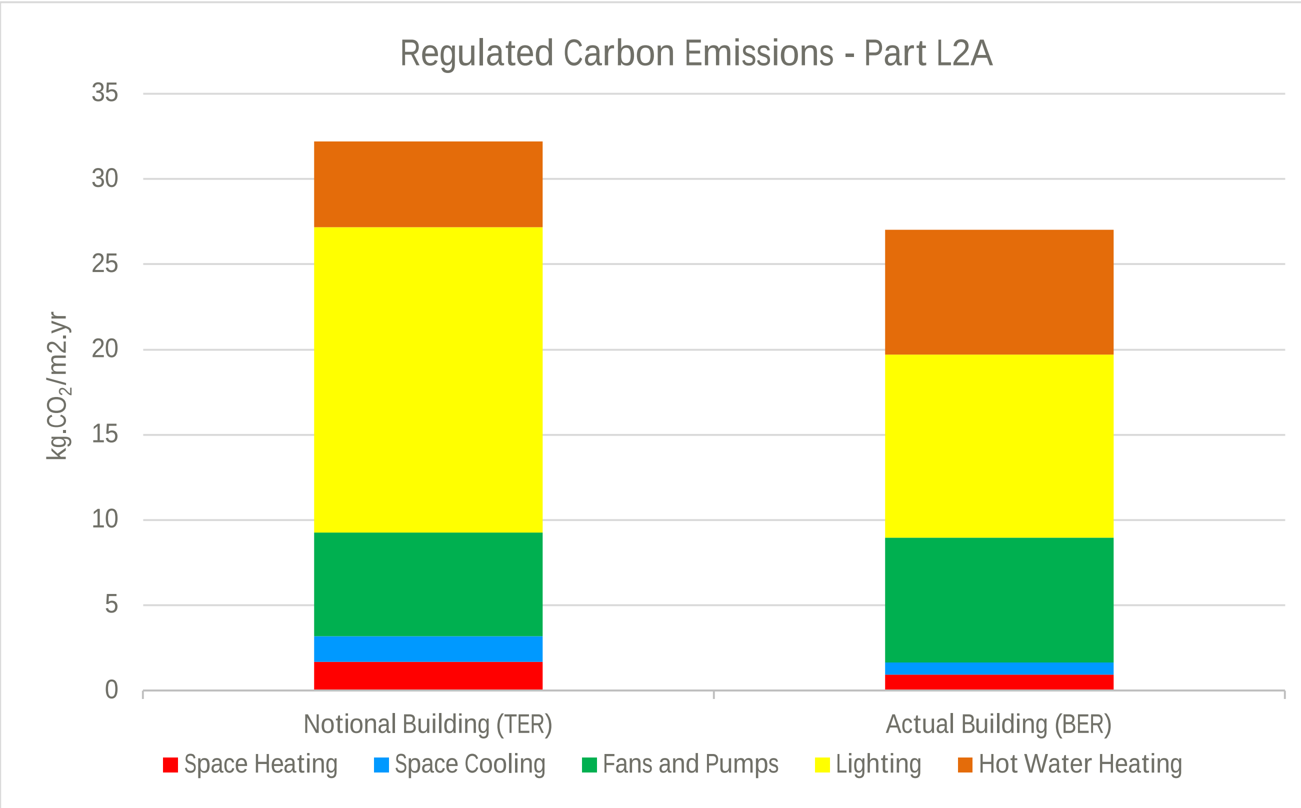
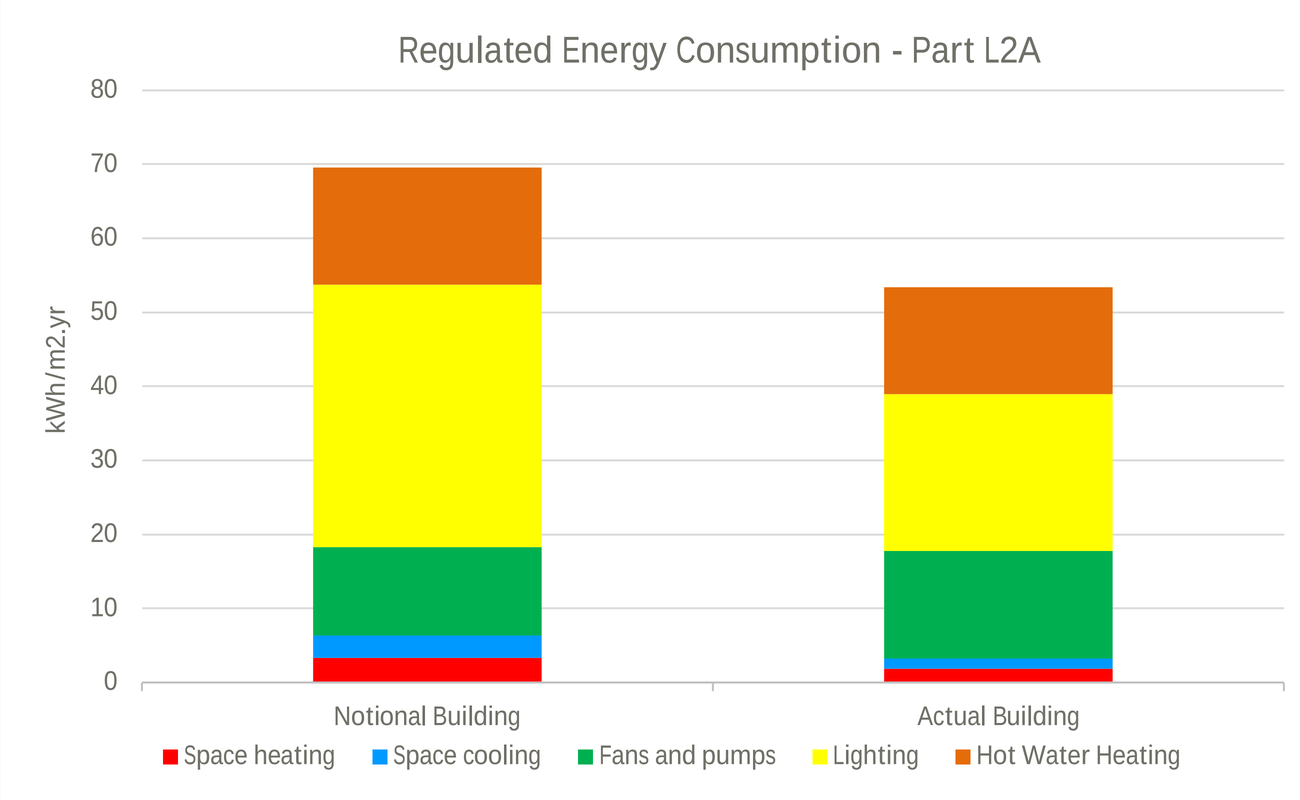


Figure 12: Part L2A regulated energy consumption (proposed design) (main memorial building only)



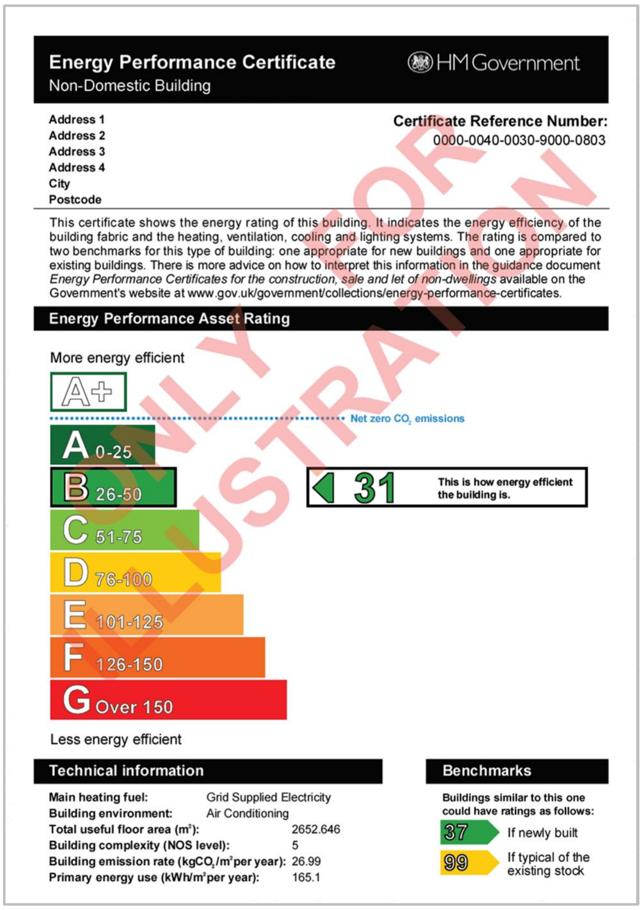
4.2.1 DISCUSSION

- The building performance indicated in Figure 11 and Figure 12 is for the proposed design, which, in sustainable design terms, represents an optimised building
- Figure 11 and Figure 12 demonstrate how small the combined heating and cooling energy is, compared with fans and pumps, lighting and hot water
- The BRUKL documents for each level of the London Plan Energy Hierarchy are provided in Appendix D1 (Be Lean), D2 (Be Clean) and D3 (Be Green).
- The Part L results shown are indicative only at this stage. Further design developments between Planning Submission and Handover could affect the result, so this should not be taken as final. Further checks will be carried out as the design develops

4.3 DRAFT ENERGY PERFORMANCE CERTIFICATE (EPC)

Figure 13 shows the draft (design stage) energy performance certificate.

Figure 13: Draft EPC



4.3.1 DISCUSSION

- The draft EPC shown above is indicative only at this stage. Further design developments between Planning Submission and Handover could affect the result, so this should not be taken as final. Further checks will be carried out as the design develops.
- We are not aware of any minimum standard regarding the EPC rating for this development.

4.4 BREEAM CREDITS

Figure 14 shows a screenshot from the BREEAM Ene01 (reduction of energy use and carbon emissions) calculator, completed with the building area and BRUKL metrics from the final stage of the London Plan Energy Hierarchy (the proposed design).

Figure 14: BREEAM Ene01 calculator - screenshot

BREEAM UK New Construction 2014 Pre-Assessment Estimator: Assessment Issue Scoring BREEAM® UK

Warning: All Mandatory fields in the assessment details worksheet must be completed/defined to reveal the applicable assessment issues.

Man | H&W | Energy | Transport | Water | Materials | Waste | LU&E | Pollution | Innovation

New Construction (Fully fitted)

Building floor area	2653	m2

Notional building heating and cooling energy demand	71.29	MJ/m2yr
Actual building heating and cooling energy demand	53.53	MJ/m2yr
Notional building primary energy consumption	187.76	kWh/m2yr
Actual building primary energy consumption	165.10	kWh/m2yr
Target emission rate (TER)	32.20	kgCO2/m2yr
Building emission rate (BER)	27.00	kgCO2/m2yr
Building emission rate improvement over TER	16.2%	
Heating & cooling demand energy performance ratio (EPR_{ED})	0.238	
Primary consumption energy performance ratio (EPR_{PC})	0.221	
CO_2 Energy performance ratio (EPR_{CO2})	0.194	
Overall building energy performance ratio (EPR_{NC})	0.652	

Where specified, please confirm the energy production from onsite or near site energy generation technologies	0	$kWh/m^2 yr$
Equivalent % of the building's 'regulated' energy consumption generated by carbon neutral sources and used to meet energy demand from 'unregulated' building systems or processes?		
Is the building designed to be 'carbon negative' ?		
If the building is defined as 'carbon negative' what is the total (modelled) renewable/carbon neutral energy generated and exported?		

Total BREEAM credits achieved	8
Total contribution to overall building score	5.22%
Total BREEAM innovation credits achieved	0
Minimum standard(s) level	Outstanding level

4.4.1 DISCUSSION

- The number of credits shown above are indicative only at this stage. Further design developments between Planning Submission and Handover could affect the result, so this should not be taken as final. Further checks will be carried out as the design develops.
- The minimum number of credits required to be eligible for BREEAM Excellent (under the 2014 scheme document) is 5. Considering, the design is indicating 8 credits, this is deemed to be a sufficient safety margin at this stage.

4.5 OVERHEATING ANALYSIS

Table 8: The overheating analysis results

Room	Winter Heating Setpoint	Suggested Summer Operative Temperature Range (CIBSE Guide A)	Peak Operative Temperature (°C)	Max PPD (%)	PMV
B1_Cafe and Retail	21	21-25	24.8	11.45	0.56
B1_Learning Centre	19	21-25	24.9	11.75	0.57
B2_CCTV	21	22-25	24.9	14.13	0.43
B2_Info Desk	21	22-25	24.9	15.89	0.43
B2_Learning Centre	19	21-25	25.0	15.6	0.58
B2_Meeting Room 1	21	22-25	24.8	13.94	0.42
B2_Meeting Room 2	21	22-25	24.8	14.01	0.43
B2_Office	21	22-25	24.8	13.99	0.43

4.5.1 DISCUSSION

- The building is fully conditioned (both upper and lower temperature limits are controlled), therefore TM52 is not valid as a methodology for assessing the comfort profile. Instead the ‘peak operative temperature’, ‘max PPD (percentage persons dissatisfied)’ and ‘PMV (predicted mean vote)’ are used in compliance with the BREEAM Hea04 credit requirements.
- The results show that a comfortable and reasonable temperature profile is anticipated within the completed building.
- The thermal profile shown above is indicative only at this stage. Further design developments between Planning Submission and Handover could affect the result, so this should not be taken as final. Further checks will be carried out as the design develops.
- The result also demonstrates compliance with the BREEAM Hea04 first credit (thermal modelling), although further work will be carried out to evidence the second credit (climate change adaption). This will be detailed in the WSP report entitled ‘BREEAM Low Carbon Design Study’ (not included in this submission)

Appendix A

HYDROGEOLOGICAL STUDY

CONTENTS

FIGURES

TABLES

1 EXECUTIVE SUMMARY

1.1.1 SITE LOCATION & LAYOUT

The proposed site for the Holocaust Museum is located within Victoria Tower Gardens located adjacent to, and south of, the Houses of Parliament, Westminster, Central London. The site grid reference is 530260 179200 and ground elevation at the site is approximately +5mAOD.

The proposed development is located within the confines of Victoria Tower Gardens, which comprises an elongated area of grass parkland surrounded by mature trees extending approximately 400m from north to south in the direction of Lambeth Bridge.

1.1.2 REQUIREMENTS

Peak cooling demand is estimated at 147kW, with an annual cooling requirement of 0.04GWh. Peak heating demand is 65kW and the annual heating requirement is estimated at 0.03GWh, resulting in a net annual imbalance bias towards cooling of approximately 0.01GWh.

The groundwater system will provide both heating and cooling and will be configured and operated to provide a close balance between the two over a typical year, thus minimising the cumulative net imbalance over the operating lifetime of the museum.

1.1.3 CASE FOR GROUNDWATER

This report assesses the feasibility of using groundwater for heating and cooling at the proposed Holocaust Museum, Westminster and, specifically, provides an indicative cost estimate, programme and assessment of risk.

The groundwater system under consideration will be designed to provide a close balance between meeting the heating and cooling requirements of the proposed development. The estimated design loads are small compared to similar applications of the technology in the site vicinity and elsewhere, this has a bearing on project risks (considered low due to the small heating and cooling loads) and also on project economics.

In the context of other established and emerging low carbon heating and cooling technologies the cost of developing a groundwater heating and cooling system is likely to be considerably higher. However, the authors of this report understand that there are other drivers guiding the choice of technology, including an aspiration not to use fossil fuels (for heating) and aesthetic considerations (minimal/negligible surface expression).

Justification of the anticipated higher cost of developing the groundwater heating and cooling system described in this report should be considered in the context of these and other drivers.

1.1.4 PROVISIONAL COST ESTIMATE & RISK PROFILE

Typically the cost of developing the borehole infrastructure for a groundwater heating and cooling system of the size and configuration under consideration at the development site is of the order of £0.5M with a risk profile as described in Birks et al 2016.

Due to the fact that estimated heating and cooling loads at the proposed development site are so small (i.e. net heat rejection 0.5% of that of the Royal Festival Hall system and peak loads estimated to be approximately 10%) the principal geoscience risks are reduced considerably. Notwithstanding, the client (and his advisors) need to understand and accept that there is an inherent risk associated with the technology that can only be eradicated completely once the wells are drilled, tested and proven.

The cost of constructing and commissioning two Chalk water wells for the proposed development is estimated at £0.5M. This does not include the cost of further development or establishment of the heating and cooling system which would typically comprise; heat pumps, heat exchangers, pipe routes from the wellheads to the plant rooms, integration, commission and handover.

1.1.5 ASSESSMENT

Assessment of ability to meet the specified cooling and heating requirements follows the approach set out in Birks et al 2016 and evaluates the proposed development in the context of four principal geoscience risks common to all groundwater cooling systems of this type as follows:

- Risk 1, Abstraction;
- Risk 2, Recharge;
- Risk 3, Filtration and water chemistry; and
- Risk 4, Thermal Degradation.

1.1.6 DEVELOPMENT ROUTE MAP

This report should be used as a basis comparing the commercial case for a groundwater heating and cooling system with other viable technologies. If the case for a groundwater heating and cooling system is favourable then further development should be undertaken in accordance with the route map outlined in section 9 of this report.

2 INTRODUCTION

2.1 TERMS OF REFERENCE

This report assesses the feasibility of using groundwater for heating and cooling at the proposed Holocaust Museum, Westminster, London. This report has been carried out in accordance with WSP's proposal (February 2018) following instruction to proceed in email correspondence dated 6th February 2018.

2.2 PROVISIONAL ESTIMATE OF HEATING AND COOLING REQUIREMENT

A provisional estimate of the peak and annual average cooling and heating requirements for the proposed development was provided by WSP Building Services Team in email correspondence dated 19th March 2018, in which the estimated annual cooling and heating loads were:

- Peak Cooling 147kW; and
- Peak Heating 65kW.

And estimated annual heating and cooling demand were;

- Annual Cooling 0.04GWh; and
- Annual Heating 0.03GWh.

Resulting in a net imbalance of approximately 0.01GWh, which is small in the context of other ground water heating and cooling applications in Central London. This equates to a substantially reduced development risk as explained later in this report.

The peak heating and cooling requirement effectively defines the maximum groundwater flows out of and back into the aquifer via the existing boreholes. Ideally flows out of and into the aquifer should be sufficient to satisfy the heating and cooling peaks whilst maintaining effluent water temperatures at ± 10°C of the abstracted groundwater temperature, which is typically 14°C in Central London.

The required flows needed to achieve the stated peak heating and cooling loads is given by the equation:

> Peak Heating Requirement (kW) = Flow (L/sec) x induced temperature change (K) x specific heat capacity of water (4.18 kJ/L/K)

To satisfy the peak heating/cooling demand a minimum flow of 3.52L/sec will be required, rounded up to 4L/sec for the purposes of this assessment.

One of the key aims of this report is to assess whether a single abstraction well will be capable of yielding 4L/sec and a single recharge well sustaining 4L/sec flow back into the aquifer, consistently and reliably over the full working life of the museum.

The long term sustainability of groundwater heating and cooling systems is effectively defined by the net difference in annual heating and cooling (expressed as GWh per annum). For groundwater heating and cooling systems to work effectively it is important that the thermal capacity of the ground in which the boreholes are installed has sufficient thermal storage capacity. The ground has a finite capacity to yield and absorb heat as shown in Figure 2-12-1 below and when the net imbalance between heating and cooling exceeds this capacity the efficiency of the system starts to diminish. However, the net imbalance at the Holocaust Museum is very low (<1%) when compared to similar systems in Central London, rendering the risk of thermal degradation extremely small, as explained in greater detail later in this report.

Figure 2-1 Capacity of Common Geologic Materials to Yield and Absorb Heat

2.3 PURPOSE OF THIS REPORT

Taking into consideration the stated heating and cooling requirements in section 2.2 above, this report evaluates the ability of the ground and borehole infrastructure required to satisfy the stated requirements. Specifically, the ability of the aquifer and a single abstraction and single recharge borehole (2 boreholes in total) to provide the requisite quantities of water to and from the plant room and the ability of the ground to yield and absorb heat such that a sustainable mode of operation is defined.

Our analysis follows the approach set out in Birks et al 2015 and takes into consideration the key (geoscience) design principals described in Younger 2008 and Clarkson et al 2009. Birks et al 2015 identified four principal geoscience risks common to all groundwater cooling systems of this type, regardless of the geological setting. These are represented schematically in Figure 2-22-2 and summarised below:

— Risk 1, Abstraction. The aquifer and/or wells installed within the aquifer may not be capable of supporting the requisite flow rates;

— Risk 2, Recharge. There may be problems with recharging effluent water back into the aquifer and, over time, there may be problems associated with clogging which could potentially cause flooding;

— Risk 3, Filtration and water chemistry. Poorly designed and/or constructed wells can result in poor water quality, including a high sediment content. This can cause problems with filtration, clogging in heat exchangers and potentially clogging of recharge wells (thus exacerbating recharge risk outlined above); and

— Risk 4, Thermal Degradation. The volume of rock in which the abstraction and recharge boreholes interact has a finite capacity to absorb heat. The amount and rate of heat rejection needs to be balanced with the capacity of the ground.

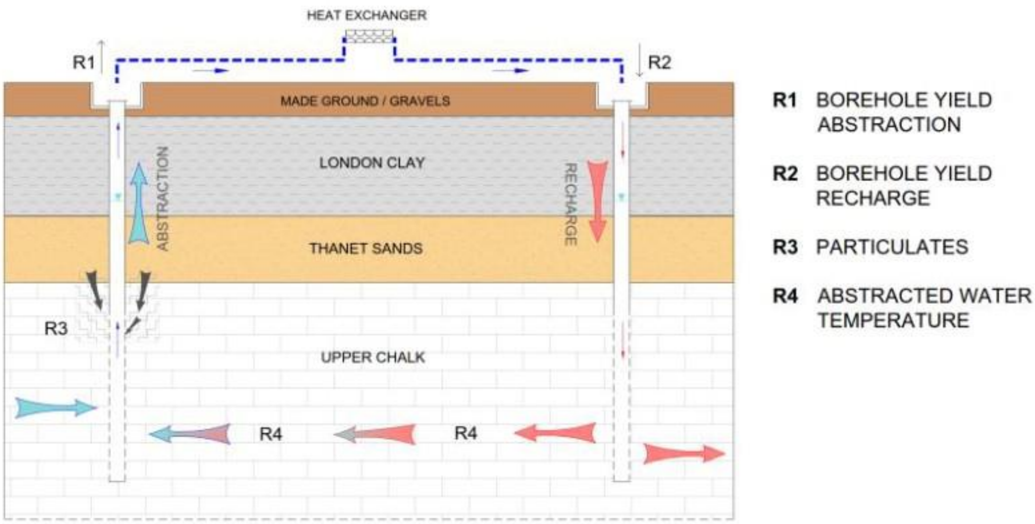


Figure 2-2 Representation of Principal Geoscience Risks (after Birks et al 2016)

2.4 STRUCTURE OF REPORT

This report is organised as follows:

- **Section 3** presents the heating and cooling requirements as defined by WSP Building Services Team in email correspondence dated 19th March 2018. This defines the sizing requirements in terms of flows and heat storage;
- **Section 4** describes the general setting and key geological and hydrogeological features and what is known of the existing wells in terms of condition and performance;
- **Section 5** describes current groundwater usage in the vicinity of the proposed Holocaust Museum and nearby activities including construction of the Thames Tideway;
- **Section 6** presents our assessment of the borehole infrastructure required to meet the stated requirements and a recommended configuration/mode of operation;
- **Section 7** presents a budget estimate for constructing/commissioning the existing boreholes;
- **Section 8** presents a recommended route map for the development;
- **Section 9** presents our conclusions and recommendations; and
- **Section 10** details the references.

3 HEATING AND COOLING REQUIREMENTS

3.1 ANNUAL HEATING AND COOLING REQUIREMENT

An annual heating and cooling load profile is presented in Figure 3-3-11 below. Peak cooling is estimated at 147kW with an annual cooling requirement of 0.04GWh/yr. Peak heating is 65kW with the annual heating requirement estimated at 0.03GWh/yr, resulting in a net annual imbalance between heating and cooling of approximately 0.01GWh/yr.

The groundwater system will provide both heating and cooling and will be configured and operated to provide a close balance between heating and cooling over a typical year, thus minimising the cumulative net imbalance over the operating lifetime of the museum.

To satisfy the stated annual cooling requirement of 0.04GWh, whilst maintaining an average effluent water temperature of 5-10°C above the abstracted water temperature, the system will require approximately 3,500 m^3 to 7,000m^3 abstraction and recharge per annum. If summer cooling is to be balanced by winter heating a similar (albeit slightly lower) figure will be required. Thus to satisfy the combined heating and cooling requirements an Environment Agency licence of circa 15,000 to 20,000m^3 will be required. As context, the groundwater cooling systems at the Royal Festival (Clarkson et al 2009) and comparable systems elsewhere in London are considerably larger than this (typically >200,000m^3 per annum), such that the amount required for the Holocaust Museum should not present significant problems in relation to Environment Agency consents.

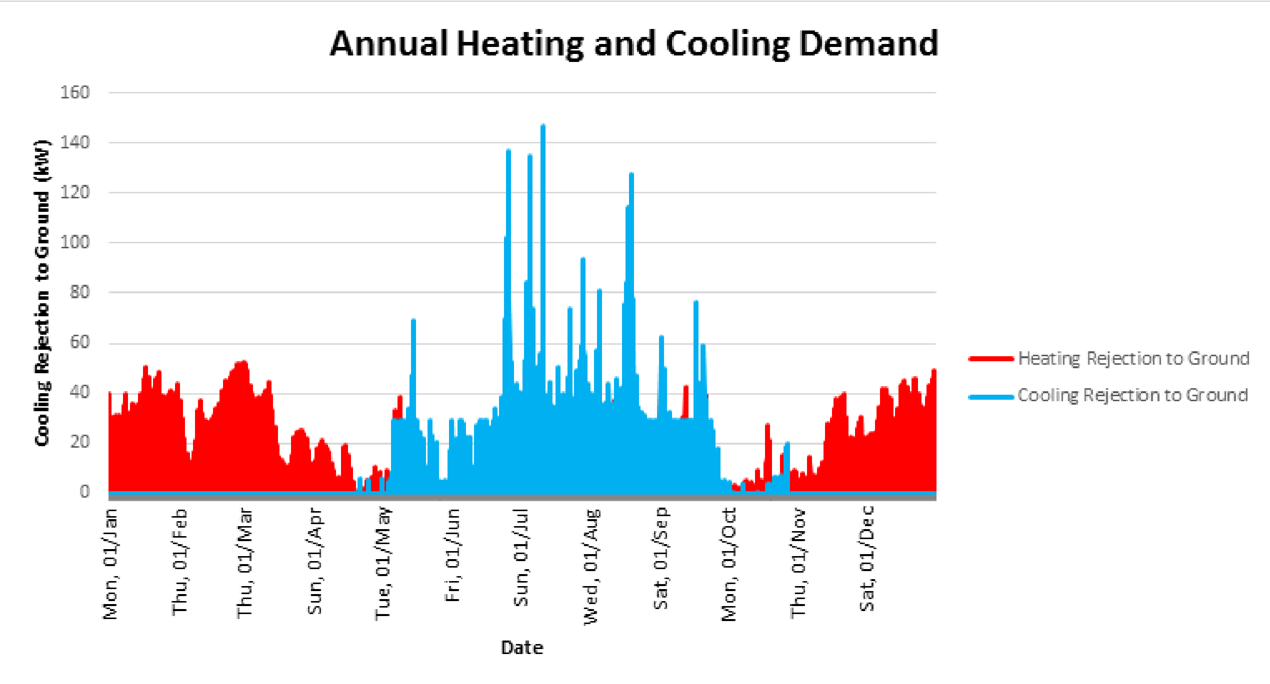


Figure 3-1 - Annual Heating and Cooling (from WSP Building Services, 19th March 2018)

3.1.1 COOLING

Peak cooling based on July predictions is as shown Figure 3-3-22 below. The maximum predicted instantaneous cooling peak is 147kW on 11 July and the total estimated cooling requirement in this peak cooling 24 hour period is 784.2kWh. Assuming a constant flow of 4L/sec over this 24 hour period the average effluent water temperature is predicted to be approximately 2°C above the abstracted water temperature.

For the month of July the predicted total cooling requirement is 9692kWh. Assuming constant flow of 4L/sec over this 1 month period (24 hours per day) the average effluent water temperature is predicted to be 0.8°C above the abstracted water temperature.

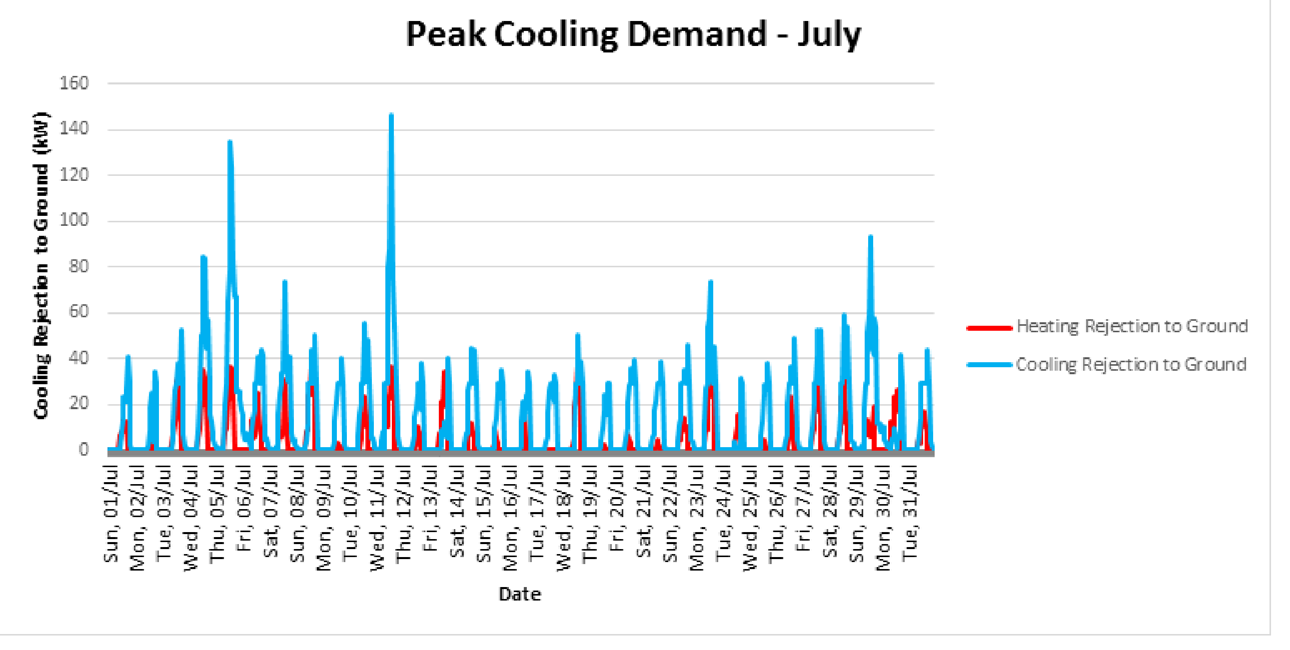


Figure 3-2 Peaking Cooling – July Predictions

3.1.2 HEATING

Peak heating based on January predictions is as shown in Figure 3-3-33 below. The maximum predicted instantaneous heating peak is 52kW on 17th January and the total estimated heating requirement in this peak heating 24 hour period is 268kWh. Assuming a constant flow of 4/sec over this 24 hour period the average effluent water temperature is predicted to be approximately 0.55°C below the abstracted water temperature.

For the month of January the predicted total heating requirement is 5037kWh. Assuming a constant flow of 4L/sec over this 1 month period for 24 hours per day the average effluent water temperature is predicted to be 0.45°C below the abstracted water temperature.

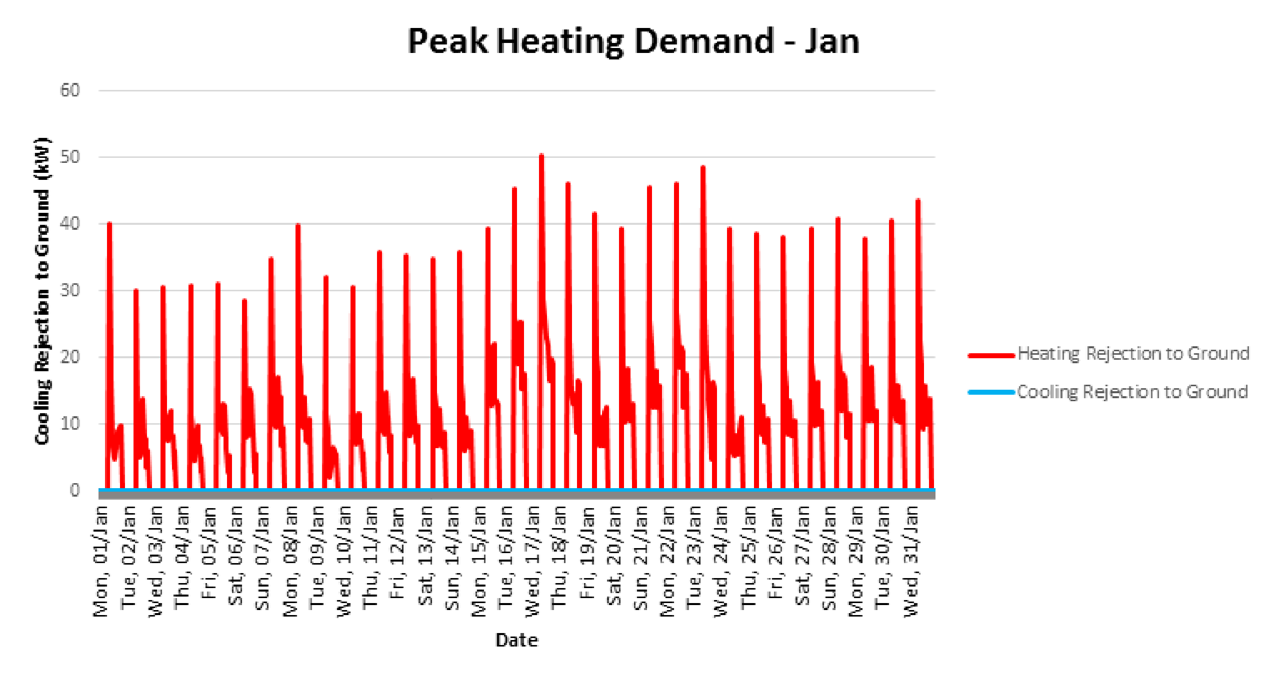


Figure 3-3 Peak Heating – January Predictions

4 SITE SETTING

4.1 SITE LOCATION

The proposed site for the Holocaust Museum is located within Victoria Tower Gardens located adjacent to and south of the Houses of Parliament, Westminster, Central London. The site location is shown in Figure 4-4-11 below. The site grid reference is 530260 179200 and ground elevation at the site is approximately +5mAOD.

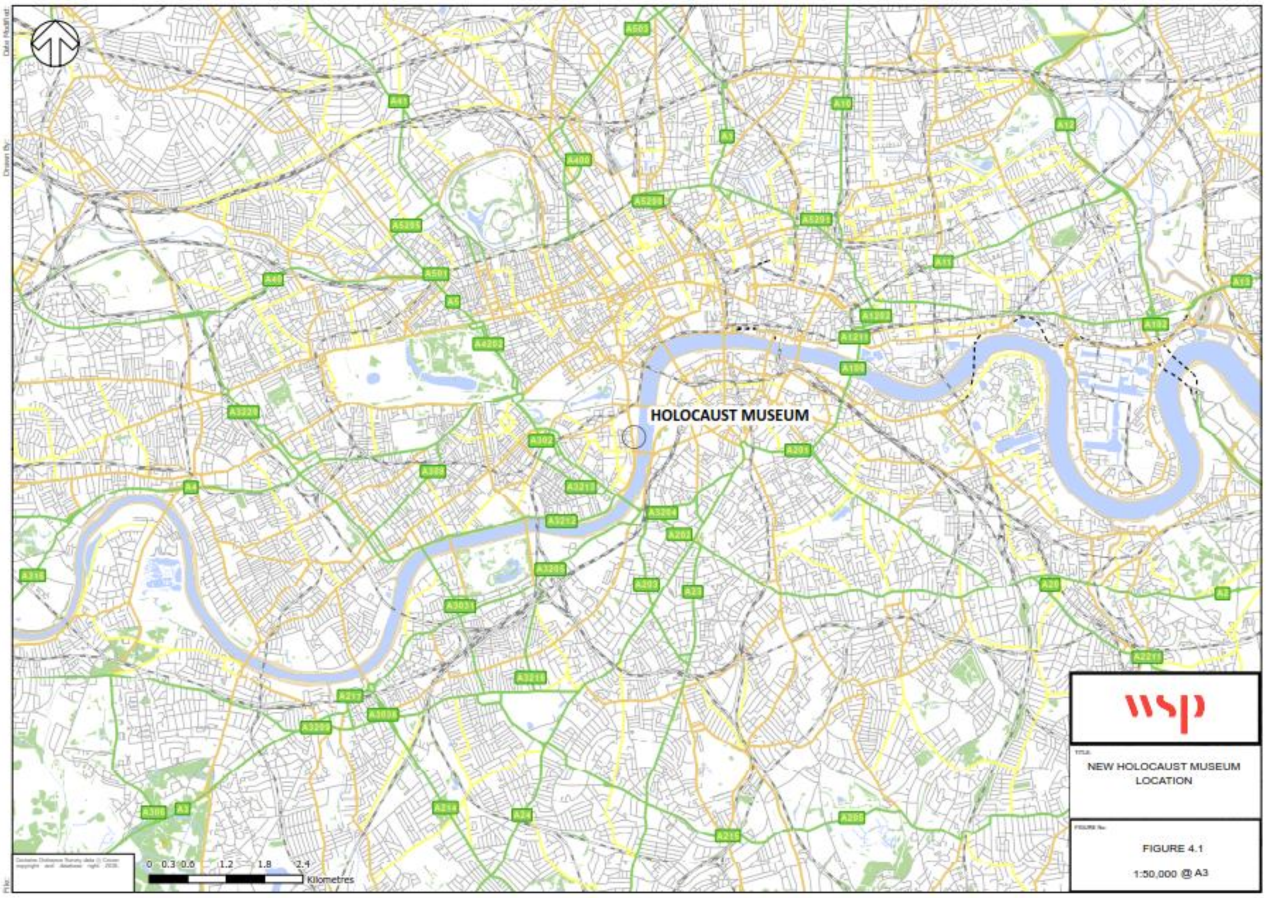


Figure 4-1 Holocaust Museum Site Location

The proposed development is located within the confines of Victoria Tower Gardens, which comprises an elongated area of grass parkland surrounded by mature trees extending approximately 400m from north to south in the direction of Lambeth Bridge as shown in Figure 4-2 below. The development footprint is as shown in Figure 4-3.

Figure 4-2 View of Victoria Tower Gardens from Houses of Parliament looking South Towards Lambeth Bridge

Figure 4-3 Proposed Footprint of Holocaust Museum within Victoria Tower Gardens

At its northern end the site is approximately 90m wide and at the southern end reduces to a width of approximately 20m. The site is flanked by mature trees on its eastern and western sides, is bounded by Mill Road to the west, the River Thames embankment to the east, the Houses of Parliament to the north and Lambeth Bridge to the south. The site area is approximately 1.9ha, most of which is grass parkland.

As shown in Figure 4-3, from west to east the proposed development footprint will extend over the almost the full width of the park and from north to south the development will extend between Black Rods Garden in the north into the playing area to the south of Victoria Tower Gardens.

In order to achieve a sensible separation between abstraction and recharge wells (>150m) and access for future maintenance it is envisaged that the wells will be located outside the proposed development as indicated in Figure 4-4 below.

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Figure 4-4 Provisional Locations of Abstraction and Recharge Wells

5 GEOLOGY & HYDROGEOLOGY

5.1 GEOLOGICAL SUCCESSION

The general geological succession and key hydrogeological factors described in this section are derived from:

— British Geological Survey, Open access geological mapping of the UK (http://mapapps.bgs.ac.uk/geologyofbritain/home.html?mode=boreholes);
— British Geological Survey Archive Data, 28 No. Borehole Records; and
— Environment Agency report entitled "Management of the London Basin Chalk Aquifer", Status Report, 2014;

Figure 5-1 shows the locations of boreholes for which records were obtained from the British Geological Survey (BGS) and Table 5-1 presents a summary of salient details obtained from these borehole records.

Figure 5-2 and Figure 5-3 present geological cross sections through the Chalk aquifer and overlying strata, which is based on WSP interpretation of information obtained from the BGS borehole archive. A summary of the anticipated geological sequence at the proposed development site is given in Table 5-2.

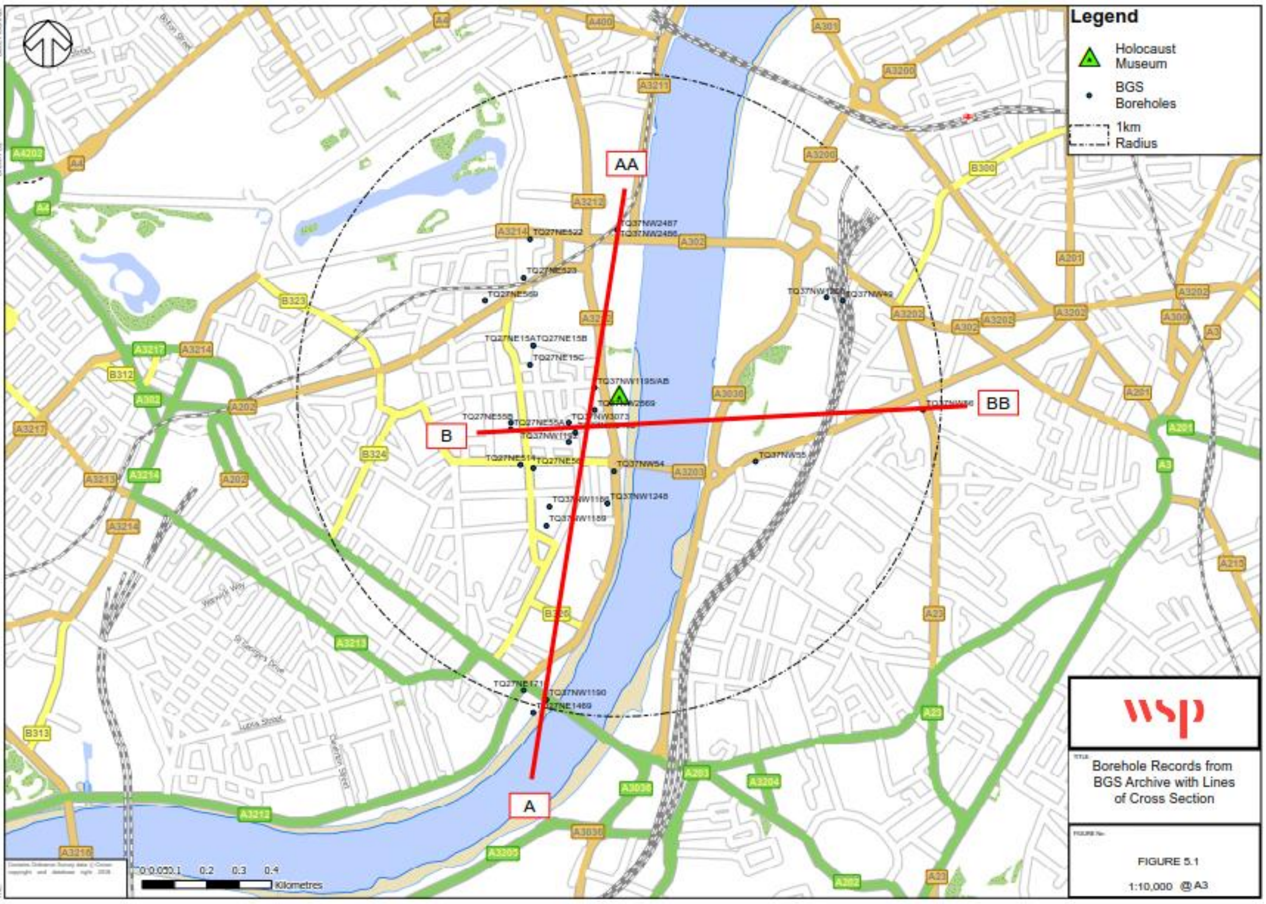

Figure 5-1 Borehole Records from BGS Archive & Selected Lines of Geological Cross Section

Table 5-1 Salient Details from Borehole Records Obtained from the BGS Archive

BGS ID	Easting	Northing	BH Depth	Ground Level
	(m)	**(m)**	**(m)**	**(mAOD)**
TQ27NE523	529960	179550	145	4.88

TQ27NE569	529840	179480	137.2	2.13
TQ27NE15A	529990	179340	182.9	4.87
TQ27NE15B	529990	179340	185	4.87
TQ27NE15C	529980	179280	182.8	4.87
TQ27NE55B	529920	179100	184.4	5.18
TQ27NE55A	529920	179080	131	5.18
TQ27NE514	529950	178970	182.9	4.57
TQ27NE56	529990	178960	91.4	4.57
TQ37NW1186	530040	178840	182.9	6.1
TQ37NW1248	530220	178850	137.2	5.18
TQ37NW54	530240	178950	93	4.26
TQ37NW1192	530100	179040	137.3	5.18
TQ37NW2152	530120	179070	141.7	5
TQ37NW3073	530100	179100	111	5
TQ37NW2569	530180	179140	137.2	5
TQ37NW1195/AB	530180	179210	152.4	6.4
TQ37NW2486	530250	179700	121	5
TQ37NW2487	530250	179700	125	5
TQ37NW1200	530900	179490	137.8	4.57
TQ37NW55	530680	178980	97.5	4.9
TQ37NW1189	530030	178780	182.9	4.57
TQ27NE1718	529960	178270	152.4	5.63
TQ37NW1190	530030	178240	137.2	6.1
TQ27NE1469	529990	178200	153	5.64
TQ27NE522	529980	179670	137.2	5.2
TQ37NW49	530950	179480	123	3.05
TQ37NW56	531200	179140	127	4.9

Table 5-2 Anticipated Geological Sequence

Geological Unit	Approximate Elevation of top of unit (mAOD)	Approximate Elevation of base of unit (mAOD)	Estimated Thickness (m)
Drift/Superficial Deposits	5	0 to -5	5 – 10
London Clay	0 to -5	-30 to -45	25 – 40
Woolwich & Reading Beds	-30 to -45	-50 to -60	20 -30
Thanet Sand	-50 to -60	-60 to -75	10 – 15
Upper Chalk	-60 to -75	>-140	>85

The general geological succession at development site is as shown in Figure 5-2 and Figure 5-3 below and comprises:

— A thin veneer of made ground, drift, alluvium and River Terrace Deposits giving a combined thickness of approximately 5 to 10m;

— Approximately 30m to 40m thickness of London Clay underlies the made ground and superficial deposits. The base of the London Clay is encountered at a depth of approximately 30m to 45m below ground level (mbgl);

— A sequence of silt and sand known collectively as the Woolwich and Reading Beds underlies the London Clay. This unit is approximately 20m thick and the base of the unit is encountered at a depth of approximately 55m to 65mbgl;

— Approximately 10 – 15m thickness of Thanet Sand forms the base of the Lower London Tertiaries with a depth to base of between 65m and 80mbgl; and

— The Chalk aquifer underlies the superficial deposits, London Clay and Lower London Tertiaries and extends to a depth of > 150m.

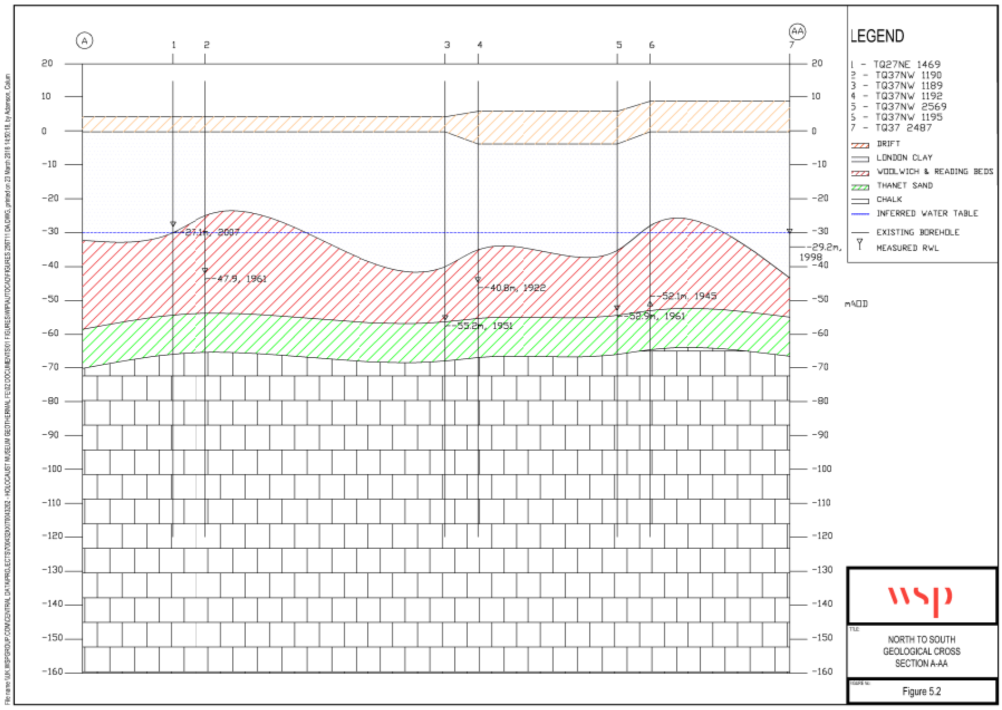

Figure 5-2 Geological Cross Section A - AA

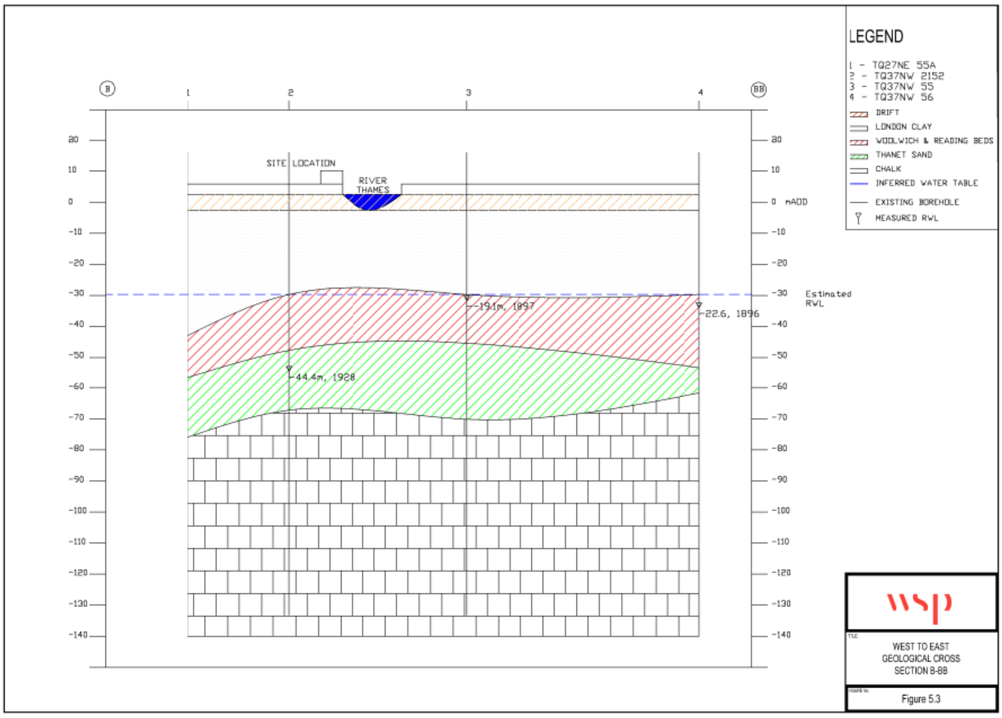

Figure 5-3 Geological Cross Section B - BB

Figure 5-2 and Figure 5-3 above indicates that rest water levels in the Chalk aquifer beneath the site have risen by approximately 20m – 30m since the late 1960's. This is consistent with a trend of rising water levels in Central London, which is monitored and reported annually by the Environment Agency. A rest water level in the Chalk aquifer of approximately -30mAOD is reported in the latest Environment Agency monitoring reports, approximately 30m to 40m above the upper surface of the Chalk aquifer.

5.2 GENERAL HYDROGEOLOGICAL

Consultation with the Environment Agency Groundwater Source Protection Zone online tool shows the location of a large groundwater abstraction for public water supply located at Battersea. Given the size (7ML/day) and proximity of the Thames Water public water supply to the development site it is considered likely that it will affect water levels locally and induce a southerly groundwater flow direction when pumped at or close to full licence capacity. Over the period 2015 – 2017 WSP understands that the Battersea water supply abstraction has been pumped at 25% of its full licenced capacity (Pers Comm ESI Consulting, June 2017), increasing to >50% in 2018 (Pers comm J. H. Groundwater Ltd).

5.3 HISTORIC PUMP TEST DATA FROM BRITISH GEOLOGICAL SURVEY ARCHIVE

Pumping test data was available for a number of the borehole records obtained from the British Geological Survey archive and this is summarised in Table 5-3 below, together with an estimate of specific capacity (flow rate per unit drawdown).

Table 5-3 Pump Test Summary & Derived Specific Capacity Values

BGS ID	Ground Level	Pump Rate	Pump Rate	RWL	PWL	Drawdown	Specific Capacity
	(mAOD)	(m³/hour)	(m³/day)	(mAOD)	(mAOD)	(m)	m³/day/m
TQ27NE523	4.88	20.7	496.8	-73.62	-75.62	2	248
TQ27NE569	2.13	17.6	422.4	-60.37	-64.62	4.25	99
TQ27NE15A	4.87	2.1	50.4	-63.73	-107.93	44.2	1
TQ27NE15B	4.87	25.5	612	-62.13	-67.33	5.2	118
TQ27NE15C	4.87	13.6	326.4	-69.13	-116.73	47.6	7
TQ27NE55B	5.18	11.9	285.6	-50.6	-58.68	8.08	35
TQ27NE55A	5.18	27.3	655.2	nr	nr	nr	nr
TQ27NE514	4.57	16.7	400.8	-54.83	-58.83	4	100
TQ27NE56	4.57	nr	nr	nr	nr	nr	nr
TQ37NW1186	6.1	18.1	434.4	-56.7	-58.5	1.8	241
TQ37NW1248	5.18	18.9	453.6	-41.12	-45.42	4.3	105
TQ37NW54	4.26	nr	nr	nr	nr	nr	nr
TQ37NW1192	5.18	5.7	136.8	-40.82	-68.82	28	5
TQ37NW2152	5	14	336	-44.4	-67.8	23.4	14
TQ37NW3073	5	nr	nr	-37.5	nr	nr	nr
TQ37NW2569	5	13.7	328.8	-52.9	nr	nr	nr
TQ37NW1195/AB	6.4	4.55	109.2	-52.12	nr	nr	nr
TQ37NW2487	5	72	1728	-29.2	nr	nr	nr
TQ37NW1200	4.57	70	1680	-45.73	-54.83	9.1	185

TQ37NW55	4.9	18.2	436.8	-19.1	nr	nr	nr
TQ37NW1189	4.57	19.52	468.48	-55.17	-58.53	3.36	139
TQ27NE1718	5.63	13.65	327.6	-41.92	-79.07	37.15	9
TQ37NW1190	6.1	29.6	710.4	-47.85	-54.25	6.4	111
TQ27NE1469	5.64	42	1008	-27.09	-56.53	29.44	34
TQ27NE522	5.2	9.1	218.4	-48.1	nr	nr	nr
TQ37NW49	3.05	31.85	764.4	-24.35	nr	nr	nr
TQ37NW56	4.9	45.5	1092	-43.4	-58.5	15.1	72
Mean			749				85

Notes: nr = Not Reported

Table 5-3 above confirms generally good yields from test boreholes in the site vicinity with a mean value of 749m^3/day (8.67l/sec) and a range of 50 to 1728m^3/day. The derived mean is more than twice the 4L/sec required and, importantly, for those boreholes where reported yields were less than 4L/sec (345m^3/day) nearly all were tested between 1920 and 1960 when groundwater levels in the Chalk aquifer were at historic lows.

A more reliable measure of productiveness in the Chalk aquifer is approximated by the specific capacity, i.e. the pumping rate (yield) divided by the (stabilised) drawdown. A mean specific capacity of approximately 85m^{3}m^{-1}day^{-1} is derived from the data, with a range of 5 to 248 m^{3}m^{-1}day^{-1}.

In summary, the available information indicates that the aquifer is capable of yielding relatively large quantities of good quality groundwater. From the information reviewed, WSP considers that the probability of properly designed and constructed boreholes yielding >4lsec^{-1} to be high.

6 CURRENT GROUNDWATER USAGE IN VICINITY OF PROPOSED DEVELOPMENT

6.1 GENERAL

Nearby groundwater usage may affect water levels and water quality at the proposed development site. In order of anticipated importance these are considered further under the headings below:

1. Licenced Groundwater Abstractions and Battersea Public Water Supply Abstraction;
2. Proposed Construction and Dewatering under the Thames Tideway Programme; and
3. Existing Groundwater Heating and Cooling Systems.

6.2 LICENCED GROUNDWATER ABSTRACTIONS

Groundwater levels in the Chalk aquifer beneath Central London are influenced to a significant extent by groundwater abstraction for private and public supply. At the peak of abstraction in the 1960's groundwater levels had dropped to around 88m below sea level (Environment Agency Status Report, 2014). Since the mid 1960's, with the demise of heavy industry, groundwater levels have started to rise and have risen by an estimated 20m to 30m beneath the development site. Due to the threat to structures in the London Basin, including London Underground Tunnels, the General Aquifer Research Development and Investigation Team (GARDIT) strategy to control water levels was implemented in 1992. The objective of the strategy was "to control groundwater level in the Chalk aquifer under Central London in order to maintain the integrity of underground structures and foundations in the London Clay".

Implementation of the strategy was achieved by abstraction licencing (overseen and regulated by the Environment Agency) with numerous large public water supply abstractions licenced to Thames Water between the late 1990's and 2004. The large public water supply at Battersea was developed under the GARDIT strategy and monitoring during testing of this supply and subsequent operation is ongoing.

Licenced groundwater abstractions in the vicinity of the proposed development are shown in Figure 6-6-1 below and details of those located within 1000m of the site are summarised in Table 5-1. These details have been obtained from the Environment Agency National Abstraction Licence Database (NALD's) Returns commissioned for a previous project.

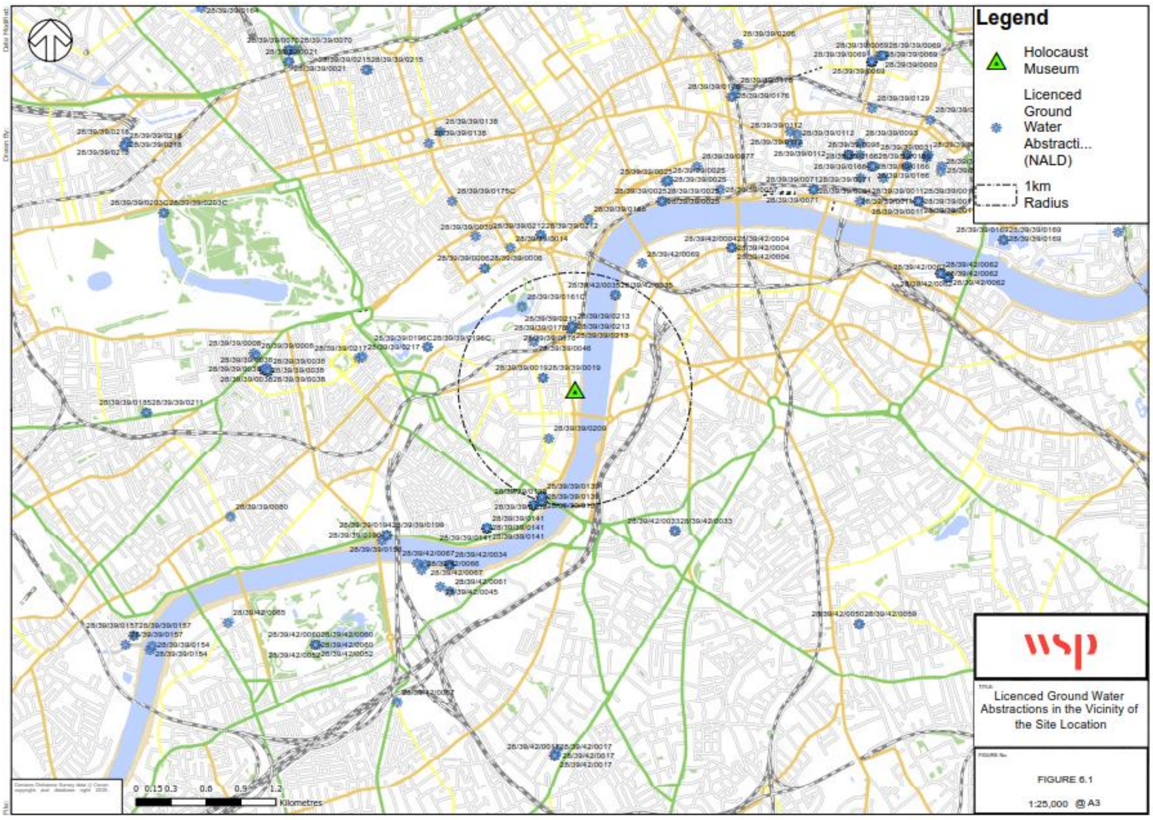

Figure 6-1 Licenced Groundwater Abstractions in Vicinity of Development (those circled within 1000m)

The nearest licenced groundwater abstraction is located approximately 330m northwest of the site (licence no. 28/39/39/0019). The largest abstraction is licence no. 28/39/42/0061, located >2km to the south-southwest. This is owned by Thames Water and used for public water supply with a maximum permissible daily abstraction of 7500m^3/day.

Given the proposed use of groundwater at the development site (and quantity of water required), WSP considers that there is negligible risk of adversely affecting these existing licenced abstractions.

Table 6-1 Licenced Groundwater Abstractions within 1000m of Development

ID	Name	Easting	Northing	Distance (m)
28/39/42/0035	SHELL SERVICES INTERNATIONAL	530600	180000	948
28/39/39/0019	CORPORATION OF THE CHURCH HOUSE	529980	179290	331
28/39/39/0046	THE CENTRAL HALL	529900	179600	605
28/39/39/0019	CORPORATION OF THE CHURCH HOUSE	529980	179290	331
28/39/39/0139	BENCHMARK (RIVERMILL) LTD	529970	178230	932
28/39/39/0139	BENCHMARK (RIVERMILL) LTD	529970	178270	894
28/39/39/0178	CORPORATE OFFICER OF THE HOUSE OF COMMONS	530230	179730	616
28/39/39/0178	CORPORATE OFFICER OF THE HOUSE OF COMMONS	530220	179710	596
28/39/39/0178	CORPORATE OFFICER OF THE HOUSE OF COMMONS	530230	179730	616
28/39/39/0178	CORPORATE OFFICER OF THE HOUSE OF COMMONS	530220	179710	596
28/39/39/0139	BENCHMARK (RIVERMILL) LTD	529970	178230	932
28/39/39/0139	BENCHMARK (RIVERMILL) LTD	529970	178270	894
28/39/39/0139	BENCHMARK (RIVERMILL) LTD	529970	178230	932
28/39/39/0139	BENCHMARK (RIVERMILL) LTD	529970	178270	894
28/39/39/0161C	ROYAL PARKS AGENCY	529800	179900	910
28/39/39/0139	BENCHMARK (RIVERMILL) LTD	529970	178230	932
28/39/39/0139	BENCHMARK (RIVERMILL) LTD	529970	178270	894
28/39/39/0209	WESTMINSTER GARDENS LIMITED	530030	178770	415
28/39/42/0035	SHELL INTERNATIONAL LTD	530600	180000	948
28/39/39/0139	BENCHMARK (RIVERMILL) LTD	529970	178230	932
28/39/39/0139	BENCHMARK (RIVERMILL) LTD	529970	178270	894
28/39/39/0213	CORPORATE OFFICER OF THE HOUSE OF COMMONS	530220	179710	596
28/39/39/0139	PANORAMIC MANAGEMENT CO LTD	529970	178230	932
28/39/39/0139	PANORAMIC MANAGEMENT CO LTD	529970	178270	894
28/39/39/0139	PANORAMIC MANAGEMENT CO LTD	529970	178230	932

28/39/39/0139	PANORAMIC MANAGEMENT CO LTD	529970	178270	894
28/39/39/0213	CORPORATE OFFICER OF THE HOUSE OF COMMONS	530230	179730	616
28/39/39/0213	CORPORATE OFFICER OF THE HOUSE OF COMMONS	530220	179710	596
28/39/39/0139	PANORAMIC MANAGEMENT CO LTD	529970	178230	932
28/39/39/0139	PANORAMIC MANAGEMENT CO LTD	529970	178270	894
28/39/39/0139	PANORAMIC MANAGEMENT CO LTD	529970	178230	932
28/39/39/0139	PANORAMIC MANAGEMENT CO LTD	529970	178270	894
28/39/39/0213	CORPORATE OFFICER OF THE HOUSE OF COMMONS	530230	179730	616

6.3 THAMES TIDEWAY CONSTRUCTION & DEWATERING RISKS

This section presents our assessment of potential impact to the proposed groundwater heating and cooling system resulting from construction of the Thames Tideway Tunnel and associated shafts in terms of derogation (reduced yields in boreholes at the development site) and water quality. The extent of the proposed Tideway Tunnel in relation to the proposed development is shown in
Figure 6-2 below.

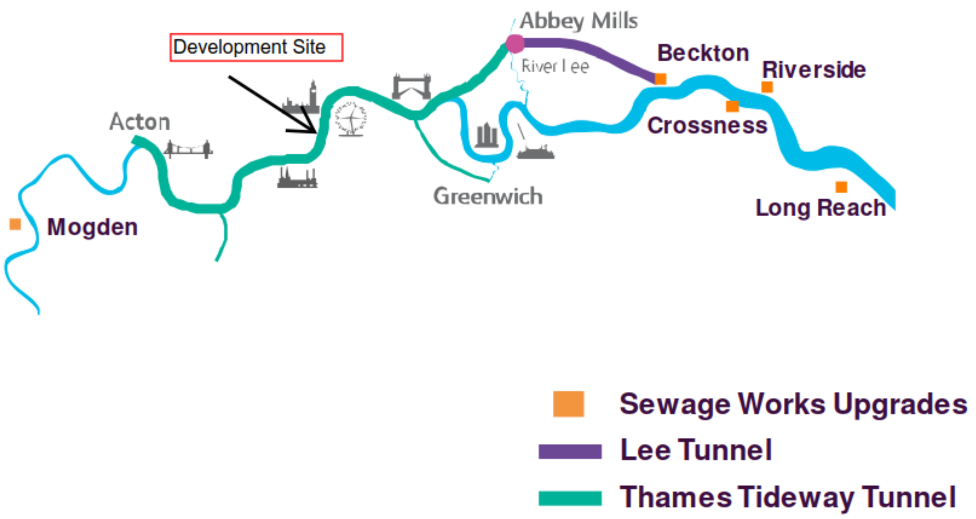

Figure 6-2 Thames Tideway Tunnel Route Relative to Proposed Development Site

Our assessment of risks to the proposed use of groundwater for heating and cooling at the development site due to the Thames Tideway Tunnel is as follows:

- Assuming that the Tideway dewatering works occur before development of the groundwater system at the development site there should be no impact at all. It is reported that these works are temporary and we have assumed rapid recovery of groundwater levels on cessation of dewatering. The timing of these works should be established;

- We do not envisage that the Tideway dewatering works will affect groundwater quality at the development site. This is due to the fact that the tunnel alignment itself is located in strata overlying the Chalk aquifer rather than within the aquifer itself as indicated in Figure 6-3 and the fact that the tunnel alignment and nearest shafts are located >500m from the development site.

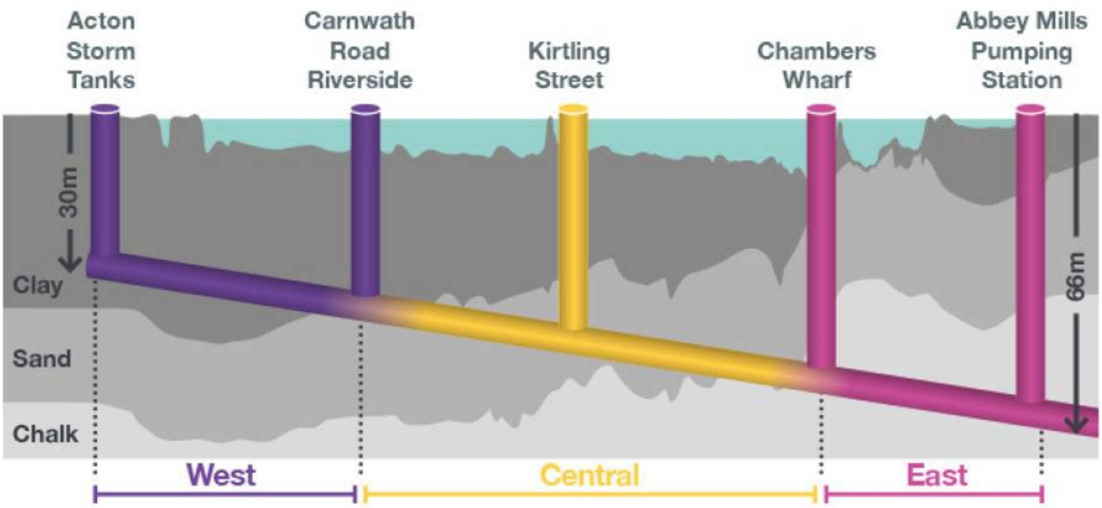

Figure 6-3 Schematic Cross Section through Thames Tideway Tunnel and Associated Shafts (Chambers Wharf, where the tunnel penetrates below the strata overlying the Chalk is >5km east of the Development Site)

6.4 OTHER GROUNDWATER HEATING AND COOLING SYSTEMS

Details of all licenced groundwater heating and cooling schemes in the Thames region were obtained from an Environment Agency database (2014). An update was requested recently but we were advised by the Environment Agency that the database has not been updated since 2014. The database holds records of 54 licenced groundwater heating and cooling systems in the Thames region, many of these being located in Central London.

Figure 6-4 shows the location of all licenced groundwater heating and cooling systems in Central London and Figure 6-5 shows existing systems within 1000m distance of the proposed development site, of which there are three:

- The Royal Festival Hall, approximately 1000m northeast of the site;
- The Cabinet Office, approximately 800m north of the site; and
- Queen Anne's Gate, approximately 800m northwest of the site.

WSP considers that none of the identified groundwater heating and cooling systems are close enough to adversely affect the proposed use of groundwater at the development site.

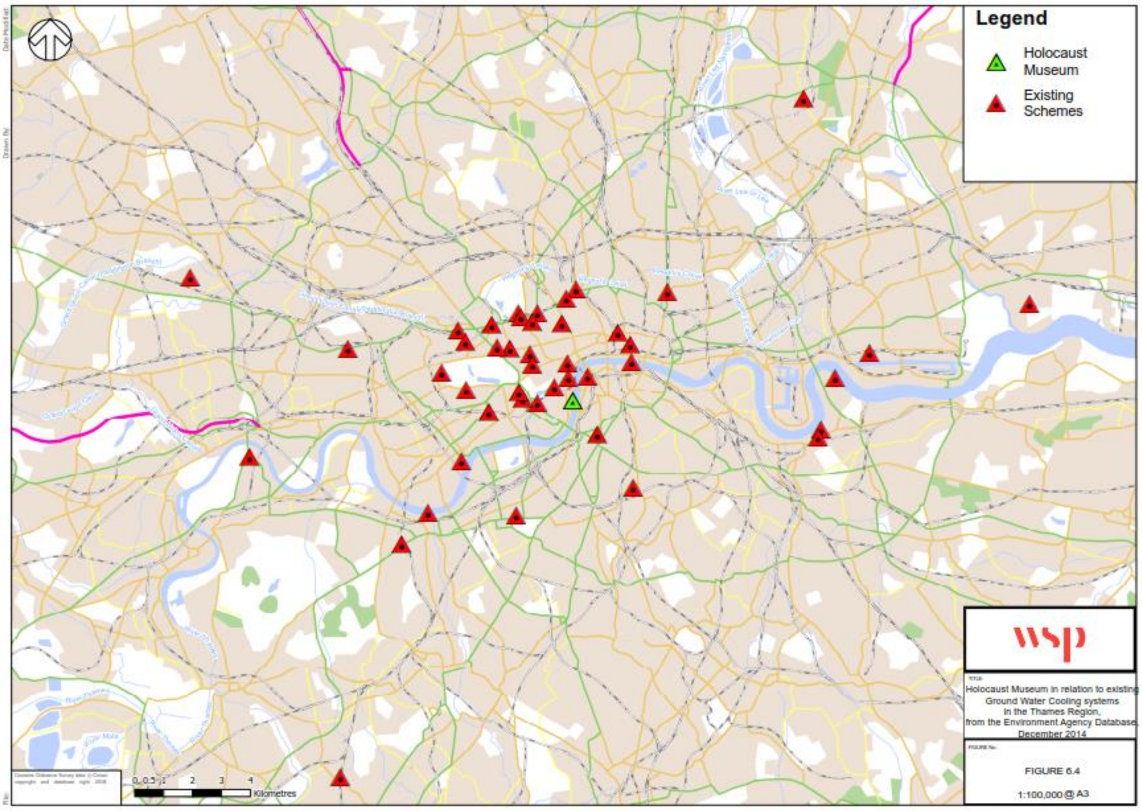

Figure 6-4 Development Site in relation to existing Ground Water Cooling Systems in the Thames Region

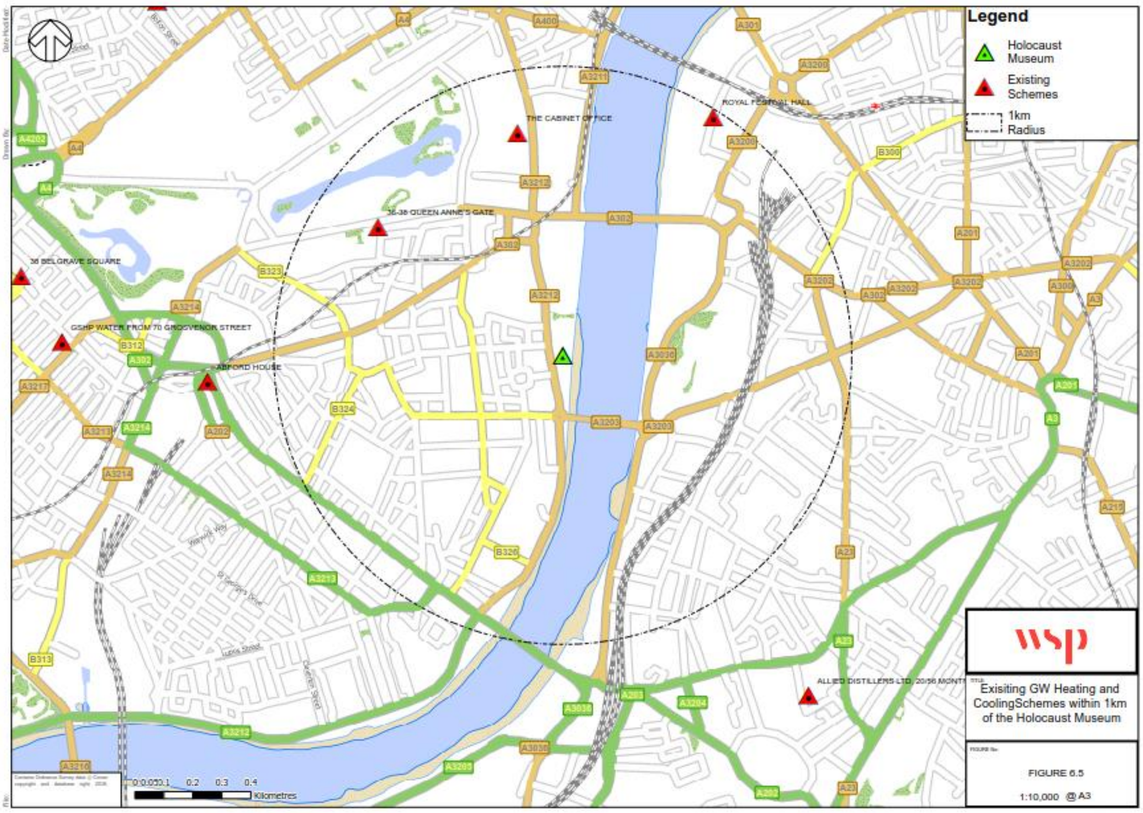

Figure 6-5 Development Site in relation to nearest existing Ground Water Cooling Systems

6.5 LONDON UNDERGROUND TUNNELS

The location of London Underground Tunnels and over-ground rail lines in relation to the proposed development site is shown in Figure 6.6 below.

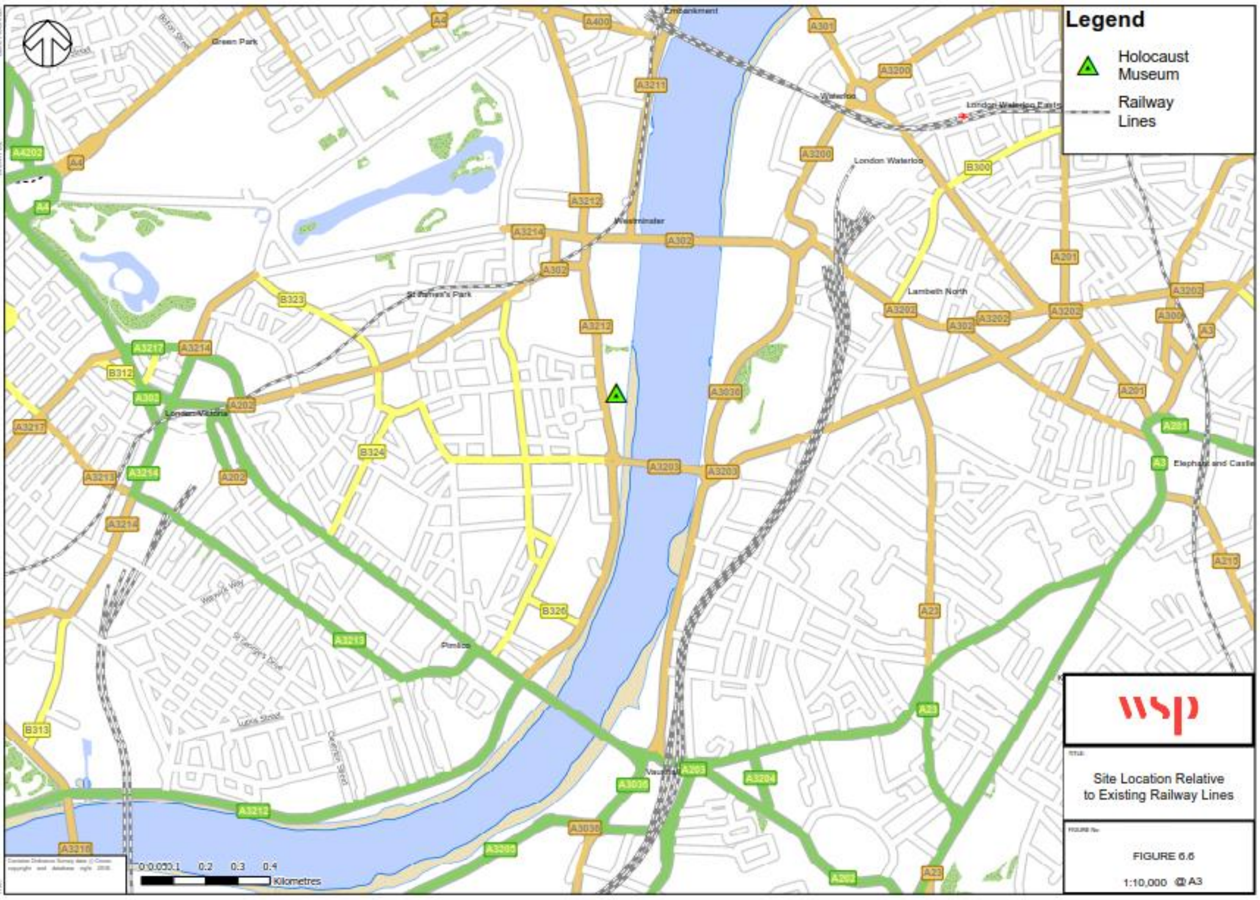

Figure 6-6 Development Site in relation to nearest existing London Underground Tunnels

Based upon the above map (and subject to consultation with TfL) it is not anticipated that existing or future rail lines will impact upon the proposed development.

7 ASSESSMENT OF ABILITY TO MEET REQUIREMENT

Assessment of ability to meet the specified cooling and heating requirements follows the approach set out in Birks et al 2015 and takes into consideration the key (geoscience) design principals described in Younger 2008 and Clarkson et al 2009. Birks et al 2015 identified four principal geoscience risks common to all groundwater cooling systems of this type, regardless of the geological setting. These are represented schematically in Figure 2-1 (pg. 8) and summarised below:

— Risk 1, Abstraction. The aquifer and/or wells installed within the aquifer may not be capable of supporting the requisite flow rates;

— Risk 2, Recharge. There may be problems with recharging effluent water back into the aquifer and, over time, there may be problems associated with clogging which could potentially cause flooding;

— Risk 3, Filtration and water chemistry. Poorly designed and/or constructed wells can result in poor water quality, including a high sediment content. This can cause problems with filtration, clogging in heat exchangers and potentially clogging of recharge wells (thus exacerbating recharge risk outlined above); and

— Risk 4, Thermal Degradation. The volume of rock in which the abstraction and recharge boreholes interact has a finite capacity to absorb heat. The amount and rate of heat rejection needs to be balanced with the capacity of the ground.

The specified cooling and requirements are as given in Section 0. In summary:

— Peak Cooling 147kW;

— Peak Heating 65kW;

— Annual Cooling 0.04GWh;

— Annual Heating 0.03GWh

7.1 ABSTRACTION AND RECHARGE (R1 & R2)

Based on the available information we consider that flows of 4L/sec out of and back into the aquifer will be achievable utilising a single abstraction and a single recharge well. A pumping test with simultaneous abstraction and injection will be required when the wells are constructed to confirm this.

The relationship between water levels in abstraction and recharge wells describes a hydraulic balance as indicated in Figure 7.1 below. During operations water level in the abstraction well will drop and water level in recharge well will rise. The amount of drop and rise will depend on the flow rate and is dependent on the hydraulic properties of the wells. Based on available information we consider that respective drops and rises in water levels will be small (<10m). The rest water level beneath the development site is approximately 35 – 40m below ground level.

The amount of rise in injection wells is particularly important because there is a flooding risk if injected water levels are allowed to rise too much. Similarly, if abstraction rates are too high then the water levels can cause the wells to dry out with resultant decrease in abstraction rate and possible damage of pumps due to dry running.

The hydraulic balance should be demonstrated through a programme of pump testing including a continuous (7 – 14 days) test at the maximum rate (4L/sec).

Using the flow and water level data in Figure 7-7-1 the time taken for groundwater to recirculate between the recharge and abstraction wells with a nominal distance of 200m between them can be estimated by reworking the Darcy flow equation below;

i) $Q = (KA\ x\ dh/dl)/ne$

Where *Q = flow rate (346m^{3}day^{-1});*

A = cross sectional area perpendicular to the flow (assuming most flow in top 25m of Chalk)

K = Hydraulic Conductivity (10mday^{-1}, assuming most flow in top 25m of Chalk)

dh/dl = hydraulic gradient (10m/200m = 0.05) ; and

ne = effective porosity(Typical fracture porosity Chalk, 0.01)

Groundwater velocity (vx) is then derived by reworking equation (ii) as follows:

ii) $V_x = \frac{Q}{neA} = \frac{Kdh}{dl}/ne$ = 50 mday^{-1}

Based on equation (ii) above the time taken for groundwater to recirculate between the recharge well and the abstraction well through a distance of 200m is 4 days. In the context of groundwater movement this is consistent with the groundwater travel time predicted by Clarkson et al 2009 at the Royal Festival Hall of approximately 16 hours (0.67 day).

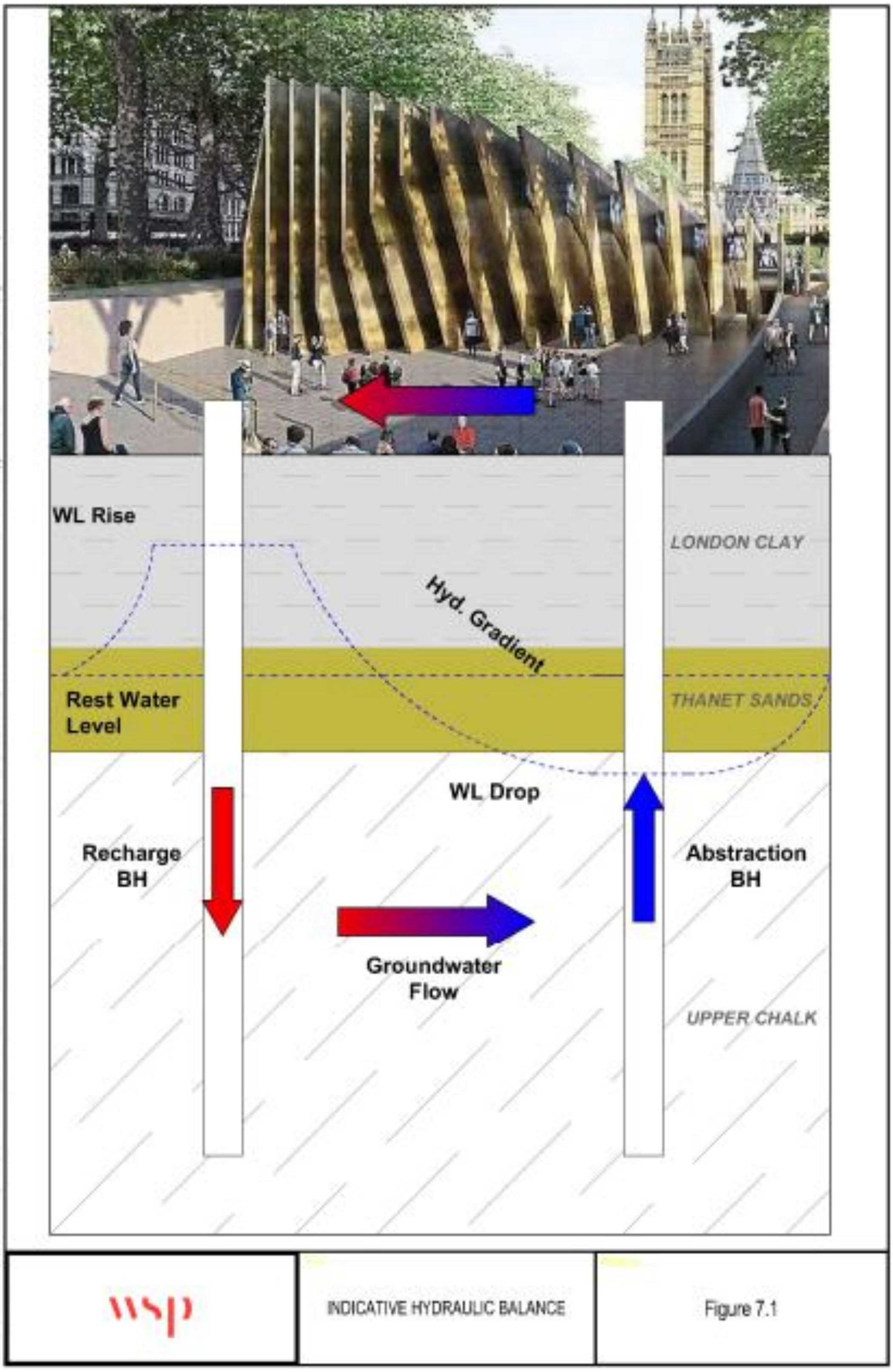

Figure 7-1 Indicative Hydraulic Balance

7.2 FILTRATION AND WATER CHEMISTRY (R3)

Properly designed/constructed Chalk water wells in Central London typically yield water of a very high, near potable quality. Testing when the wells are constructed will establish water quality but typically (and demonstrated by longstanding use of nearby wells including the Royal Festival Hall) particulate filtration is the only form of treatment required. A summary of water quality (chemistry and suspended solids) results obtained during commissioning at the Royal Festival Hall (Clarkson et al 2009) is given below:

- Hardness 200mg/l to 240 mg/l;
- Calcium 48 mg/l to 171 mg/l;
- Dissolved iron <0.005 mg/l to 0.058 mg/l;
- Iron Total 0.1mg/l to 0.25mg/l;
- Dissolved manganese 0.017mg/l;
- Total manganese 0.021mg/l to 0.03mg/l;
- Carbonate Alkalinity <2mg/l to 60mg/l;
- Bicarbonate Alkalinity 220mg/l to 280mg/l;
- Conductivity 1.5mS/cm to 1.6mS/cm;
- Potassium 11mg/l to 12mg/l;
- Sodium 250mg/l to 290mg/l;
- Chloride 160mg/l to 170mg/l;
- Total dissolved solids 740mg/l to 820mg/l;
- Total suspended solids <10mg/l to 18mg/l;
- pH 7.88 to 8.66;
- Volatile Organic Compounds <0.001 mg/l

Whilst there are some well documented examples of water wells in the site vicinity yielding poor water quality (e.g. Portcullis House), such problems are usually avoidable through good borehole design and procurement of a competent water well drilling contractor. In 2007 - 2008 WSP undertook a rigorous review of the water well drilling contractor supply chain on behalf of London Underground Ltd and derived a shortlist of contractors deemed competent in water well drilling and satisfying rail industry health, safety and environmental requirements. More recently (2018), WSP has completed the procurement of a water well drilling contractor on behalf of a local planning authority.

7.3 THERMAL BALANCE (R4)

7.3.1 PRELIMINARY HEAT BUDGET

The body of rock into which abstracted and re-injected groundwater interacts is defined as the thermal volume (Birks et al 2016). As a basis of a preliminary heat budget the following assumptions were made:

— Heated groundwater radiates outward from the injection well;

— A proportion of heated water is recirculated back towards the abstraction well; and

— A proportion of the heated groundwater is lost via the regional hydraulic gradient.

— The aerial extent of the flow field is estimated to be approximately 6000m^2 (200m long with an average dispersion of 30m).

Within the Chalk Aquifer (thickness 50m assumed for thermal assessment) heat is assumed to transmit via both conduction and advection. Within the overlying and underlying layers (chalk below and predominantly clay above) heat is assumed to transmit via conduction a vertical distance of 50m. The basis of this assumption is from using analytical equations presented in Westaway et al (2015). The thickness of the derived thermal volume is thus estimated to be 150m, lateral dispersion 30m (accounting for advection and conduction) and a minimum distance between abstraction and injection of 200m. This gives a total thermal volume of 900,000 m^3.

Key elements of the heat budget requiring definition as input parameters are:

— Qin = Heat injected into the thermal volume;

— Ql = Injected heat which is transported out of the thermal volume via regional groundwater flow;

— Qr = Injected heat which is transported into the thermal volume via recirculating groundwater;

— Hc = Heat losses within the aquifer via advection and conduction and into overlying and underlying strata via conduction.

The amount of heat injected into the ground (Qin) is quantified quite precisely (section 2) at 0.01 GWh per year.

Input parameters used in defining the thermal volume and heat budget parameters are presented in Table 7-7-11 below.

Table 7-1 Input parameters for thermal calculations

Input Parameter	Value	Unit	Comment
Net Heat input over 1 year period of operation	0.01	GWh	Sections 2 & 3
Flow rate per day	346	m^3	Sections 2 & 3
Flow rate per year	20,000	m^3	Sections 2 & 3
Ambient groundwater temperature	14	°C	Clarkson et al 2009
Average injected water temperature	24	°C	Assumed
Aquifer thickness	25	m	Ellison et al 2004 & Clarkson et al 2009
Regional hydraulic gradient (conservative worst case)	0.00	Dimensionless	Environment Agency Status Report (2014) assumed variable/flat
Average chalk transmissivity	250	m^{2}day^{-1}	Assumed flow in top 25m of the Chalk, section 7
Hydraulic conductivity (assuming a 25m saturated thickness)	10	mday^{-1}	Section 4 well performance evaluation
Density of saturated chalk rock	1740	kgm^{-3}	Banks, D. 2012. An Introduction to Thermogeology: Ground Source Heating and Cooling, 2nd edition, John Wiley & Sons, Chichester, 526pp. ISBN: 978-0-470-67034-7.

Density of saturated clay	2133	kgm^{-3}	a/a
Specific heat capacity of saturated chalk rock	2.4	$kJkg^{-1}K^{-1}$	a/a
Specific heat capacity of saturated clay	2.09	$kJkg^{-1}K^{-1}$	a/a

It has been assumed that the injected heat disperses radially outward from the injection well. The ground will warm up from an ambient ground temperature of approximately 14°C to a temperature approaching the average injected water temperature of 24°C and the distance over which warming occurs will increase with time.

A uniform warming of the rock mass was assumed between abstraction and injection wells. This is a significant simplification because there will be a temperature gradient from the point of water injection to the edge of the assumed radial distance. However, the assumption is rationalised by constraining temperature changes in the underlying and overlying layers and therefore the quantity of heat that will penetrate into these bodies.

Using the input parameters in Table 7-7-1 above and applying equation (iii) below the estimated rise in temperature within the thermal volume is approximately 0.5°C over a 50 year working life (assumed 0.01GWh per annum net heat rejection over 50 years, 0.5GWh total). As a first pass heat balance analysis this is considered acceptable.

$$\text{(iii)} \qquad Q = \frac{\Delta T \times M \times SHC}{3600}$$

Where:

- Q = heat input or output (kWh);
- ΔT = induced change in temperature within the thermal volume (°C);
- M = mass within thermal volume (kg); and
- SHC = specific heat capacity (kJ/kg°C)

7.3.2 THERMAL BREAKTHROUGH TIME & LONG TERM EQUILIBRIUM TEMPERATURE

The estimated groundwater travel time derived in Section 7.1 was 96 hours (4 days) and was based on a continuous flow of 4L/sec (346m^3/day). Thermal breakthrough is defined as the time when abstracted groundwater temperature starts to rise after a period of sustained heat rejection and usually lags the groundwater travel time by a considerable margin. In effect, heat transport is retarded relative to the groundwater flow because heat is absorbed into the rock through which the water passes. Banks (2012) proposes the following equation to derive a thermal retardation factor (R):

$$\textit{iii)} \qquad R = \frac{xHyd}{xTherm} = SVCaq/(ne\ x\ SVCwater)$$

Where R is the thermal retardation factor (dimensionless), xHyd is the hydraulic breakthrough time (days), xTherm is the thermal breakthrough time (days), SVCaq is the volumetric heat capacity of the aquifer (assumed 2.2$MJm^{-1}K^{-1}$), ne is effective porosity and SVCwater is the volumetric heat capacity of water.

The above derives a retardation factor (R) of 52 from which a thermal breakthrough time of 200 days is estimated for a 200m well separation. Assuming that cooling is required for approximately 5 months of the year (150 days, see Figure 3.1) thermal breakthrough is unlikely to be significant. Provided that a close balance is maintained between heating and cooling annually (0.01GWh per annum), then any change in water temperature will be kept within acceptable limits.

However, if a large imbalance between heat inputs and outputs (>>0.01GWh) is sustained over a number of consecutive years then the changes in abstracted water temperature may become problematic.

8 BUDGET ESTIMATE FOR PROPOSED DEVELOPMENT

8.1 INTRODUCTION

Typically the cost of developing the borehole infrastructure for a groundwater heating and cooling system of the size and configuration under consideration at the development site is of the order of £0.5M with a risk profile as indicated in Figure 8-8-1 below.

Due to the fact that estimated heating and cooling loads at the proposed development site are so small (i.e. net heat rejection 0.5% of that of the Royal Festival Hall and peak loads approximately 10%) the principal geoscience risks are reduced considerably. Notwithstanding, the client (and his advisors) need to understand and accept that there is an inherent risk associated with the technology that can only be eradicated completely once the wells are drilled, tested and resource is proven.

The cost of constructing and commissioning two Chalk water wells for the proposed development is estimated at £0.5M. The basis of this cost estimate is presented in Section 8.2 below.

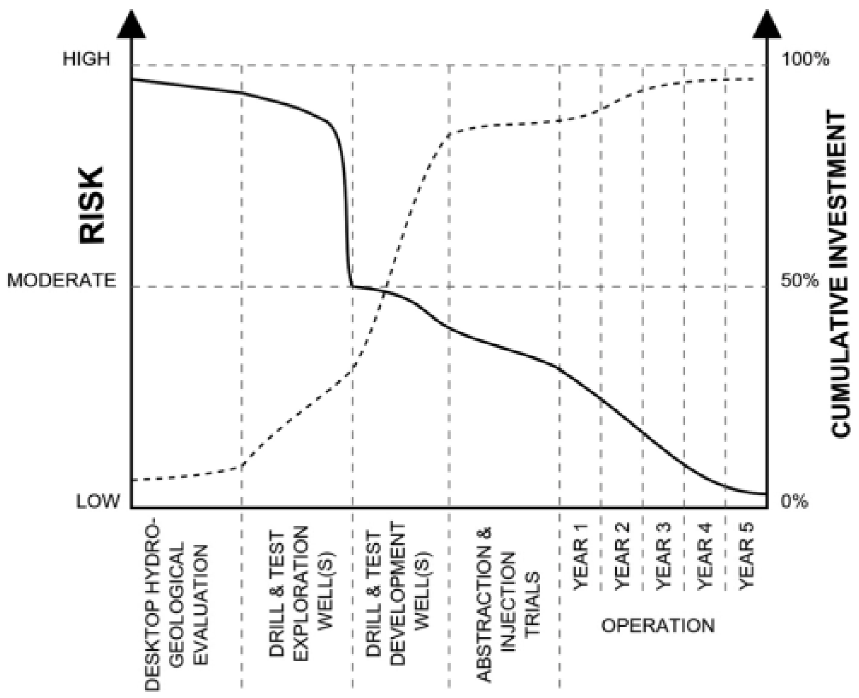

Figure 8-1 Typical Risk Investment Profile for Groundwater Cooling and Heating System Development (after Birks et al 2016)

8.2 PRELIMINARY BUDGET COST ESTIMATE

A preliminary budget cost estimate for construction of the borehole infrastructure at the development site is given in Table 8-8-1 below.

Table 8-1 Preliminary Cost Estimate for Re-purposing Wells

Cost Element	Description	Budget Cost (£)
DETAILED FEASIBILITY		
Interface Thames Water & Thames Tideway	Understand timing and scope of activities associated with Battersea Public Water Supply and Thames Tideway	5,000
Interface Environment Agency & Licencing	In Principal Agreement; Testing Requirements for Licence Application; Make Licence Application	5,000
Prepare Specification for Construction and Testing of 2 Chalk water wells	(Example Specification available on request)	10,000
Procurement of Competent Water Well Drilling Contractor through Competitive Tender	(Example scoring matrix and recommendation letter for an ongoing project available on request)	10,000
Subtotal Detailed Feasibility		**30,000**
CONSTRUCTION & TESTING OF 2 CHALK WATER WELLS		
Contractor Costs	Based on other similar and recent experience	400,000
WSP supervision/attendance during construction and testing	Assumed full (daytime) supervision for 12 weeks, 5 days per week	50,000
WSP Reporting	(Example report available on request)	20,000
Subtotal Construction and Testing of 2 Chalk Water Wells		**470,000**

INTEGRATION		
Pipe work from wellheads to plant rooms	Excluded	Excluded
Installation/Commissioning of Heat Pumps/Heat Exchangers within Plan Room	Excluded	Excluded
GRAND TOTAL		**500,000**

9 RECOMMENDED ROUTE MAP FOR DEVELOPMENT

9.1 DEVELOPMENT ROUTE MAP

A provisional route-map for development of the proposed groundwater heating and cooling system is presented in Figure 9-9-1 Figure 2-1below.

Detailed Feasibility (3 months) Including:

- Agree Well Locations;
- Interface MEPH;
- Interface Environment Agency;
- Interface Thames Tideway;
- Interface London Underground;
- Interface other Underground Utilities;
- Prepare Specification;
- Contractor Procurement

↓

Construction & Testing of 2 Chalk Water Wells (4-5 months) Including:

- Contractor Mobilisation;
- Consents (Environment Agency & Thames Water;
- Construction of Chalk Well 1 (allow 6 weeks);
- Testing Chalk Well 1 (allow 2 weeks):
- Construction Chalk Well 2 (allow 6 weeks)
- Testing Chalk Well 2 (allow 2 weeks);
- Hydraulic Balance Test from Chalk Well 1 to Chalk Well 2 (allow 2 weeks); and
- WSP Report (allow 2 weeks)

↓

Integration (programme tbc) Including:

- Pipe Connections between Wellheads and Plant Room(s);
- Procurement of Heat Pumps & Heat Exchange Equipment;
- Installation of Heat Pumps & Heat Exchange Equipment;
- Commissioning & Testing;
- Operation and Maintenance Schedule; and
- Handover.

Figure 9-1 Provisional Route-map for Establishing Groundwater Heating and Cooling System at the Holocaust Museum

10 CONCLUSIONS & RECOMMENDATIONS

10.1 CONCLUSIONS

This report assesses the feasibility of using groundwater for heating and cooling at the proposed Holocaust Museum, Westminster and, specifically, provides an indicative cost estimate, programme and assessment of risk.

The groundwater system under consideration is designed to provide a close balance between heating and cooling and the estimated loads are small compared to similar applications of the technology in the near vicinity of the site and elsewhere in other established schemes. This has a bearing on project risk (considered low due to the small heating and cooling loads) and also on the economics.

In the context of other established and emerging low carbon heating and cooling technologies the cost of developing a groundwater heating and cooling system is likely to be considerably higher. However, the authors of this report understand that there are other drivers, including an aspiration not to use fossil fuels (for heating) and aesthetic considerations (minimal/negligible surface expression). Justification of the anticipated higher cost of developing the groundwater heating and cooling system described in this report should be considered in the context of these and other drivers.

10.2 RECOMMENDATIONS

This report should be used as a basis comparing the commercial case for a groundwater heating and cooling system with other viable technologies. If the case for a groundwater heating and cooling system is favourable then further development should be undertaken in accordance with the route map outlined in Section 9 of this report.

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Appendix B

TOPIC PAPER

CONTENTS

FIGURES

APPENDICES

EXECUTIVE SUMMARY

WSP have prepared this 'Topic Paper' on the subject of Energy and Sustainable Construction to form the basis for discussions between the development team and Westminster Planning Officers during the Concept Stage (RIBA Stage 2) of the National Holocaust Memorial development project, planned for the 23rd March.

The concept building has been designed as a subterranean structure with subdivided rooms and corridors intended to house exhibits and articles relating to the persecution of minorities during the Holocaust.

The memorial will be a place for quiet reflection, learning and understanding. The layout of the building, lighting, architectural finishes and atmospheric conditions must be designed to facilitate this.

The building will also be an occupied space requiring ventilation, heating, cooling, lighting and humidification, primarily to make the space comfortable, healthy and safe; these services will also to help create an environment appropriate to its use.

The site opportunities are very limited (thermal mass of the ground; presence of a below ground aquifer; potential for hiding services in the ground; site location next to the river Thames).

The site constraints were more numerous (sensitive location; limited space for services to be located; the architectural philosophy and inherent requirement for the building and all services to be discrete/ hidden; security, particularly in relation to the threat of terrorism; no physical rooftop to the building on which to install solar technologies or building services plant; no potential for wind generation; and the requirement for gas-utility services to be avoided due to cultural sensitivity).

The team's ideas about the building envelope design and how the building could be serviced were guided by the London Plan Energy Hierarchy (Be Lean, Be Clean, Be Green) and the 'fabric-first' approach. The main drivers were acknowledged as being: minimising carbon emissions and the demand for energy and the avoidance of overheating.

We carried out a comparison exercise to compare 6 energy strategy options and used a model to evaluate the relative performance of each. The options were:

1. Ground source heat pumps using closed loop boreholes
2. Ground source heat pumps using open loop abstraction from the ground
3. Water-cooled chiller with gas-fired boiler
4. Heat rejection using fins with gas-fired boiler
5. Reverse-cycle air source heat pumps
6. District heating with water-cooled chiller

The study showed that all options would be better than the minimum performance standard of UK Building Regulations Part L by 27–32%. The worst option was 'Heat rejection fins & gas fired boilers' and the best was closed loop GSHPs. Open loop GSHPs system was a close second best. However, all options performed similarly.

Further investigation highlighted that: closed loop GSHPs could be difficult to accommodate on the site due to space constraints; gas-fired boilers would not be a viable option due to cultural sensitivity; air source heat pumps could not both be hidden and work effectively; and the closest district heat network branch was several hundred metres away. This information led the team to begin focussing on a system design which incorporated GSHPs using open loop abstraction from chalk or the Thames gravel.

A key finding was that heating and cooling energy is a very small component of the overall energy demand for the building; the majority is for auxiliary (mainly fans), lighting and equipment (unregulated - was estimated using benchmarks). The low heating and cooling energy demands result from the building being underground and thus are tempered by the ground's thermal mass – which is a key advantage.

Using the results of the options and modelling study and research, the concept design was developed further. At the close of Stage 2, the main design features are:

- **Optimised lighting –** all lighting in the building will utilise high efficiency lamps and luminaires with optimised controls, including auto on/off sensor controls to minimise energy use when the building is not occupied. Due to the nature and intended operational characteristics of this building, the lighting levels will be relatively low, compared with other building types (offices/schools for example). This will create the intended environment, but also significantly reduce energy consumption.
- **Thermal labyrinth** – will supply fresh air into the occupied spaces of the building via a distribution plenum chamber located underneath the floor of the building. The plenum would be a fabricated concrete labyrinth into which fresh air is supplied from air handling plant and from which air is supplied to the occupied spaces of the building. This will pre-heat or pre-cool the air due to its thermal mass and dwell-time and reduce the requirement for energy consumption for heating and cooling over the course of the year.
- **Displacement ventilation system** - will supply fresh tempered air at floor level and extract stale air at high level. This solution is compatible with the use, estimated loads and occupancy profile of the building, as well as being the best technical solution to partner with the labyrinth. It will also allow heat recovery to maximise efficiency.
- **Underfloor heating and cooling system** - the coils for which would be installed in the concrete floor between the labyrinth and the occupied spaces and would be carefully coordinated with both the ventilation system and all electrical services.
- **Non-reliance on renewables** - opportunities for incorporating renewable energy technologies into the design are extremely limited. It was identified that photovoltaics, solar thermal collectors would not be possible as the roof of the building is parkland and hardstanding public realm or secure areas; similarly wind turbines would not be appropriate in this location. To compensate, the design team recognises that the building itself needs to be as efficient as possible and all inherent energy and carbon-saving opportunities should be exploited.

The above are all tried and tested solutions and suitable case studies and precedents are available.

Further modelling and testing will be carried out during the developed and detailed design stages (RIBA Stages 3 and 4).

CONCLUSIONS

- At the end of the Stage 2 design, during which a wide range of potential options were considered and tested using good/best practice principles and building physics modelling, the optimum building services systems were identified as:
  - Optimised U-values and taking advantage of the thermal mass of the ground
  - Optimised lighting and controls
  - Thermal labyrinth to supply fresh, tempered air
  - Open loop ground source heat pumps utilising 3-4 boreholes on the site
  - Displacement ventilation system
  - Underfloor heating and cooling system
- Heating and cooling energy is a relatively very small component of the overall energy demand for the building, the majority of which is for fans, lighting and equipment.
- It was shown that incorporating renewable energy systems into the design of the building would not be possible due to the site, location and project constraints.

- The building was modelled and it was shown around a 30% improvement against Part L 2013 could be achieved.
- The team understands that this is compliant with the GLA London Plan 2016 requirements under Policy 5.2 ‘Minimising Carbon Dioxide Emissions’ which, for the 2016-2019 window requires non-domestic buildings to meet the requirements of the Building Regulations.
- In terms of other policy drivers, it was determined that a connection to a district heat network would not be possible due to the excessive distance between the existing proposed network branch (c.400m) to the site; and the minimum renewable energy generation target set by Westminster is not feasible due to the site and project constraints.

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1 INTRODUCTION

1.1 PURPOSE OF REPORT

WSP were asked to prepare a ‘Topic Paper’ on the subject of energy and sustainability to form the basis for discussions between the development team and Westminster Planning Officers during the Concept Stage (RIBA Stage 2) of the National Holocaust Memorial development project. A meeting is planned for the 23rd March 2018 in Westminster, during which these matters are to be discussed.

1.2 BACKGROUND

The National Holocaust Memorial has been designed as a subterranean building with a series of subdivided rooms and corridors intended to house exhibits and articles relating to the persecution of minorities during the Holocaust.

As a design team, our understanding is that the memorial will be a place for quiet reflection, learning and understanding. The layout of the building, the lighting, the architectural finishes, the atmosphere, have all been designed to facilitate this.

2 CONCEPT DEVELOPMENT

2.1 BUILDING DESIGN BASIS

The building will be an occupiable space requiring ventilation, heating, cooling, lighting and humidification, primarily to make the space comfortable, healthy and safe, but also to help create an appropriate atmospheric environment.

The Architect's boards they developed for the original project competition are included in Appendix A for reference.

A range of opportunities and constraints were identified during the initial stages and these are listed in 2.2 and 2.3 below, including those relating to the site itself and the building.

2.2 SITE OPPORTUNITIES

- Thermal mass of the ground
- Below ground aquifer
- Potential for hiding the services in the ground
- Location adjacent to the river Thames

2.3 SITE CONSTRAINTS

- Sensitive location
- Limited space for services to be located
- Architectural philosophy - requirement for the building and all services to be discrete/hidden
- Security, particularly in relation to the threat of terrorism
- No physical rooftop to the building on which to install solar technologies
- No potential for a wind turbine
- Requirement for gas-utility services to be avoided, due to cultural sensitivity

2.4 EARLY DESIGN DEVELOPMENT

The engineering team were presented with the building, in the context of the above opportunities and constraints, and began to develop some ideas about the building envelope design and how the building could be serviced.

This was guided by the London Plan Energy Hierarchy (Be Lean, Be Clean, Be Green) and in this regard the 'fabric-first' approach was adopted, followed by consideration of energy efficient means of serving the building and occupants' requirements, before finally looking at opportunities to implement renewable energy technologies to serve the residual energy demands. The main drivers were acknowledged as being: minimising carbon emissions and the demand for energy.

The team's initial ideas and the rationale behind them are illustrated in the early concept sketch in figure 1 (larger version in Appendix B).

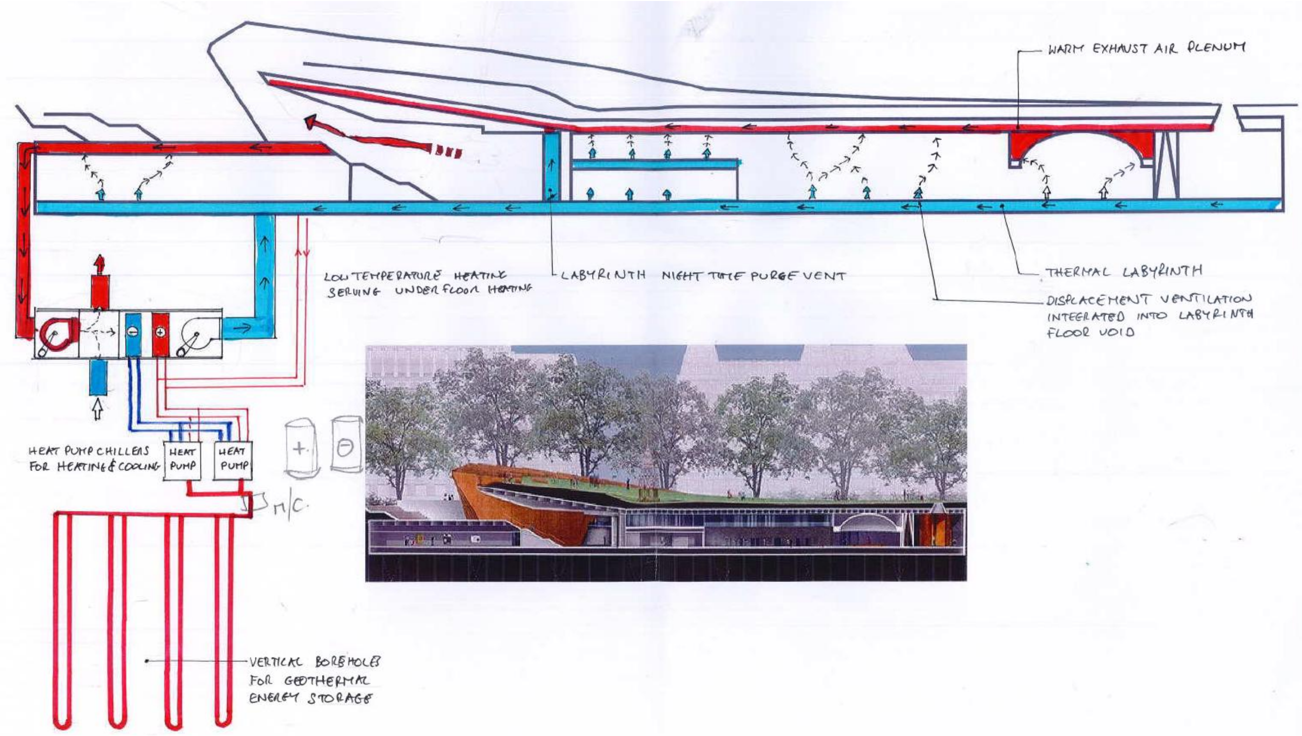


Figure 1: Early concept sketch of the design ideas, including ground source heating and cooling and thermal labyrinth

The next stage was to explore the range of energy options to ensure that the design made use of all potential opportunities – this was performed as an options appraisal, and is detailed in Section 3.

3 OPTIONS APPRAISAL

3.1 INTRODUCTION

The design team explored all opportunities to ensure that our concept design to be progressed was the optimum choice, in terms of technical design coordination, use of the on or near-site opportunities and minimisation of energy consumption and carbon emissions, whilst meeting the detailed requirements of the brief.

To explore these, we carried out a comparison exercise to compare the 6 main options identified. We used a model of the building constructed using the IES VE dynamic simulation modelling software to evaluate the relative performance of each.

3.2 OPTIONS

After an initial workshop between engineers, it was ascertained that certain elements of the design had very limited scope for optioneering – notably the lighting (beyond applying high efficiency lamps and luminaires with optimised controls, very few opportunities exist for reducing energy demand) and the ventilation system. Given that the ventilation system needed to be concealed, the only way to introduce fresh air to the building is to use the floor voids for distribution. This makes a thermal labyrinth an obvious choice – especially seeing as this would provide additional energy-reducing benefits (thermal transfer into and from the ground, utilising the ground's thermal stability). Further, the need to maximise efficiency means that heat recovery is a must. It was decided therefore to build these optimised systems into the base building services design and concentrate on the heating and cooling systems in the options appraisal.

The team noted that it was important to assess opportunities to use the ground (ground source heat pumps), both open and closed loop options, chillers and boilers as a more traditional approach (ignoring any constraints at this time), appraising the sculptural fins' potential for services integration, and finally researching opportunities to connect to local district heat networks, in line with Westminster and the wider GLA's strategic drivers.

To this end, the options assessed were:

1. Ground source heat pumps using closed loop boreholes
2. Ground source heat pumps using open loop abstraction from chalk or Thames gravel
3. Water-cooled chiller with gas-fired boiler
4. Heat rejection using fins with gas-fired boiler
5. Reverse-cycle air source heat pumps
6. District heating with water-cooled chiller

Sections 3.2.1-6 explain the options in much more detail, providing technical details, schematic drawings and an assessment of the range of pros and cons for each.

Section 3.3 provides details of the modelling carried out to assess the Part L performance (against which the London Plan policy 5.4 performance is measured).

Section 3.4 sets out the corresponding results for each of the options.

3.2.1 OPTION 1

Description: Ground source heat pumps using closed loop boreholes

Technical details:

- Currently estimated that circa 50 boreholes will be required for heat rejection/abstraction - each borehole is based on a depth of 100 m to give an 8 kW output
- Borehole spacing is based on 5m centres to ensure adequate heat storage and recovery
- Additional heat rejection coil in ventilation AHU is provided to prevent saturating the ground temperature if the load is unbalanced
- Boreholes can be located either in the park or below the building itself (space saving, although lightly more complex in terms of buildability)
- 10 m^2 pipework manifold room required for connection interface to the boreholes
- 4 x 100 kW heat pumps to be situated in building plant area. This gives an element of plant redundancy
- Borehole design and construction method would need to adhere to environment agency guidance (could affect borehole cost)

Figure 2 shows a schematic representation of the main system components. Figure 3 shows a layout plan for the closed loop borehole array.

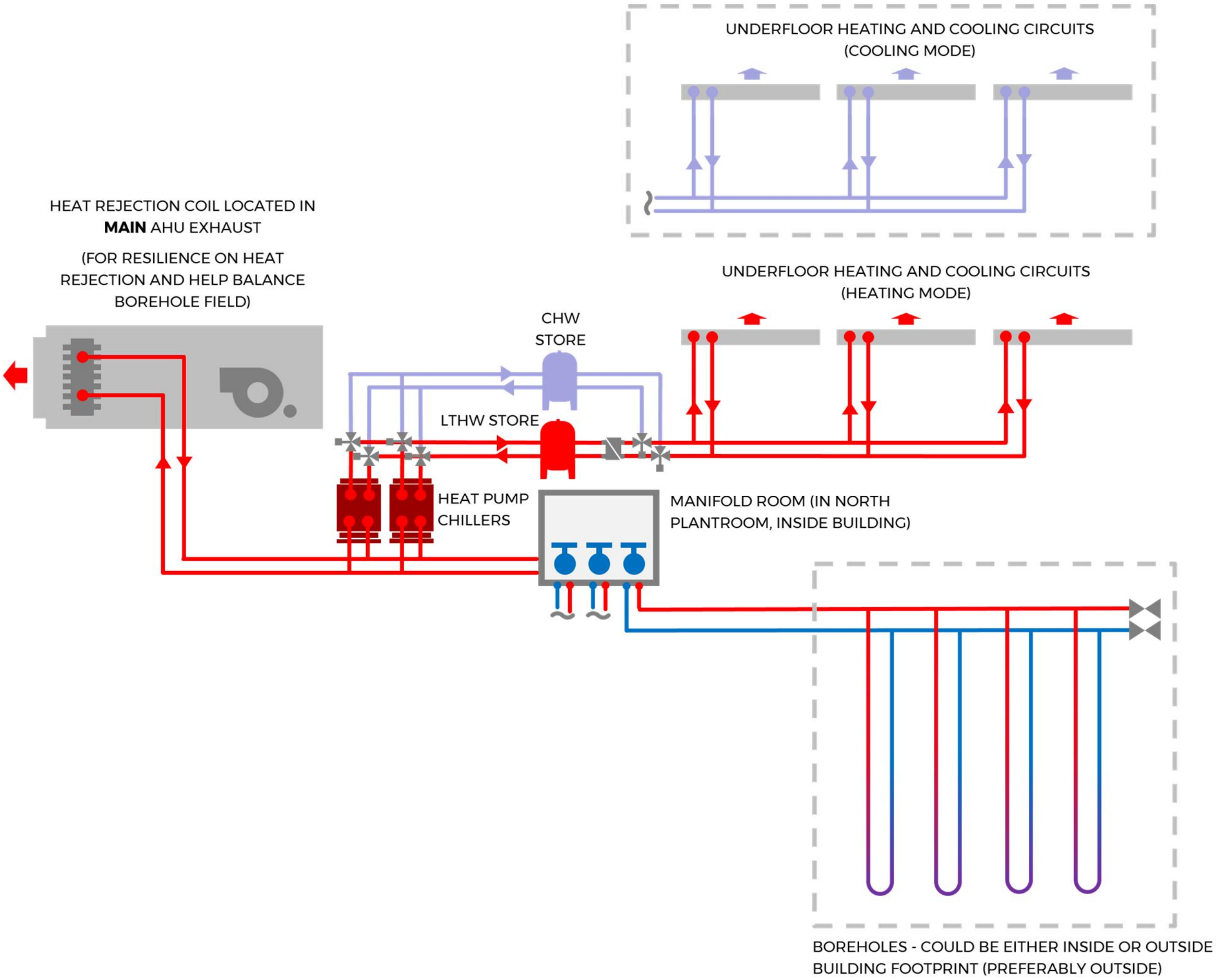


Figure 2: Ground source heat pumps using closed loop boreholes for Option 1

CLOSED LOOP BOREHOLE LAYOUT PLAN

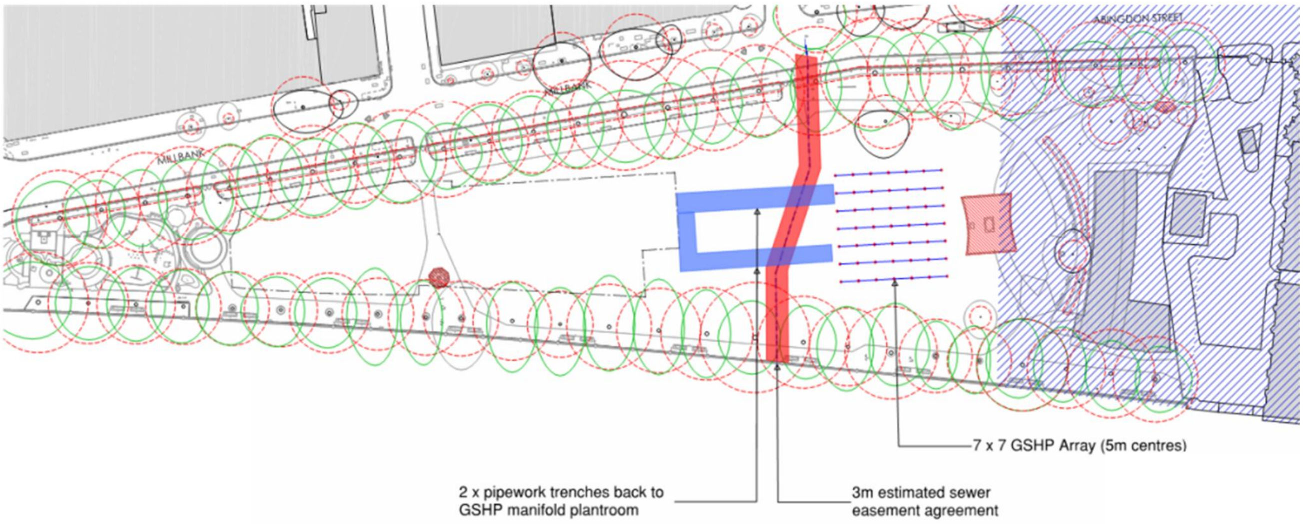


Figure 3: Closed loop borehole layout plan

The pros and cons of this option are summarised in table 1.

Table 1: Option 1 – pros and cons

Pros	Cons
• Most efficient heating and cooling solution available to this site • Best chance of meeting the stringent Westminster and GLA energy and carbon emissions performance standards • Usually no environmental licences are required for closed loop borehole systems • Possible to meet all space heating and cooling demands with a single system • Back-up system could also be electric • No flues required, no vapours/chimneys • No gas supply to site necessary • All HVAC services could be hidden • Fins could remain structural/ sculptural - no need to integrate services	• Likely to be the most expensive option • Significant area outside the building footprint required to be excavated/ drilled if boreholes are not located under the building - this would have to be carefully managed during the construction phase

3.2.2 OPTION 2

Description: Ground source heat pumps using open loop abstraction from chalk or Thames gravel

Technical details:

- Currently estimated that two boreholes will be required for heat rejection & recovery (can provide up to 400 kW per borehole (fewer potential points of failure compared to closed loop)
- Minimum separation distance of 150 m should be provided which is easily achieved within the site constraints, but outside of building footprint
- No manifold room required, so circa 10 m^2 space saving over closed loop option
- Environment Agency license required for this system which can take circa 6 months to obtain
- Additional heat rejection coil in ventilation AHU is provided to prevent saturating the ground temperature if the load is unbalanced
- 150 m separation distance between boreholes (not under building footprint, so trenching will be required) and larger thermal capacity of the system compared to closed loop option
- No pollutants used (glycol) in designated principal aquifer

Figure 4 shows a schematic representation of the main system components. Figure 5 shows a layout plan for the open loop boreholes.

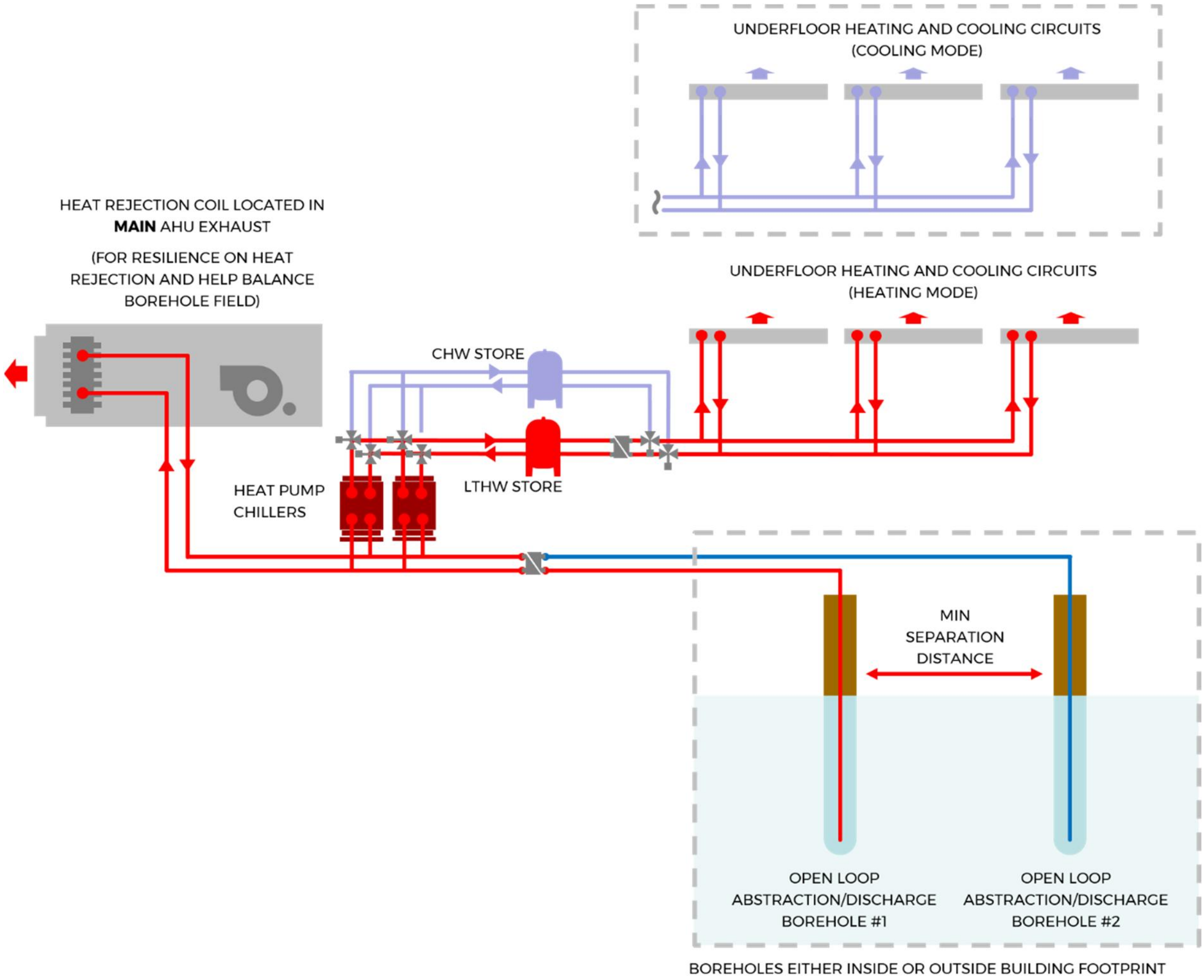


Figure 4: Ground source heat pumps using open loop abstraction from chalk or Thames gravel

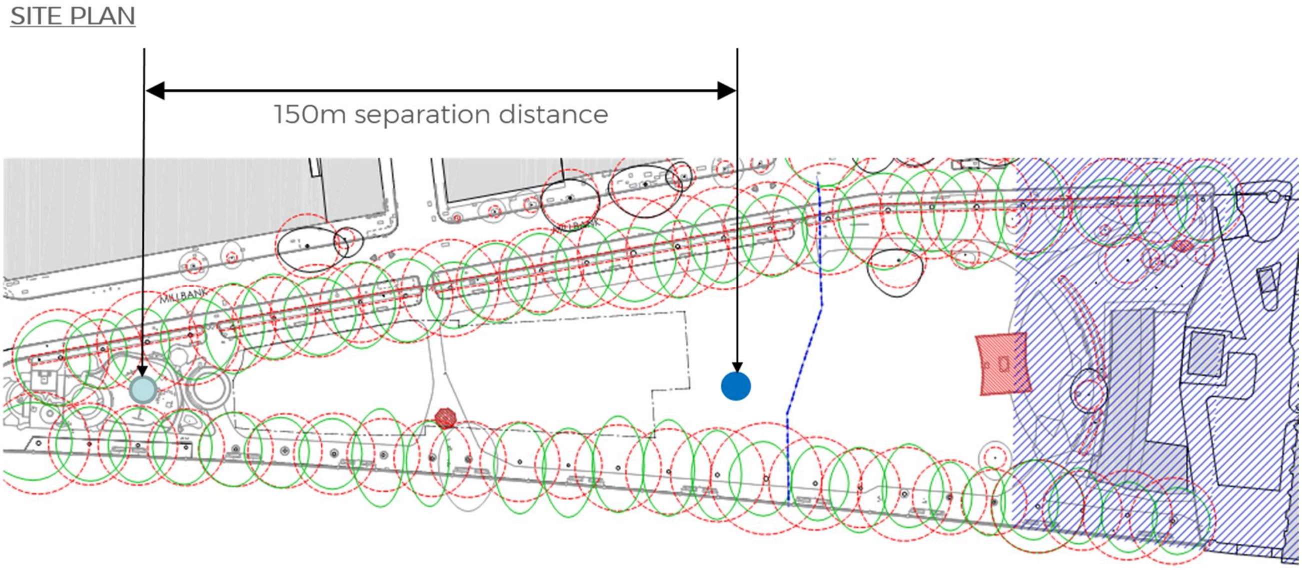


Figure 5: Open loop borehole layout plan

The pros and cons of this option are summarised in table 2.

Table 2: Option 2 – pros and cons

Pros	Cons
• Second most efficient heating and cooling solution • Good chance of meeting the stringent Westminster and GLA energy and carbon emissions performance standards • Possible to meet all space heating and cooling demands with a single system • Back-up system could also be electric • No flues required, no vapours/chimneys • No gas supply to site necessary • All HVAC services could be hidden • Fins could remain structural/ sculptural - no need to integrate services • Number of boreholes would be considerably fewer	• Likely to be an expensive option (similar cost to closed loop) • Abstraction/ discharge licences are required which have a long lead time (c. 6 months) • Required more annual maintenance than closed loop solution • Higher life cycle cost associated with pump replacement

3.2.3 OPTION 3

Description: Water-cooled chiller with gas-fired boiler

Technical details:

- Heat rejection coil selection based on 360 kW
- 24 m^3/s air flow required for heat rejection
- Dedicated duct and fan system will be required to provide enough pressure to force air over the coil. Auxiliary energy expected to be high
- 16 m^2 equivalent area required for intake & exhaust (per louvre)

Figure 6 shows a schematic representation of the main system components.

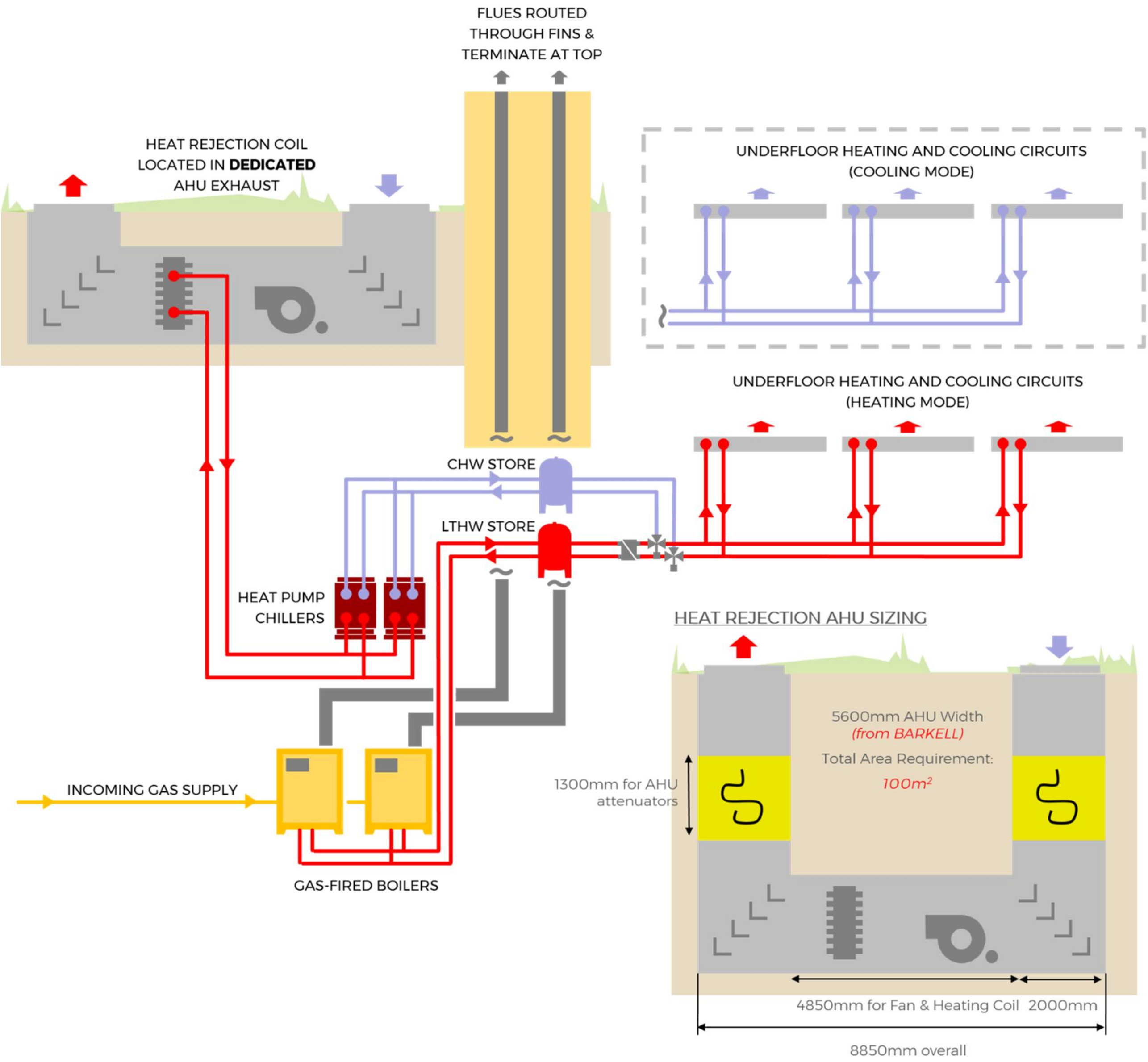


Figure 6: Water-cooled chiller with gas-fired boiler

The pros and cons of this option are summarised in table 3.

Table 3: Option 3 – pros and cons

Pros	Cons
• May be able to either reduce or eliminate the ground source heating and cooling boreholes, providing the cooling load could be met with sufficient heat rejection • Considerably less expensive than either ground source option	• Unlikely to meet the Westminster or GLA energy and carbon reduction requirements. Extra Air Handling Unit required (thus more plant space) to provide minimum air volume required for heat rejection • Gas connection required to site. • Increased construction cost due to larger basement • Possible visible heat plume/heat haze on discharge (plus condensing in the winter) so the discharge location needs to be disconnected form the building

3.2.4 OPTION 4

Description: Heat rejection using fins with gas-fired boiler

Technical details:

- Heat rejection coil selection based on 18kW heat rejection per fin
- 3 m^3/s air flow required for heat rejection. Assuming circa 0.2 m^2 free face area available through the fins, air velocity would be around 15 m/s which is likely to be a noise and energy (pressure drop) issue
- Fan would be required to provide enough pressure to force air through the fins which will result in a complicated ducting strategy to distribute air to all of the fins

Figure 7 shows a schematic representation of the main system components.

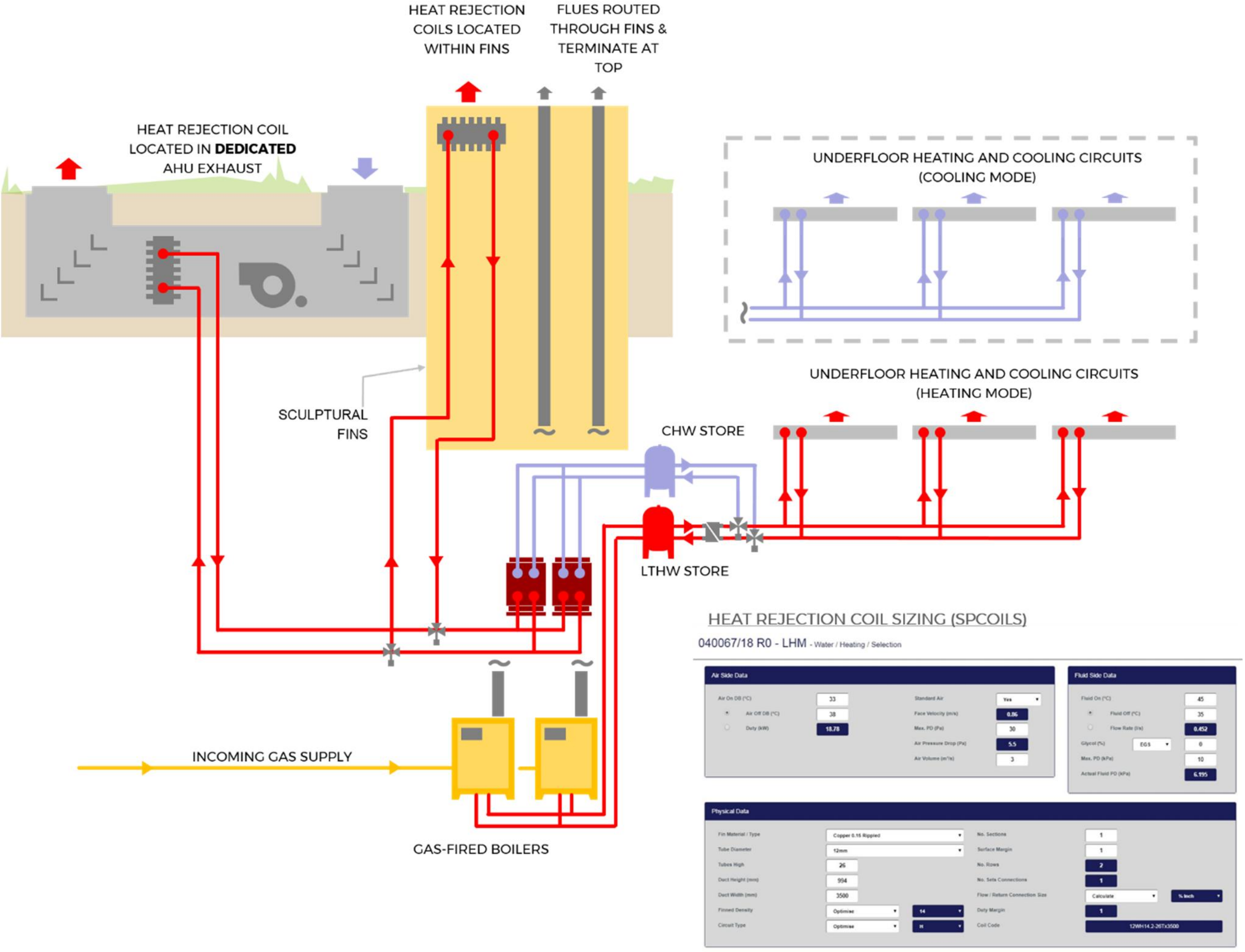


Figure 7: Heat rejection using fins with gas-fired boiler

The pros and cons of this option are summarised in table 4.

Table 4: Option 4 – pros and cons

Pros	Cons
• May be able to either reduce or eliminate the number of boreholes in the ground source system • Services remain hidden	• Might be difficult to integrate the required HVAC plant into the fins whilst meeting all of their other performance and aesthetic requirements • Heat rejection capacity of the fins projected to be quite low without the use of fans which would be a noise and maintenance concern • Possibility of visible heat plume on discharge from each fin • May affect structural integrity of the fins

3.2.5 OPTION 5

Description: Reverse-cycle air source heat pumps

Technical details:

- ASHP selection based on 360 kW required load with N+1 redundancy
- CLIMAVENETA ERACS2-Q 1762 selected for the purposes of the study
- Large external plant space area would be required
- Acoustics would need further consideration

Figure 8 shows a schematic representation of the main system components.

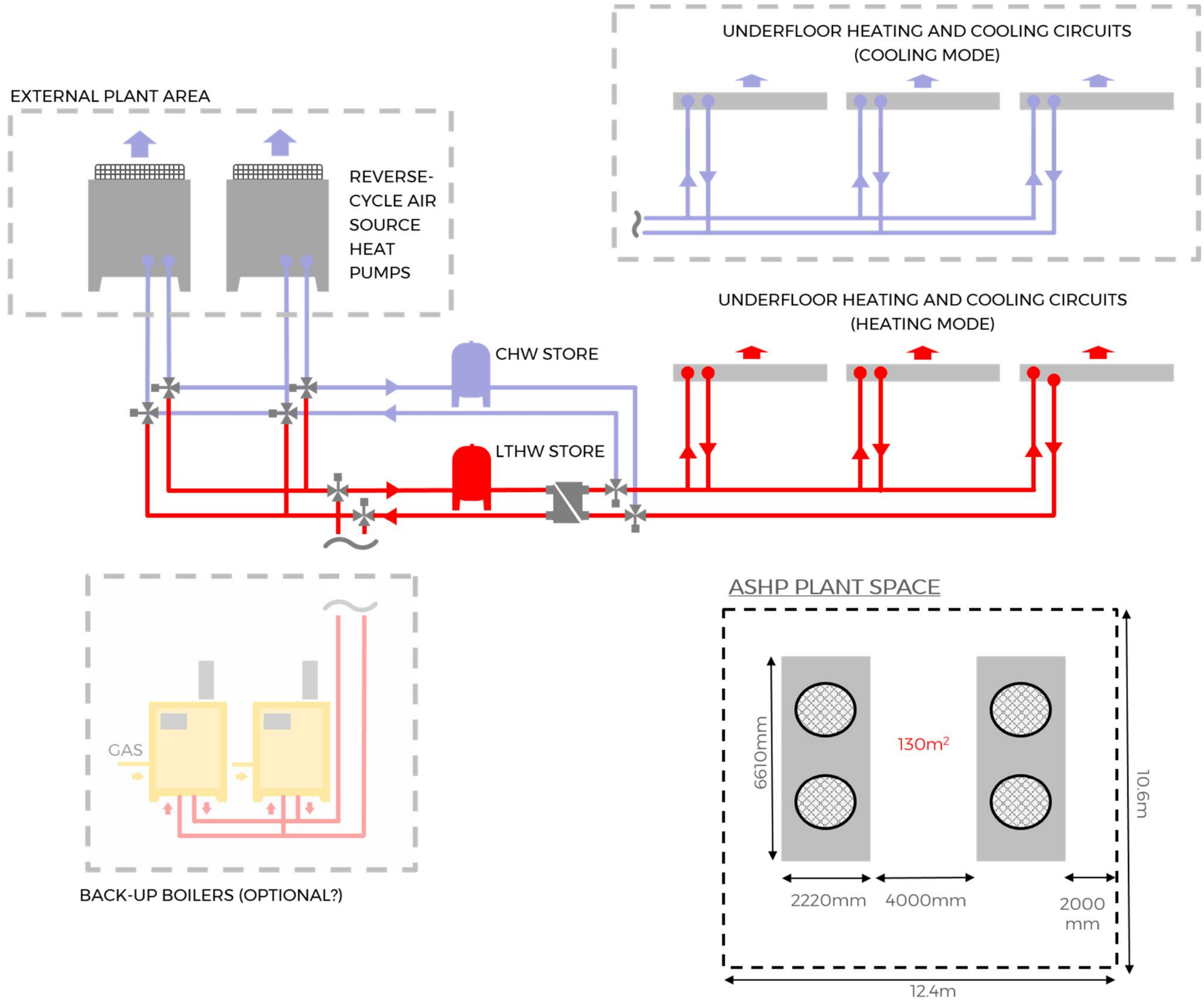


Figure 8: Reverse-cycle air source heat pumps

The pros and cons of this option are summarised in table 5.

Table 5: Option 5 – pros and cons

Pros	Cons
• Less expensive than the ground source systems • Easier to maintain	• Requires a large external plant space. Creates noise concerns in the park • Significantly less efficient than the ground source systems • Unlikely to get close to meeting the GLA carbon emissions standards • possibility that visible emissions may be present

3.2.6 OPTION 6

Description: District heating with water-cooled chiller

Technical details:

- Heat rejection coil selection based on 360 kW
- 24 m^3/s air flow required for heat rejection
- Dedicated duct and fan system will be required to provide enough pressure to force air over the coil. Auxiliary energy expected to be high
- 16 m^2 equivalent area required for intake & exhaust (per louvre)

Figure 9 shows a schematic representation of the main system components.

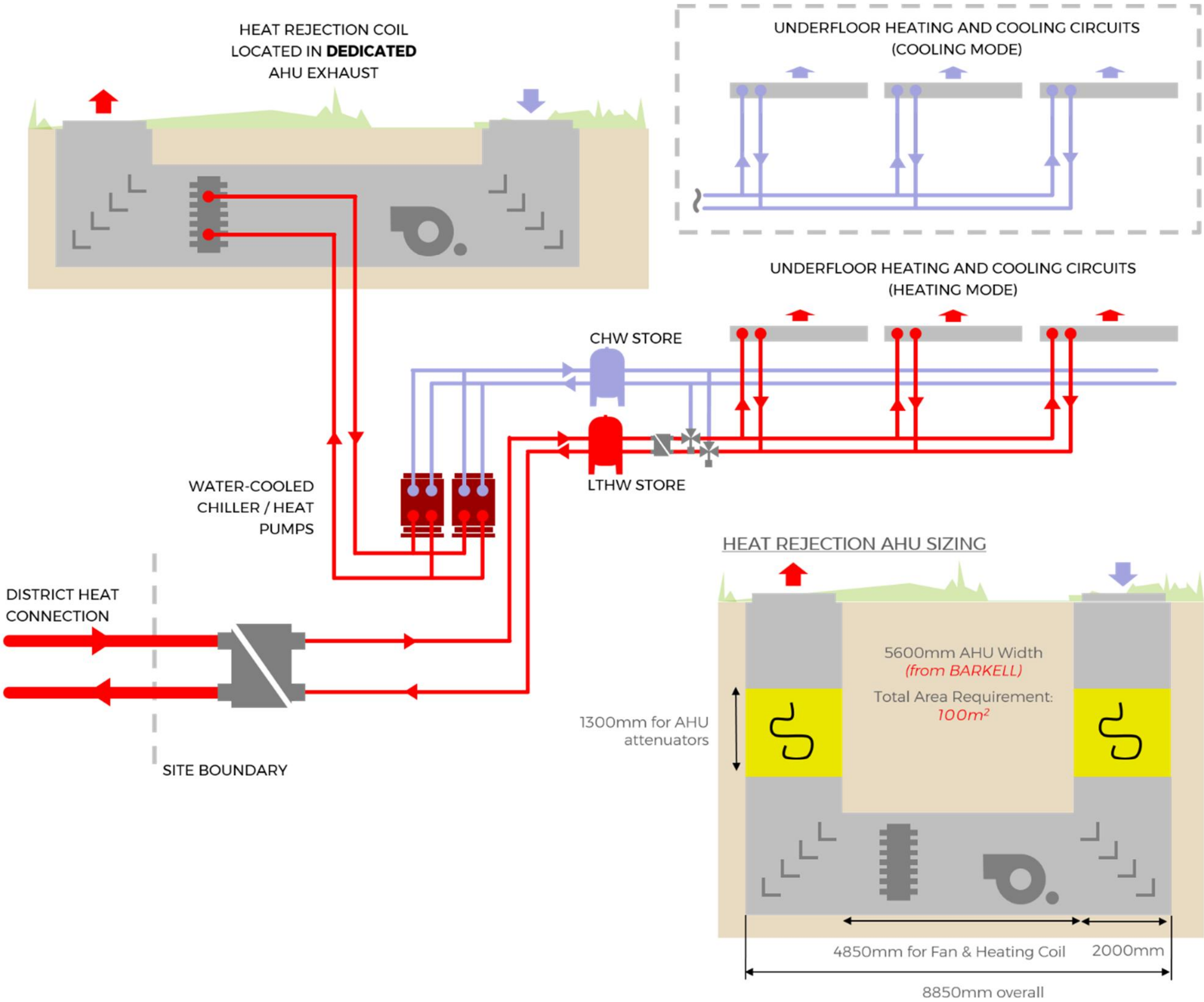


Figure 9: District heating with water-cooled chiller

The pros and cons of this option are summarised in table 6.

Table 6: Option 6 – pros and cons

Pros	Cons
• Tie-in with Westminster energy strategy drivers? • Negates the need for a gas connection • Less on site heating plant • Cheap to install up to the point of the site boundary	• No district heat network branch within reach of the site (checked the London Heat Map – see figure 10) • Closest branch for an existing buried heat main is the corner of Whitehall and Great George Street c. 450 m away from site • Also, potential future network branches do not pass adjacent to the site

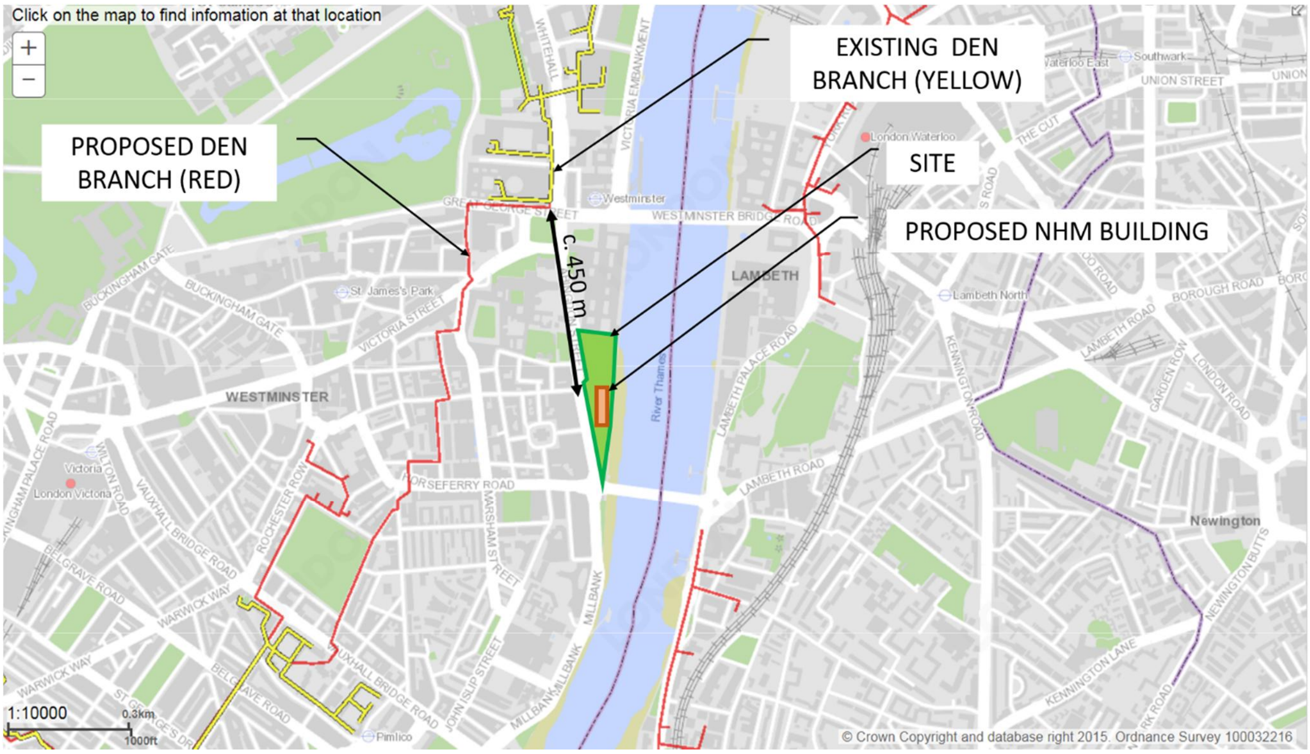


Figure 10: Drawing showing the distance from the nearest DEN branch to the building, based on the London Heat Map

3.3 MODELLING

To help us understand the comparative performance of each of the six options, we built a simplified 'shoebox' model of the building in CIBSE AM11 accredited IES VE software (see figure 11). The model was given the same physical and operational characteristics as the actual building (approximate dimensions, ground adjacencies, roof light, shading characteristics around the entrance/exit area, split floor sub-ground floor/mezzanine, weather file location).

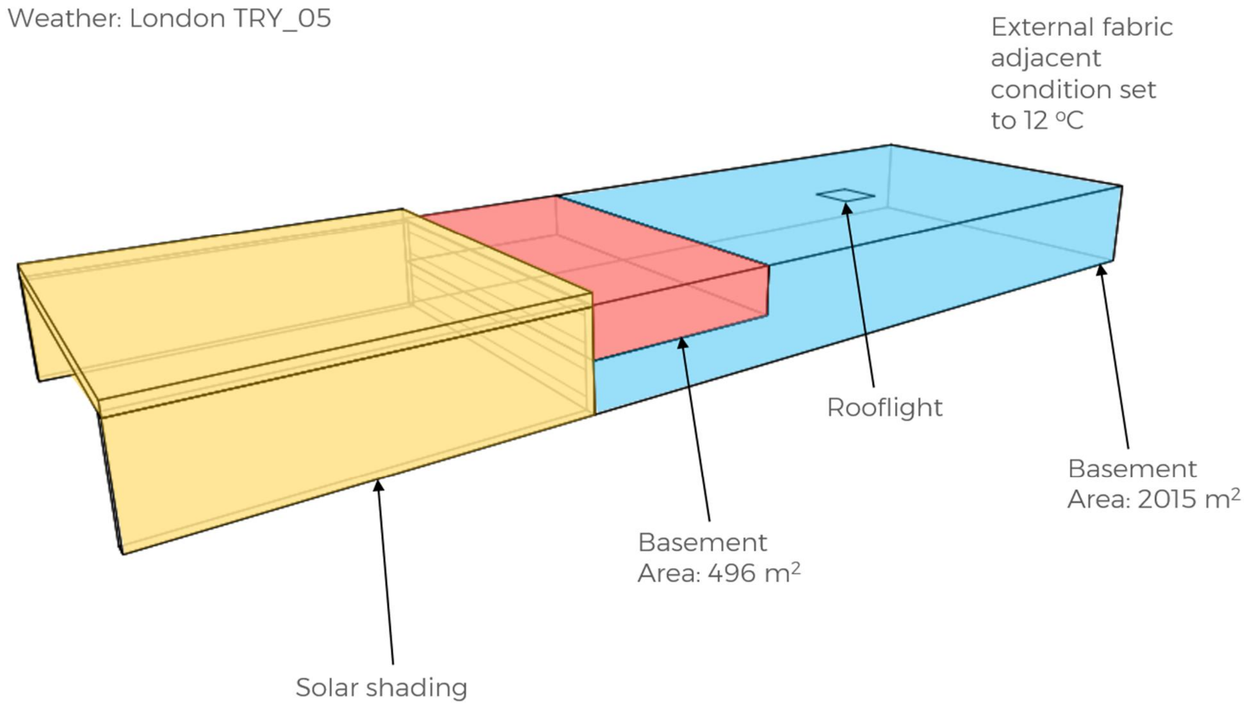


Figure 11: IES shoebox model geometry

The model was populated with assumptions appropriate to the type and use of the building, in addition to its situation – thermal transmittance of the building fabric, air permeability, lighting efficiency and ventilation system efficiency (see table 7).

Table 7: Model input data

PARAMETER		VALUE	UNITS
U-values	*External wall*	0.23	W/m^2.K
	Ground floor	0.23	W/m^2.K
	Roof	0.23	W/m^2.K
Air permeability		3.00	m^3/hr.m^2
Lighting efficacy	*Lamps*	80	lm/W
	Display	40	lm/W
Auxiliary energy	*Specific fan power*	2.00	W/l.s
	Heat recovery efficiency	50	%

Tests were carried out using a range of different insulation values for the floor/walls/roof so we could better understand the optimum standards for an underground building – starting from 'no insulation', all the way up to significantly better than the minimum Part L standards. The 'sweet spot' (minimising the carbon emissions from serving the annual heating and cooling loads combined) was found to be achieved using a U-value of around 0.23 W/m^2.K for all building fabric. This will be investigated further during the design stage.

Finally, six versions of the resulting model were created, each representing a heating/cooling/ventilation system for one of the options. Table 8 lists the heating and cooling system efficiencies assumed at this stage.

Table 8: Shoebox model options heating and cooling efficiencies assumed

OPTION		HEATING EFFICIENCY (COP)	COOLING EFFICIENCY (SEER)
1	GSHP (closed loop)	8.00	8.00
2	GSHP (open loop)	5.00	5.00
3	Heat rejection fins & gas fired boiler	0.91	2.00
4	Water cooled chiller & gas fired boiler	0.91	3.00
5	Reverse cycle ASHP	3.00	3.50
6	Water cooled chiller & district heating	1.00	3.00

3.4 RESULTS

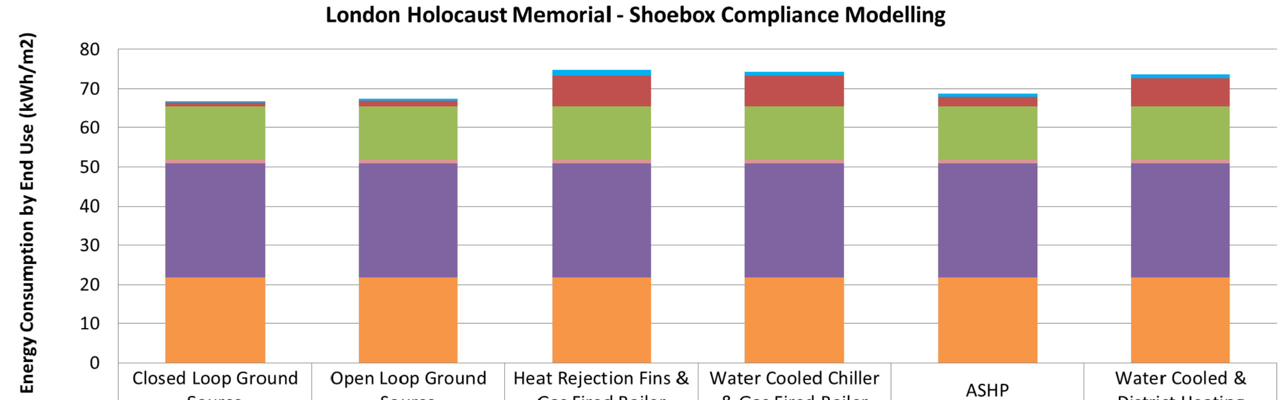
The models were run in VE Compliance to evaluate the performance against the UK Building Regulations Part L2A 2013. Table 9 summarises the compliance results (TER, BER and % improvement) and estimated number of BREEAM credits achievable. Figures 12 and 13 summarise the energy consumption results.

The results show that all of the options would be better than the minimum performance standard of UK Building Regulations Part L (which measures carbon emissions from regulated energy) by 27–32%. The 'worst' performer was the 'heat rejection fins & gas fired boilers'; the best option was 'closed loop GSHPs'; the 'open loop GSHP' system being a close second best. However, all options were fairly similar in this respect.

A key finding was that heating and cooling energy is a relatively small component of the overall energy demand for the building; the overwhelming majority of which is for auxiliary (pumps, fans and controls), lighting and equipment (unregulated and estimated using benchmarks at this stage). It is believed that the low heating and cooling energy demands are a result of the building being underground and tempered by the ground's thermal mass.

Table 9: Shoebox modelling compliance results

OPTION		TER ($kgCO_2/m^2$)	BER ($kgCO_2/m^2$)	% IMPROV'T	BREEAM ENE 01 CREDITS
1	GSHP (closed loop)	39.5	26.9	31.9%	11
2	GSHP (open loop)	39.5	27.3	30.9%	11
3	Heat rejection fins & gas fired boiler	39.6	28.7	27.5%	11
4	Water cooled chiller & gas fired boiler	39.6	28.4	28.3%	11
5	Reverse cycle ASHP	39.5	27.9	29.4%	11
6	Water cooled chiller & district heating	39.5	27.9	29.4%	11



	Closed Loop Ground Source	Open Loop Ground Source	Heat Rejection Fins & Gas Fired Boiler	Water Cooled Chiller & Gas Fired Boiler	ASHP	Water Cooled & District Heating
Cooling	0.35	0.57	1.42	0.94	0.81	0.94
Heating	0.91	1.46	8	8	2.43	7.28
Equipment	13.59	13.59	13.59	13.59	13.59	13.59
Hot Water	0.92	0.92	0.92	0.92	0.92	0.92
Lighting	29.12	29.12	29.12	29.12	29.12	29.12
Auxiliary	21.82	21.82	21.82	21.82	21.82	21.82

Figure 12: Shoebox modelling results (energy consumption by end use in kWh/m²)

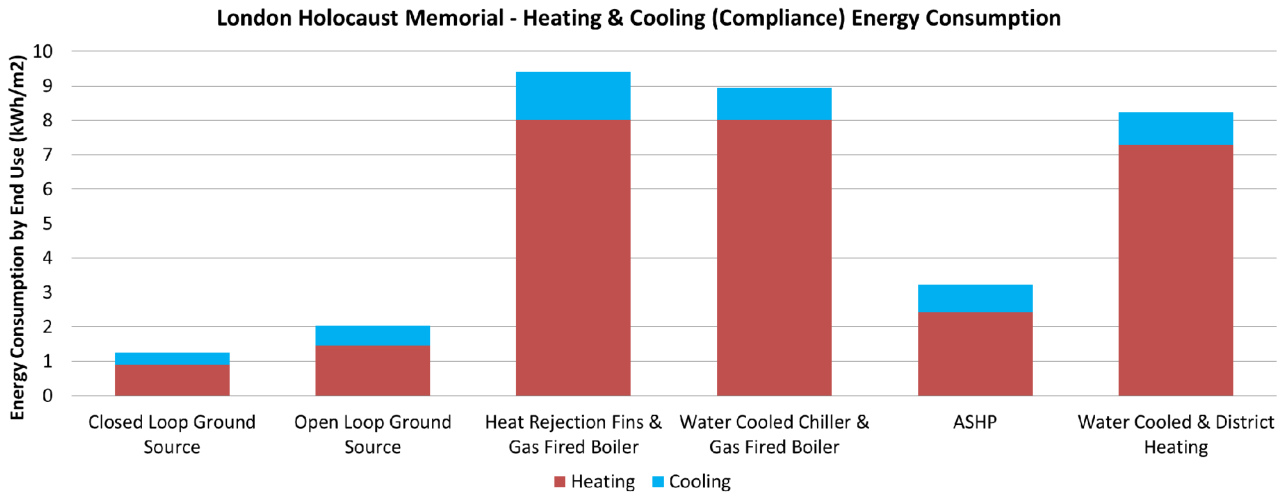


Figure 13: Shoebox modelling results (heating and cooling only energy consumption in kWh/m²)

3.4.1 DISCUSSION

In general, the findings of the modelling study indicated that around a 30% improvement could be achieved, compared against the 2013 Part L2A target emission rate (TER).

Our understanding is that this is compliant with the GLA London Plan 2016 (with Jan 2017 fix) requirements under Policy 5.2 'Minimising Carbon Dioxide Emissions' (see summary of policy in Appendix C) which, for the 2016-2019 window only requires non-domestic buildings to meet the requirements of the Building Regulations.

It is recognised that although the policy requirement is not as challenging as it was previously, the higher the performance of the building will mean it will have a lower impact on the environment, be less expensive to operate and be less reliant on primary energy supplies.

3.5 CONCEPT SOLUTION

Using the findings of the options appraisal and modelling study, the concept solution was developed. The main components of this are listed below. The strategy represents a coordinated system of tried and tested solutions and suitable case studies and precedents are available.

3.5.1 OPTIMISED LIGHTING

All lighting in the building will utilise high efficiency lamps and luminaires with optimised controls, including auto on/off sensor controls to minimise energy use when the building is not occupied. Due to the nature and intended operational characteristics of this building, the lighting levels will be relatively low, compared with other building types (offices/schools for example). This will create the intended environment, but also significantly reduce energy consumption.

3.5.2 UTILISING THE THERMAL MASS OF THE GROUND

Given that the building is to be located underground, with very little fabric exposed to the atmosphere, the opportunity to utilise the thermal stability of the ground has been carefully considered. Modelling was used to help understand the optimum combination of thermal transmittance (U-values), placing an emphasis on carbon emission and energy demand reduction, whilst helping to maintain appropriate comfort conditions for the building occupants.

3.5.3 GROUND-COUPLED VENTILATION LABYRINTH

The requirement for concealed services led to the idea of supplying fresh air into the occupied spaces of the building via a distribution plenum chamber located underneath the floor of the building, using displacement ventilation method. In our concept design, the plenum is a fabricated concrete labyrinth (see Appendix D for sketch) into which fresh air is supplied from air handling plant located in the South plantroom and from which air is supplied to the occupied spaces of the building. In addition to this allowing the air distribution means to be hidden, a subterranean labyrinth would also pre-heat or pre-cool the air due to its thermal mass and dwell-time and reduce the requirement for energy consumption for heating and cooling over the course of the year. Access requirements for periodic cleaning and maintenance of the labyrinth have been considered, in addition to how this would be coordinated with the building's structural design.

3.5.4 DISPLACEMENT VENTILATION

Our displacement ventilation system will supply fresh tempered air at floor level and extract stale air at high level, the principle is that stale air containing unwanted heat gains gets pushed upwards towards the extract points with a layer of fresh air in the occupied zone. This solution is compatible with the use, estimated loads and occupancy profile of the building, as well as being the best technical solution to partner with the labyrinth.

Our concept design also provides a return path for the exhausted air so that heat recovery can take place in the plant room, optimising the efficiency of the system by minimising the requirement for primary energy consumption.

3.5.5 ALL-ELECTRIC BUILDING SERVICES SOLUTION

The provision of heat generation in the building is subject to significant constraints due to the requirement for gas-utility services, all of which require chimneys/flues to be avoided, due to cultural sensitivity at the very heart of the project. This means that gas-fired boilers, combined heat and power units and gas-fired heat pumps are not viable options and the only technologies which remain are electric. Direct electric heating (electric boilers or local panel heaters) are extremely inefficient and are generally avoided unless there is no other option. In this instance, heat pumps appear to be highly viable – especially ground source (see below).

3.5.6 GROUND SOURCE HEAT PUMPS

This technology uses the ground as a heat source and heat sink, meaning that the same system can be utilised for both heating and cooling, as and when dictated by the building's requirements. Such a system would be powered by mains electricity, with the potential to utilise renewably-generated electricity and would have a high efficiency (with CoPs in the region of 5-8). The system components would also be discrete (no parts of the system would be visible to the public) and, crucially for this project, no flues would be required.

Although still in the feasibility study stage (a hydrogeological study of the ground and local aquifer capacity was being carried out at the time of writing), it is expected that an ‘open-loop’ ground source heat pump system would be both the most cost-effective and space-efficient alternative, utilising 2-4 open-loop boreholes in the vicinity of the development site.

It is anticipated that the heating and cooling loads of the building will be fairly well balanced over the course of the year, which presents an ideal situation by minimising the possibility of eventual thermal saturation of the ground. Our design also incorporates a means of rejecting excess heat to the atmosphere during times when it is not beneficial to reject to the ground. This also provides a key climate change adaption measure, allowing the building to adapt to progressively warmer environmental temperatures.

3.5.7 UNDERFLOOR HEATING AND COOLING

Also in keeping with our all-electric discrete system design is our provision of space heating and cooling, for which we have proposed a dual underfloor heating and cooling coil system. The coils would sit in the concrete floor between the labyrinth and the occupied spaces and would be carefully coordinated with both the ventilation system and all electrical services.

Given that the building will be in use at all times of the year, and based on our concept stage assessment of the likely loads, it was determined that both heating and cooling will be required at different times. The coils would utilise a ‘wet-system’ approach allowing thermal energy in the form of heat to be transferred to the occupied spaces from the plant room (where it would be generated by the heat pumps), and in a similar way for chilled water for space cooling when required.

3.5.8 RENEWABLE ENERGY

The building’s location, particularly the siting beneath a recreational park and is designed specifically as a predominantly underground space means that opportunities for incorporating renewable energy technologies into the design are extremely limited. During an early assessment, it became apparent that it would not be possible to implement photovoltaics, solar thermal collectors (the roof of the building is parkland and hardstanding public realm or secure areas) or wind turbines (not appropriate in this location). Because of this, the design team has put a substantial amount of effort into making the building as efficient as possible and making the most of all inherent energy and carbon-saving opportunities.

4 SUMMARY CONCLUSIONS

4.1 SUMMARY

- WSP prepared this 'Topic Paper' on the subject of energy and sustainable construction to form the basis for discussions between the development team and Westminster Planning Officers during the Concept Stage (RIBA Stage 2) of the National Holocaust Memorial development project, planned for the 23rd March.
- The concept building has been designed as a subterranean structure with subdivided rooms and corridors intended to house exhibits and articles relating to the persecution of minorities during the Holocaust.
- As a design team we understand the memorial will be a place for quiet reflection, learning and understanding, and the layout of the building, lighting, architectural finishes and atmospheric conditions will be designed to facilitate this.
- The building will also be an occupied space requiring ventilation, heating, cooling, lighting and humidification, primarily to make the space comfortable, healthy and safe; these services will also to help create an environment appropriate to its use.
- The site opportunities identified were limited to: the thermal mass of the ground; the presence of a below ground aquifer; potential for hiding services in the ground; and the site location next to the river Thames.
- The site constraints were more numerous, these being: sensitive location; limited space for services to be located; the architectural philosophy and inherent requirement for the building and all services to be discrete/ hidden; security, particularly in relation to the threat of terrorism; no physical rooftop to the building on which to install solar technologies or building services plant; no potential for wind generation; and the requirement for gas-utility services to be avoided due to cultural sensitivity.
- The team's ideas about the building envelope design and how the building could be serviced were guided by the London Plan Energy Hierarchy (Be Lean, Be Clean, Be Green) and the 'fabric-first' approach. The main drivers were acknowledged as being: minimising carbon emissions and the demand for energy and the avoidance of overheating.
- The team explored a range of options to ensure the concept design was the optimum choice of technologies, in terms of design coordination, the use of the on or near-site opportunities and minimisation of energy consumption, and carbon emissions and the detailed requirements of the brief.
- We carried out a comparison exercise to compare 6 options and used a model to evaluate the relative performance of each. The options assessed were:

    7. Ground source heat pumps using closed loop boreholes
    8. Ground source heat pumps using open loop abstraction from chalk or Thames gravel
    9. Water-cooled chiller with gas-fired boiler
    10. Heat rejection using fins with gas-fired boiler
    11. Reverse-cycle air source heat pumps
    12. District heating with water-cooled chiller

- A 'shoebox' model of the building was built in IES and initially tests were carried out to identify the optimum insulation value of the building fabric. Then six versions of the model were created, each representing a heating/cooling/ventilation system for one of the options. The models were run in VE Compliance to evaluate the performance against the UK Building Regulations Part L2A 2013.
- The modelling study results showed that all of the options would exceed (be better than) the minimum performance standard of UK Building Regulations Part L, which measures carbon emissions from regulated energy, by 27–32% with the worst performer being 'Heat rejection fins & gas fired boilers'

and the best being closed loop GSHPs with the open loop GSHPs system being a close second best. However, all options were fairly similar in this respect.

- The ground source heating and cooling options both also performed best with regard to energy consumption.
- It became apparent later that: closed loop GSHPs could be difficult to accommodate on the site due to space constraints; gas-fired boilers would not be a viable option due to cultural sensitivity; air source heat pumps could not both be hidden *and* work effectively; and the closest district heat network branch was several hundred metres away. This information led the team to begin focussing on a system design which incorporated GSHPs using open loop abstraction from chalk or the Thames gravel.
- GSHP technology uses the ground as a heat source and heat sink so the same system can be utilised for both heating and cooling as dictated by the building's requirements. The system would be powered by mains electricity and would have a high efficiency (with CoPs in the region of 5-8).
- A hydrogeological study of the ground and local aquifer capacity is being carried out at the time of writing and it is expected that an open-loop ground source heat pump system would be both the most cost-effective and space-efficient alternative, utilising 2-4 open-loop boreholes in the vicinity of the development site.
- A key finding of the modelling study was that heating and cooling energy is a relatively very small component of the overall energy demand for the building; the overwhelming majority of which is for auxiliary (pumps, fans and controls), lighting and equipment (unregulated and estimated using benchmarks at this stage). It is believed that the low heating and cooling energy demands are a result of the building being underground and tempered by the ground's thermal mass.
- The other aspects of the concept design which the team developed and which will contribute towards the performance of the building and brief requirements are:
  - **Optimised lighting –** all lighting in the building will utilise high efficiency lamps and luminaires with optimised controls, including auto on/off sensor controls to minimise energy use when the building is not occupied. Due to the nature and intended operational characteristics of this building, the lighting levels will be relatively low, compared with other building types (offices/schools for example). This will create the intended environment, but also significantly reduce energy consumption.
  - **Thermal labyrinth** – will supply fresh air into the occupied spaces of the building via a distribution plenum chamber located underneath the floor of the building. The plenum would be a fabricated concrete labyrinth into which fresh air is supplied from air handling plant and from which air is supplied to the occupied spaces of the building. This will pre-heat or pre-cool the air due to its thermal mass and dwell-time and reduce the requirement for energy consumption for heating and cooling over the course of the year.
  - **Displacement ventilation system** - will supply fresh tempered air at floor level and extract stale air at high level. This solution is compatible with the use, estimated loads and occupancy profile of the building, as well as being the best technical solution to partner with the labyrinth. It will also allow heat recovery to maximise efficiency.
  - **Underfloor heating and cooling system** - the coils for which would be installed in the concrete floor between the labyrinth and the occupied spaces and would be carefully coordinated with both the ventilation system and all electrical services.
  - **Non-reliance on renewables** - opportunities for incorporating renewable energy technologies into the design are extremely limited. It was identified that photovoltaics, solar thermal collectors would not be possible as the roof of the building is parkland and hardstanding public realm or secure areas; similarly wind turbines would not be appropriate in this location. To compensate, the design team recognises that the building itself needs to be as efficient as possible and all inherent energy and carbon-saving opportunities should be exploited.
- The above are all tried and tested solutions and suitable case studies and precedents are available.

- Further modelling and testing will be carried out during the developed and detailed design stages.

4.2 CONCLUSIONS

- At the end of the Stage 2 design, during which a wide range of potential options were considered and tested using good/best practice principles and building physics modelling, the optimum building services systems were identified as:
  - Optimised U-values and taking advantage of the thermal mass of the ground
  - Optimised lighting and controls
  - Thermal labyrinth to supply fresh, tempered air
  - Open loop ground source heat pumps utilising 3-4 boreholes on the site
  - Displacement ventilation system
  - Underfloor heating and cooling system
- Heating and cooling energy is a relatively very small component of the overall energy demand for the building, the overwhelming majority of which is for auxiliary, lighting and equipment.
- It was identified that incorporating renewable energy systems into the design of the building would not be possible due to the site, location and project constraints.
- The building was modelled with the above system configuration and it was shown that around a 30% improvement could be achieved, compared against the 2013 Part L2A target emission rate. Our understanding is that this is compliant with the GLA London Plan 2016 requirements under Policy 5.2 'Minimising Carbon Dioxide Emissions' which, for the 2016-2019 window only requires non-domestic buildings to meet the requirements of the Building Regulations.
- In terms of other policy drivers, it was determined that a connection to a district heat network would not be possible due to the excessive distance between the existing proposed network branch (c.400m) to the site; and the minimum renewable energy generation target set by Westminster is not feasible due to the site and project constraints.

Appendix A

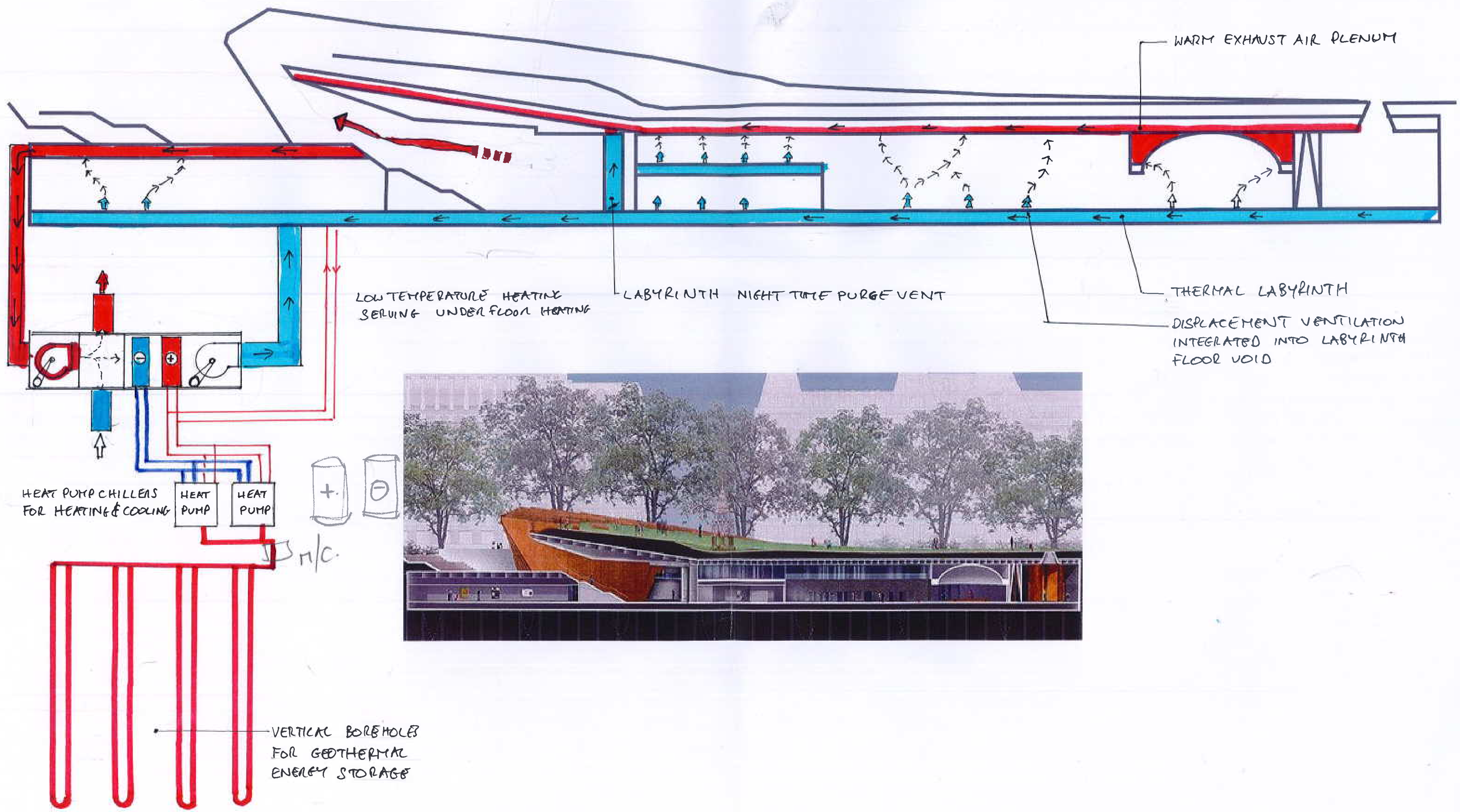
ARCHITECT'S BOARDS

Refer to architects planning documents.

Appendix B

CONCEPT BUILDING SERVICES

SKETCH


WARM EXHAUST AIR PLENUM
LOW TEMPERATURE HEATING SERVING UNDERFLOOR HEATING
LABYRINTH NIGHT TIME PURGE VENT
THERMAL LABYRINTH
DISPLACEMENT VENTILATION INTEGRATED INTO LABYRINTH FLOOR VOID
HEAT PUMP CHILLERS FOR HEATING & COOLING
HEAT PUMP
HEAT PUMP
M/C.
VERTICAL BOREHOLES FOR GEOTHERMAL ENERGY STORAGE

Appendix C

GLA LONDON PLAN POLICY 5.2

regarding how the Mayor expects London to achieve this strategic target is outlined in the Mayor's Climate Change Mitigation and Energy Strategy.

POLICY 5.2 MINIMISING CARBON DIOXIDE EMISSIONS

Planning decisions

A Development proposals should make the fullest contribution to minimising carbon dioxide emissions in accordance with the following energy hierarchy:

1 Be lean: use less energy
2 Be clean: supply energy efficiently
3 Be green: use renewable energy

B The Mayor will work with boroughs and developers to ensure that major developments meet the following targets for carbon dioxide emissions reduction in buildings. These targets are expressed as minimum improvements over the Target Emission Rate (TER) outlined in the national Building Regulations leading to zero carbon residential buildings from 2016 and zero carbon non-domestic buildings from 2019.

Residential buildings:

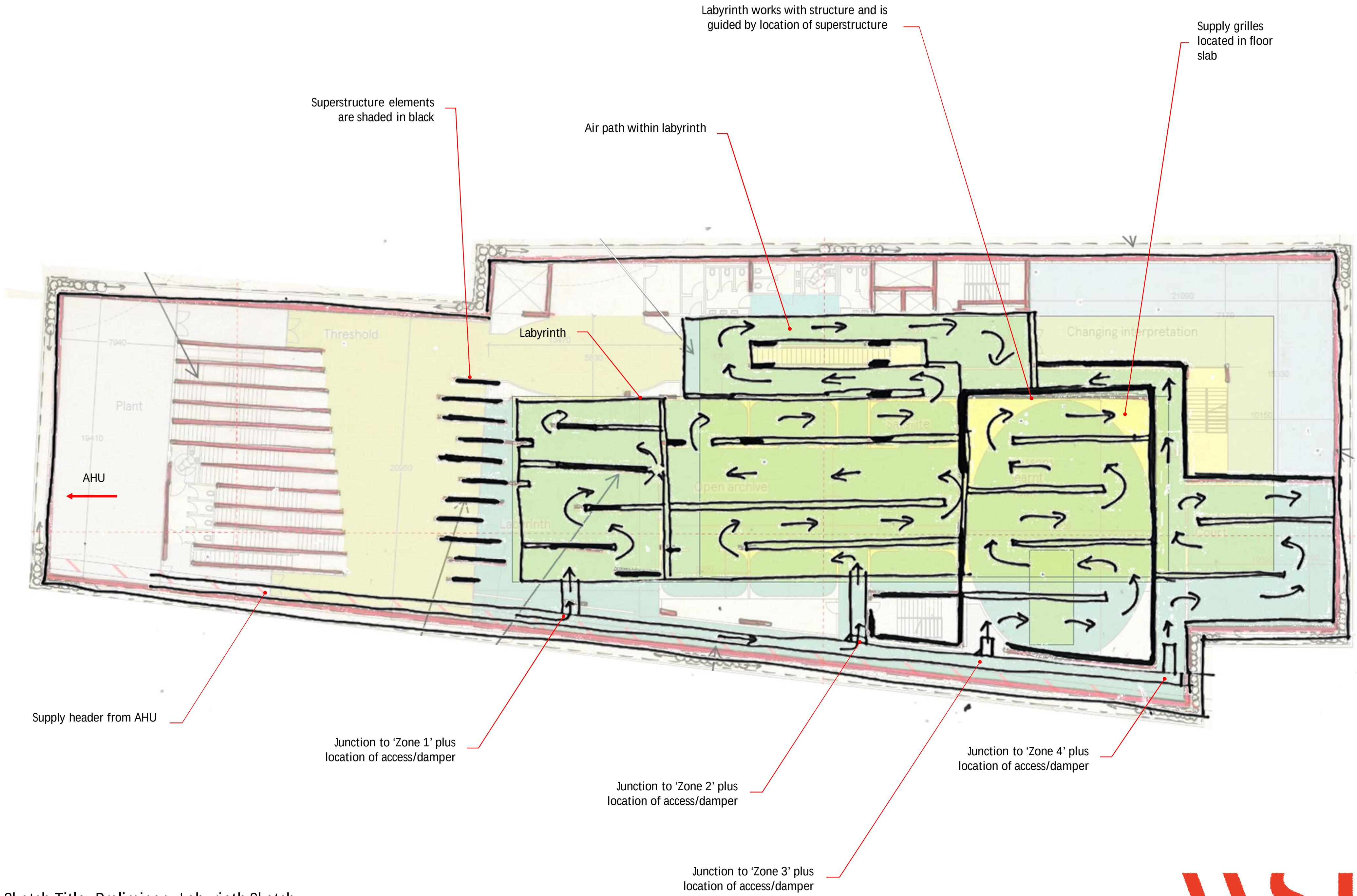
Year	Improvement on 2010 Building Regulatons
2010 – 2013	25 per cent (Code for Sustainable Homes level 4)t
2013 – 2016	40 per cent
2016 – 2031	Zero Carbon

Non-domestic buildings:

Year	Improvement on 2010 Building Regulatons
2010 – 2013	25 per cent
2013 – 2016	40 per cent
2016 – 2019	As per building regulations requirements
2019 - 2031	Zero Carbon

Appendix D

LABYRINTH SKETCH



Sketch Title: Preliminary Labyrinth Sketch
Project: London Holocaust Memorial
Date: 18th December 2017
By: Neville Rye
Checked: -

wsp

Kings Orchard
1 Queen Street
Bristol
BS2 0HQ

Appendix C

MODELLING INPUT DATA

INPUT DATA

1. NCM templates

Room	NCM Building Area Type	NCM Activity
B1_Cafe and Retail	A1A2: Retail or Office (Retail)	NCM Ret: Eating/drinking area
B2_Showers/Changing	B1: Office or Workshop (Office)	NCM Office: Changing facilities
B2_Acc WC/Shower	B1: Office or Workshop (Office)	NCM Office: Changing facilities
B2_WC	D1: Library, museum or gallery	NCM LibMusGall: Toilet
B2_WC	D1: Library, museum or gallery	NCM LibMusGall: Toilet
B1_WC	D1: Library, museum or gallery	NCM LibMusGall: Toilet
B2_Info Desk	D1: Library, museum or gallery	NCM LibMusGall: Reception
B2_Meeting Room 2	D1: Library, museum or gallery	NCM LibMusGall: Office (Meeting)
B2_Meeting Room 1	D1: Library, museum or gallery	NCM LibMusGall: Office (Meeting)
B2_Office	D1: Library, museum or gallery	NCM LibMusGall: Office
B2_CCTV	D1: Library, museum or gallery	NCM LibMusGall: Office
B2_Plant	D1: Library, museum or gallery	NCM LibMusGall: Light plant room
B2_Kitchen	D1: Library, museum or gallery	NCM LibMusGall: Food preparation area
B2_Learning Centre	D1: Library, museum or gallery	NCM LibMusGall: Display and Public areas
B1_Learning Centre	D1: Library, museum or gallery	NCM LibMusGall: Display and Public areas
B2_Store	D1: Library, museum or gallery	NCM LibMusGall: Cupboard
B2_Lockers	D1: Library, museum or gallery	NCM LibMusGall: Cupboard
B2_Cloakroom	D1: Library, museum or gallery	NCM LibMusGall: Cupboard
B2_Bin Store	D1: Library, museum or gallery	NCM LibMusGall: Cupboard
B1_Store	D1: Library, museum or gallery	NCM LibMusGall: Cupboard
B1_Store	D1: Library, museum or gallery	NCM LibMusGall: Cupboard
B2_WC Lobby	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B2_Stairs	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B2_Staircase	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B2_Lift Lobby	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B2_Lift Lobby	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B2_Corridor	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B2_Corridor	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B2_Circulation	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B2_Circulation	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B1_Staircase	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B1_Lift Lobby	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B1_Lift Lobby	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B1_Circulation	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
B1_Circulation	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
0_Staircase	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
0_Lift Lobby	D1: Library, museum or gallery	NCM LibMusGall: Circulation area
Void/Lift/Riser	-	-

2. HVAC Schedule

Room Type	Heating & Cooling Strategy	Ventilation Strategy
Exhibition/Learning Area	Trench Heating, Underfloor Cooling via GSHP (Electric)	Mechanical S&E
Ofice/Meeting Room/Info Desk	Trench Heating, Underfloor Cooling via GSHP (Electric)	Mechanical S&E
WC	Underfloor Heating via GSHP (Electric)	Extract only

Shower/Changing Room	Underfloor Heating via GSHP (Electric)	Extract only
Lockers	Underfloor Heating via GSHP (Electric)	Extract only
Store	Underfloor Heating via GSHP (Electric)	Extract only
Circulation/Stairs	Underfloor Heating via GSHP (Electric)	Mechanical S&E
Kitchen	Underfloor Heating via GSHP (Electric)	Extract only

3. HVAC System Properties

Heating	
GSHP Seasonal Coefficient of Performance	5

Cooling	
GSHP Seasonal Energy Efficiency Ratio	5

Auxiliary		
Duct Leakage CEN Classification	Class A	
AHU Leakage CEN Classification	L2	
AHU Supply Fan SFP	1.12	W/l/s
AHU Extract Fan SFP	1.12	W/l/s
AHU Supply Fan SFP	2.24	W/l/s
AHU Heat recovery efficiency (Run-Around Coil)	68	%

Pump Type	Variable speed multiple pressure sensors		

Does the system have provision for metering?	Yes
Does the metering warn "out of range values?"	Yes

	Extract Rate	
WC/Shower/Store	6	ACH
Kitchen	20	ACH

Demand Control Ventilation	
Offices/Meeting Rooms/Info Desk/Learning Areas/Café and retail	DCV based on gas sensors, speed control

4. Domestic Hot Water Systems

DHW System Type	POU Electric
Storage Available?	No
Efficiency	100%

5. Lighting

Room	Design Illuminance (lux)	NCM Database Illuminance (lux)	Luminaire Efficacy (lm/W)	Display Lighting Efficacy (lm)	Occupancy Sensing	Daylight Dimming?
0_Lift Lobby	100	100	100		Presence Detection	No
0_Staircase	100	100	100		Presence Detection	No
B1_Cafe and Retail	150	150	100	40	Manual On/Off	No
B1_Circulation	100	100	100		Presence Detection	No
B1_Circulation	100	100	100		Presence Detection	No
B1_Learning Centre	200	200	100	40	Presence Dimmable	No
B1_Lift Lobby	100	100	100		Presence Detection	No
B1_Lift Lobby	100	100	100		Presence Detection	No
B1_Staircase	100	100	100		Presence Detection	No
B1_Store	50	50	100		Presence Detection	No
B1_Store	50	50	100		Presence Detection	No
B1_WC	200	200	100		Presence Detection	No
B2_Acc WC/Shower	100	100	100		Presence Detection	No
B2_Bin Store	50	50	100		Presence Detection	No
B2_CCTV	400	400	100		Absence Detection	No
B2_Circulation	100	100	100		Presence Detection	No
B2_Circulation	100	100	100		Presence Detection	No
B2_Cloakroom	50	50	100		Presence Detection	No
B2_Corridor	100	100	100		Presence Detection	No
B2_Corridor	100	100	100		Presence Detection	No
B2_Info Desk	200	200	100	40	Absence Detection	No
B2_Kitchen	500	500	100		Manual On/Off	No
B2_Learning Centre	200	200	100	40	Presence Dimmable	No
B2_Lift Lobby	100	100	100		Presence Detection	No
B2_Lift Lobby	100	100	100		Presence Detection	No
B2_Lockers	50	50	100		Presence Detection	No
B2_Meeting Room 1	400	400	100		Absence Detection	No

B2_Meeting Room 2	400	400	100	Absence Detection	No
B2_Office	400	400	100	Absence Detection	No
B2_Plant	200	200	100	Manual On/Off	No
B2_Showers/Changing	100	100	100	Presence Detection	No
B2_Staircase	100	100	100	Presence Detection	No
B2_Stairs	100	100	100	Presence Detection	No
B2_Store	50	50	100	Presence Detection	No
B2_WC	200	200	100	Presence Detection	No
B2_WC	200	200	100	Presence Detection	No
B2_WC Lobby	100	100	100	Presence Detection	No

Appendix D

BRUKL DOCUMENTS

Appendix D.1

LEAN

BRUKL Output Document

HM Government

Compliance with England Building Regulations Part L 2013

Project name

UKHM Lean

As designed

Date: Fri Sep 28 15:57:50 2018

Administrative information

Building Details

Address: Victoria Tower Gardens, Westminster, London, SW1P 3GE

Certification tool

Calculation engine: Apache

Calculation engine version: 7.0.10

Interface to calculation engine: IES Virtual Environment

Interface to calculation engine version: 7.0.10

BRUKL compliance check version: v5.4.b.0

Owner Details

Name: Homes and Communities Agency

Telephone number: Phone

Address: Street Address, City, Postcode

Certifier details

Name: George Sigalas

Telephone number: 0117 930 6263

Address: 1 Queen Street, Bristol, BS2 0HQ

Criterion 1: The calculated CO_2 emission rate for the building must not exceed the target

CO_2 emission rate from the notional building, $kgCO_2/m^2$.annum	32.6
Target CO_2 emission rate (TER), $kgCO_2/m^2$.annum	32.6
Building CO_2 emission rate (BER), $kgCO_2/m^2$.annum	28.2
Are emissions from the building less than or equal to the target?	BER =< TER
Are as built details the same as used in the BER calculations?	Separate submission

Criterion 2: The performance of the building fabric and fixed building services should achieve reasonable overall standards of energy efficiency

Values which do not achieve the standards in the Non-Domestic Building Services Compliance Guide and Part L are displayed in red.

Building fabric

Element	$U_{a\text{-}Limit}$	$U_{a\text{-}Calc}$	$U_{i\text{-}Calc}$	Surface where the maximum value occurs*
Wall**	0.35	0.19	0.19	B1000001:Surf[3]
Floor	0.25	0.2	0.2	B1000001:Surf[0]
Roof	0.25	0.16	0.16	0G000001:Surf[5]
Windows***, roof windows, and rooflights	2.2	1.6	1.6	B1000001:Surf[2]
Personnel doors	2.2	-	-	No Personnel doors in building
Vehicle access & similar large doors	1.5	-	-	No Vehicle access doors in building
High usage entrance doors	3.5	-	-	No High usage entrance doors in building

$U_{a\text{-}Limit}$ = Limiting area-weighted average U-values [W/(m²K)]

$U_{a\text{-}Calc}$ = Calculated area-weighted average U-values [W/(m²K)]

$U_{i\text{-}Calc}$ = Calculated maximum individual element U-values [W/(m²K)]

* There might be more than one surface where the maximum U-value occurs.

** Automatic U-value check by the tool does not apply to curtain walls whose limiting standard is similar to that for windows.

*** Display windows and similar glazing are excluded from the U-value check.

N.B.: Neither roof ventilators (inc. smoke vents) nor swimming pool basins are modelled or checked against the limiting standards by the tool.

Air Permeability	Worst acceptable standard	This building
$m^3/(h.m^2)$ at 50 Pa	10	3

Building services

The standard values listed below are minimum values for efficiencies and maximum values for SFPs. Refer to the Non-Domestic Building Services Compliance Guide for details.

Whole building lighting automatic monitoring & targeting with alarms for out-of-range values	NO
Whole building electric power factor achieved by power factor correction	>0.95

1- Underfloor Heating with Supply and Extract

	Heating efficiency	Cooling efficiency	Radiant efficiency	SFP [W/(l/s)]	HR efficiency
This system	0.91	-	0.5	0	0.68
Standard value	0.91*	N/A	N/A	N/A	0.45
Automatic monitoring & targeting with alarms for out-of-range values for this HVAC system					YES

* Standard shown is for gas single boiler systems <=2 MW output. For single boiler systems >2 MW or multi-boiler systems, (overall) limiting efficiency is 0.86. For any individual boiler in a multi-boiler system, limiting efficiency is 0.82.

2- Trench Heating with Supply and Extract

	Heating efficiency	Cooling efficiency	Radiant efficiency	SFP [W/(l/s)]	HR efficiency
This system	0.91	5	0	2.24	0.68
Standard value	0.91*	2.55	N/A	1.6^	0.45
Automatic monitoring & targeting with alarms for out-of-range values for this HVAC system					YES

* Standard shown is for gas single boiler systems <=2 MW output. For single boiler systems >2 MW or multi-boiler systems, (overall) limiting efficiency is 0.86. For any individual boiler in a multi-boiler system, limiting efficiency is 0.82.

^ Limiting SFP may be extended by the amounts specified in the Non-Domestic Building Services Compliance Guide if the system includes additional components as listed in the Guide.

3- Underfloor Heating with Extract only

	Heating efficiency	Cooling efficiency	Radiant efficiency	SFP [W/(l/s)]	HR efficiency
This system	0.91	-	0.5	0	0.68
Standard value	0.91*	N/A	N/A	N/A	0.45
Automatic monitoring & targeting with alarms for out-of-range values for this HVAC system					YES

* Standard shown is for gas single boiler systems <=2 MW output. For single boiler systems >2 MW or multi-boiler systems, (overall) limiting efficiency is 0.86. For any individual boiler in a multi-boiler system, limiting efficiency is 0.82.

"No HWS in project, or hot water is provided by HVAC system"

Local mechanical ventilation, exhaust, and terminal units

ID	System type in Non-domestic Building Services Compliance Guide
A	Local supply or extract ventilation units serving a single area
B	Zonal supply system where the fan is remote from the zone
C	Zonal extract system where the fan is remote from the zone
D	Zonal supply and extract ventilation units serving a single room or zone with heating and heat recovery
E	Local supply and extract ventilation system serving a single area with heating and heat recovery
F	Other local ventilation units
G	Fan-assisted terminal VAV unit
H	Fan coil units
I	Zonal extract system where the fan is remote from the zone with grease filter

Zone name	SFP [W/(l/s)]									HR efficiency	
ID of system type	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**		
Standard value	0.3	1.1	0.5	1.9	1.6	0.5	1.1	0.5	1	**Zone**	**Standard**
0_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
0_Staircase	-	-	-	2.2	-	-	-	-	-	-	N/A

Zone name	SFP [W/(l/s)]									HR efficiency	
ID of system type	A	B	C	D	E	F	G	H	I		
Standard value	0.3	1.1	0.5	1.9	1.6	0.5	1.1	0.5	1	Zone	Standard
B1_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Staircase	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B1_Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B1_WC	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Acc WC/Shower	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Bin Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Cloakroom	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Corridor	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Corridor	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Kitchen	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Lockers	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Showers/Changing	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Staircase	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Stairs	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_WC	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_WC	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_WC Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A

General lighting and display lighting	Luminous efficacy [lm/W]			
Zone name	Luminaire	Lamp	Display lamp	General lighting [W]
Standard value	60	60	22	
0_Lift Lobby	-	100	-	48
0_Staircase	-	100	-	45
B1_Cafe and Retail	-	100	40	204
B1_Circulation	-	100	-	126
B1_Circulation	-	100	-	138
B1_Learning Centre	-	100	40	280
B1_Lift Lobby	-	100	-	32
B1_Lift Lobby	-	100	-	47
B1_Staircase	-	100	-	52
B1_Store	100	-	-	11
B1_Store	100	-	-	14
B1_WC	-	100	-	133
B2_Acc WC/Shower	-	100	-	28

General lighting and display lighting	Luminous efficacy [lm/W]			
Zone name	**Luminaire**	**Lamp**	**Display lamp**	**General lighting [W]**
Standard value	60	60	22	
B2_Bin Store	100	-	-	10
B2_CCTV	100	-	-	96
B2_Circulation	-	100	-	231
B2_Circulation	-	100	-	34
B2_Cloakroom	100	-	-	25
B2_Corridor	-	100	-	102
B2_Corridor	-	100	-	242
B2_Info Desk	-	100	40	73
B2_Kitchen	-	100	-	182
B2_Learning Centre	-	100	40	3560
B2_Lift Lobby	-	100	-	42
B2_Lift Lobby	-	100	-	57
B2_Lockers	100	-	-	16
B2_Meeting Room 1	100	-	-	98
B2_Meeting Room 2	100	-	-	75
B2_Office	100	-	-	455
B2_Plant	100	-	-	1078
B2_Showers/Changing	-	100	-	43
B2_Staircase	-	100	-	64
B2_Stairs	-	100	-	162
B2_Store	100	-	-	32
B2_WC	-	100	-	174
B2_WC	-	100	-	55
B2_WC Lobby	-	100	-	19

Criterion 3: The spaces in the building should have appropriate passive control measures to limit solar gains

Zone	Solar gain limit exceeded? (%)	Internal blinds used?
B1_Cafe and Retail	N/A	N/A
B1_Learning Centre	NO (-91.2%)	NO
B2_CCTV	N/A	N/A
B2_Info Desk	N/A	N/A
B2_Learning Centre	NO (-97.5%)	NO
B2_Meeting Room 1	N/A	N/A
B2_Meeting Room 2	N/A	N/A
B2_Office	N/A	N/A

Criterion 4: The performance of the building, as built, should be consistent with the calculated BER

Separate submission

Criterion 5: The necessary provisions for enabling energy-efficient operation of the building should be in place

Separate submission

EPBD (Recast): Consideration of alternative energy systems

Were alternative energy systems considered and analysed as part of the design process?	YES
Is evidence of such assessment available as a separate submission?	NO
Are any such measures included in the proposed design?	NO

Technical Data Sheet (Actual vs. Notional Building)

Building Global Parameters

	Actual	Notional
Area [m²]	2652.7	2652.7
External area [m²]	7225.8	7225.8
Weather	LON	LON
Infiltration [m³/hm²@ 50Pa]	3	3
Average conductance [W/K]	1403.88	0
Average U-value [W/m²K]	0.19	0
Alpha value* [%]	10.08	10

* Percentage of the building's average heat transfer coefficient which is due to thermal bridging

Building Use

% Area	Building Type
3	**A1/A2 Retail/Financial and Professional services**
	A3/A4/A5 Restaurants and Cafes/Drinking Est./Takeaways
1	**B1 Offices and Workshop businesses**
	B2 to B7 General Industrial and Special Industrial Groups
	B8 Storage or Distribution
	C1 Hotels
	C2 Residential Institutions: Hospitals and Care Homes
	C2 Residential Institutions: Residential schools
	C2 Residential Institutions: Universities and colleges
	C2A Secure Residential Institutions
	Residential spaces
	D1 Non-residential Institutions: Community/Day Centre
96	**D1 Non-residential Institutions: Libraries, Museums, and Galleries**
	D1 Non-residential Institutions: Education
	D1 Non-residential Institutions: Primary Health Care Building
	D1 Non-residential Institutions: Crown and County Courts
	D2 General Assembly and Leisure, Night Clubs, and Theatres
	Others: Passenger terminals
	Others: Emergency services
	Others: Miscellaneous 24hr activities
	Others: Car Parks 24 hrs
	Others: Stand alone utility block

Energy Consumption by End Use [kWh/m²]

	Actual	Notional
Heating	10.04	9.69
Cooling	1.4	3.02
Auxiliary	14.48	11.99
Lighting	21.22	35.37
Hot water	14.41	15.83
Equipment*	52.54	52.54
TOTAL**	61.54	**75.9**

* Energy used by equipment does not count towards the total for consumption or calculating emissions.
** Total is net of any electrical energy displaced by CHP generators, if applicable.

Energy Production by Technology [kWh/m²]

	Actual	Notional
Photovoltaic systems	0	0
Wind turbines	0	0
CHP generators	0	0
Solar thermal systems	0	0

Energy & CO_2 Emissions Summary

	Actual	Notional
Heating + cooling demand [MJ/m²]	53.53	71.29
Primary energy* [kWh/m²]	166.41	180.03
Total emissions [kg/m²]	28.2	32.6

* Primary energy is net of any electrical energy displaced by CHP generators, if applicable.

HVAC Systems Performance

System Type	Heat dem MJ/m2	Cool dem MJ/m2	Heat con kWh/m2	Cool con kWh/m2	Aux con kWh/m2	Heat SSEEF	Cool SSEER	Heat gen SEFF	Cool gen SEER
[ST] Chilled ceilings or passive chilled beams and displacement ventilation, [HS] LTHW boiler, [HFT] Natural Gas, [CFT] El									
Actual	19.3	41.8	6.5	2.5	14	0.83	4.55	0.91	5
Notional	0	0	0	0	0	0	0	----	----
[ST] Central heating using water: floor heating, [HS] LTHW boiler, [HFT] Natural Gas, [CFT] Electricity									
Actual	51.2	0	16.6	0	14.9	0.85	0	0.91	0
Notional	19.6	74.8	6.3	5.5	16.5	0.86	3.79	----	----
[ST] Central heating using water: floor heating, [HS] LTHW boiler, [HFT] Natural Gas, [CFT] Electricity									
Actual	95.7	0	31.1	0	39.7	0.85	0	0.91	0
Notional	52.8	0	17	0	4.8	0.86	0	----	----
[ST] No Heating or Cooling									
Actual	0	0	0	0	0	0	0	0	0
Notional	83.1	0	26.8	0	21.9	0.86	0	----	----

Heat dem [MJ/m2]	= Heating energy demand
Cool dem [MJ/m2]	= Cooling energy demand
Heat con [kWh/m2]	= Heating energy consumption
Cool con [kWh/m2]	= Cooling energy consumption
Aux con [kWh/m2]	= Auxiliary energy consumption
Heat SSEFF	= Heating system seasonal efficiency (for notional building, value depends on activity glazing class)
Cool SSEER	= Cooling system seasonal energy efficiency ratio
Heat gen SSEFF	= Heating generator seasonal efficiency
Cool gen SSEER	= Cooling generator seasonal energy efficiency ratio
ST	= System type
HS	= Heat source
HFT	= Heating fuel type
CFT	= Cooling fuel type

Key Features

The Building Control Body is advised to give particular attention to items whose specifications are better than typically expected.

Building fabric

Element	$U_{i\text{-}Typ}$	$U_{i\text{-}Min}$	Surface where the minimum value occurs*
Wall	0.23	0.19	0G000001:Surf[0]
Floor	0.2	0.2	B1000001:Surf[0]
Roof	0.15	0.16	0G000001:Surf[5]
Windows, roof windows, and rooflights	1.5	1.6	B1000001:Surf[2]
Personnel doors	1.5	-	No Personnel doors in building
Vehicle access & similar large doors	1.5	-	No Vehicle access doors in building
High usage entrance doors	1.5	-	No High usage entrance doors in building

$U_{i\text{-}Typ}$ = Typical individual element U-values [W/(m²K)] $U_{i\text{-}Min}$ = Minimum individual element U-values [W/(m²K)]

* There might be more than one surface where the minimum U-value occurs.

Air Permeability	Typical value	This building
$m^3/(h.m^2)$ at 50 Pa	5	3

Appendix D.2

CLEAN

BRUKL Output Document

HM Government

Compliance with England Building Regulations Part L 2013

Project name

UKHM Lean

As designed

Date: Fri Sep 28 15:57:50 2018

Administrative information

Building Details

Address: Victoria Tower Gardens, Westminster, London, SW1P 3GE

Certification tool

Calculation engine: Apache

Calculation engine version: 7.0.10

Interface to calculation engine: IES Virtual Environment

Interface to calculation engine version: 7.0.10

BRUKL compliance check version: v5.4.b.0

Owner Details

Name: Homes and Communities Agency

Telephone number: Phone

Address: Street Address, City, Postcode

Certifier details

Name: George Sigalas

Telephone number: 0117 930 6263

Address: 1 Queen Street, Bristol, BS2 0HQ

Criterion 1: The calculated CO_2 emission rate for the building must not exceed the target

CO_2 emission rate from the notional building, $kgCO_2/m^2$.annum	32.6
Target CO_2 emission rate (TER), $kgCO_2/m^2$.annum	32.6
Building CO_2 emission rate (BER), $kgCO_2/m^2$.annum	28.2
Are emissions from the building less than or equal to the target?	BER =< TER
Are as built details the same as used in the BER calculations?	Separate submission

Criterion 2: The performance of the building fabric and fixed building services should achieve reasonable overall standards of energy efficiency

Values which do not achieve the standards in the Non-Domestic Building Services Compliance Guide and Part L are displayed in red.

Building fabric

Element	$U_{a\text{-}Limit}$	$U_{a\text{-}Calc}$	$U_{i\text{-}Calc}$	Surface where the maximum value occurs*
Wall**	0.35	0.19	0.19	B1000001:Surf[3]
Floor	0.25	0.2	0.2	B1000001:Surf[0]
Roof	0.25	0.16	0.16	0G000001:Surf[5]
Windows***, roof windows, and rooflights	2.2	1.6	1.6	B1000001:Surf[2]
Personnel doors	2.2	-	-	No Personnel doors in building
Vehicle access & similar large doors	1.5	-	-	No Vehicle access doors in building
High usage entrance doors	3.5	-	-	No High usage entrance doors in building

$U_{a\text{-}Limit}$ = Limiting area-weighted average U-values [W/(m²K)]

$U_{a\text{-}Calc}$ = Calculated area-weighted average U-values [W/(m²K)]

$U_{i\text{-}Calc}$ = Calculated maximum individual element U-values [W/(m²K)]

* There might be more than one surface where the maximum U-value occurs.

** Automatic U-value check by the tool does not apply to curtain walls whose limiting standard is similar to that for windows.

*** Display windows and similar glazing are excluded from the U-value check.

N.B.: Neither roof ventilators (inc. smoke vents) nor swimming pool basins are modelled or checked against the limiting standards by the tool.

Air Permeability	Worst acceptable standard	This building
m³/(h.m²) at 50 Pa	10	3

Building services

The standard values listed below are minimum values for efficiencies and maximum values for SFPs. Refer to the Non-Domestic Building Services Compliance Guide for details.

Whole building lighting automatic monitoring & targeting with alarms for out-of-range values	NO
Whole building electric power factor achieved by power factor correction	>0.95

1- Underfloor Heating with Supply and Extract

	Heating efficiency	Cooling efficiency	Radiant efficiency	SFP [W/(l/s)]	HR efficiency
This system	0.91	-	0.5	0	0.68
Standard value	0.91*	N/A	N/A	N/A	0.45
Automatic monitoring & targeting with alarms for out-of-range values for this HVAC system					YES

* Standard shown is for gas single boiler systems <=2 MW output. For single boiler systems >2 MW or multi-boiler systems, (overall) limiting efficiency is 0.86. For any individual boiler in a multi-boiler system, limiting efficiency is 0.82.

2- Trench Heating with Supply and Extract

	Heating efficiency	Cooling efficiency	Radiant efficiency	SFP [W/(l/s)]	HR efficiency
This system	0.91	5	0	2.24	0.68
Standard value	0.91*	2.55	N/A	1.6^	0.45
Automatic monitoring & targeting with alarms for out-of-range values for this HVAC system					YES

* Standard shown is for gas single boiler systems <=2 MW output. For single boiler systems >2 MW or multi-boiler systems, (overall) limiting efficiency is 0.86. For any individual boiler in a multi-boiler system, limiting efficiency is 0.82.

^ Limiting SFP may be extended by the amounts specified in the Non-Domestic Building Services Compliance Guide if the system includes additional components as listed in the Guide.

3- Underfloor Heating with Extract only

	Heating efficiency	Cooling efficiency	Radiant efficiency	SFP [W/(l/s)]	HR efficiency
This system	0.91	-	0.5	0	0.68
Standard value	0.91*	N/A	N/A	N/A	0.45
Automatic monitoring & targeting with alarms for out-of-range values for this HVAC system					YES

* Standard shown is for gas single boiler systems <=2 MW output. For single boiler systems >2 MW or multi-boiler systems, (overall) limiting efficiency is 0.86. For any individual boiler in a multi-boiler system, limiting efficiency is 0.82.

"No HWS in project, or hot water is provided by HVAC system"

Local mechanical ventilation, exhaust, and terminal units

ID	System type in Non-domestic Building Services Compliance Guide
A	Local supply or extract ventilation units serving a single area
B	Zonal supply system where the fan is remote from the zone
C	Zonal extract system where the fan is remote from the zone
D	Zonal supply and extract ventilation units serving a single room or zone with heating and heat recovery
E	Local supply and extract ventilation system serving a single area with heating and heat recovery
F	Other local ventilation units
G	Fan-assisted terminal VAV unit
H	Fan coil units
I	Zonal extract system where the fan is remote from the zone with grease filter

Zone name	SFP [W/(l/s)]									HR efficiency	
ID of system type	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**		
Standard value	0.3	1.1	0.5	1.9	1.6	0.5	1.1	0.5	1	**Zone**	**Standard**
0_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
0_Staircase	-	-	-	2.2	-	-	-	-	-	-	N/A

Zone name	SFP [W/(l/s)]									HR efficiency	
ID of system type	A	B	C	D	E	F	G	H	I		
Standard value	0.3	1.1	0.5	1.9	1.6	0.5	1.1	0.5	1	Zone	Standard
B1_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Staircase	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B1_Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B1_WC	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Acc WC/Shower	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Bin Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Cloakroom	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Corridor	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Corridor	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Kitchen	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Lockers	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Showers/Changing	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Staircase	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Stairs	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_WC	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_WC	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_WC Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A

General lighting and display lighting	Luminous efficacy [lm/W]			
Zone name	Luminaire	Lamp	Display lamp	General lighting [W]
Standard value	60	60	22	
0_Lift Lobby	-	100	-	48
0_Staircase	-	100	-	45
B1_Cafe and Retail	-	100	40	204
B1_Circulation	-	100	-	126
B1_Circulation	-	100	-	138
B1_Learning Centre	-	100	40	280
B1_Lift Lobby	-	100	-	32
B1_Lift Lobby	-	100	-	47
B1_Staircase	-	100	-	52
B1_Store	100	-	-	11
B1_Store	100	-	-	14
B1_WC	-	100	-	133
B2_Acc WC/Shower	-	100	-	28

General lighting and display lighting	Luminous efficacy [lm/W]			
Zone name	**Luminaire**	**Lamp**	**Display lamp**	**General lighting [W]**
Standard value	60	60	22	
B2_Bin Store	100	-	-	10
B2_CCTV	100	-	-	96
B2_Circulation	-	100	-	231
B2_Circulation	-	100	-	34
B2_Cloakroom	100	-	-	25
B2_Corridor	-	100	-	102
B2_Corridor	-	100	-	242
B2_Info Desk	-	100	40	73
B2_Kitchen	-	100	-	182
B2_Learning Centre	-	100	40	3560
B2_Lift Lobby	-	100	-	42
B2_Lift Lobby	-	100	-	57
B2_Lockers	100	-	-	16
B2_Meeting Room 1	100	-	-	98
B2_Meeting Room 2	100	-	-	75
B2_Office	100	-	-	455
B2_Plant	100	-	-	1078
B2_Showers/Changing	-	100	-	43
B2_Staircase	-	100	-	64
B2_Stairs	-	100	-	162
B2_Store	100	-	-	32
B2_WC	-	100	-	174
B2_WC	-	100	-	55
B2_WC Lobby	-	100	-	19

Criterion 3: The spaces in the building should have appropriate passive control measures to limit solar gains

Zone	**Solar gain limit exceeded? (%)**	**Internal blinds used?**
B1_Cafe and Retail	N/A	N/A
B1_Learning Centre	NO (-91.2%)	NO
B2_CCTV	N/A	N/A
B2_Info Desk	N/A	N/A
B2_Learning Centre	NO (-97.5%)	NO
B2_Meeting Room 1	N/A	N/A
B2_Meeting Room 2	N/A	N/A
B2_Office	N/A	N/A

Criterion 4: The performance of the building, as built, should be consistent with the calculated BER

Separate submission

Criterion 5: The necessary provisions for enabling energy-efficient operation of the building should be in place

Separate submission

EPBD (Recast): Consideration of alternative energy systems

Were alternative energy systems considered and analysed as part of the design process?	YES
Is evidence of such assessment available as a separate submission?	NO
Are any such measures included in the proposed design?	NO

Technical Data Sheet (Actual vs. Notional Building)

Building Global Parameters

	Actual	Notional
Area [m^2]	2652.7	2652.7
External area [m^2]	7225.8	7225.8
Weather	LON	LON
Infiltration [m^3/hm^2@ 50Pa]	3	3
Average conductance [W/K]	1403.88	0
Average U-value [W/m^{2}K]	0.19	0
Alpha value* [%]	10.08	10

* Percentage of the building's average heat transfer coefficient which is due to thermal bridging

Building Use

% Area	Building Type
3	**A1/A2 Retail/Financial and Professional services**
	A3/A4/A5 Restaurants and Cafes/Drinking Est./Takeaways
1	**B1 Offices and Workshop businesses**
	B2 to B7 General Industrial and Special Industrial Groups
	B8 Storage or Distribution
	C1 Hotels
	C2 Residential Institutions: Hospitals and Care Homes
	C2 Residential Institutions: Residential schools
	C2 Residential Institutions: Universities and colleges
	C2A Secure Residential Institutions
	Residential spaces
	D1 Non-residential Institutions: Community/Day Centre
96	**D1 Non-residential Institutions: Libraries, Museums, and Galleries**
	D1 Non-residential Institutions: Education
	D1 Non-residential Institutions: Primary Health Care Building
	D1 Non-residential Institutions: Crown and County Courts
	D2 General Assembly and Leisure, Night Clubs, and Theatres
	Others: Passenger terminals
	Others: Emergency services
	Others: Miscellaneous 24hr activities
	Others: Car Parks 24 hrs
	Others: Stand alone utility block

Energy Consumption by End Use [kWh/m^2]

	Actual	Notional
Heating	10.04	9.69
Cooling	1.4	3.02
Auxiliary	14.48	11.99
Lighting	21.22	35.37
Hot water	14.41	15.83
Equipment*	52.54	52.54
TOTAL**	61.54	**75.9**

* Energy used by equipment does not count towards the total for consumption or calculating emissions.
** Total is net of any electrical energy displaced by CHP generators, if applicable.

Energy Production by Technology [kWh/m^2]

	Actual	Notional
Photovoltaic systems	0	0
Wind turbines	0	0
CHP generators	0	0
Solar thermal systems	0	0

Energy & CO_2 Emissions Summary

	Actual	Notional
Heating + cooling demand [MJ/m^2]	53.53	71.29
Primary energy* [kWh/m^2]	166.41	180.03
Total emissions [kg/m^2]	28.2	32.6

* Primary energy is net of any electrical energy displaced by CHP generators, if applicable.

HVAC Systems Performance

System Type	Heat dem MJ/m2	Cool dem MJ/m2	Heat con kWh/m2	Cool con kWh/m2	Aux con kWh/m2	Heat SSEEF	Cool SSEER	Heat gen SEFF	Cool gen SEER
[ST] Chilled ceilings or passive chilled beams and displacement ventilation, [HS] LTHW boiler, [HFT] Natural Gas, [CFT] El									
Actual	19.3	41.8	6.5	2.5	14	0.83	4.55	0.91	5
Notional	0	0	0	0	0	0	0	----	----
[ST] Central heating using water: floor heating, [HS] LTHW boiler, [HFT] Natural Gas, [CFT] Electricity									
Actual	51.2	0	16.6	0	14.9	0.85	0	0.91	0
Notional	19.6	74.8	6.3	5.5	16.5	0.86	3.79	----	----
[ST] Central heating using water: floor heating, [HS] LTHW boiler, [HFT] Natural Gas, [CFT] Electricity									
Actual	95.7	0	31.1	0	39.7	0.85	0	0.91	0
Notional	52.8	0	17	0	4.8	0.86	0	----	----
[ST] No Heating or Cooling									
Actual	0	0	0	0	0	0	0	0	0
Notional	83.1	0	26.8	0	21.9	0.86	0	----	----

Heat dem [MJ/m2]	= Heating energy demand
Cool dem [MJ/m2]	= Cooling energy demand
Heat con [kWh/m2]	= Heating energy consumption
Cool con [kWh/m2]	= Cooling energy consumption
Aux con [kWh/m2]	= Auxiliary energy consumption
Heat SSEFF	= Heating system seasonal efficiency (for notional building, value depends on activity glazing class)
Cool SSEER	= Cooling system seasonal energy efficiency ratio
Heat gen SSEFF	= Heating generator seasonal efficiency
Cool gen SSEER	= Cooling generator seasonal energy efficiency ratio
ST	= System type
HS	= Heat source
HFT	= Heating fuel type
CFT	= Cooling fuel type

Key Features

The Building Control Body is advised to give particular attention to items whose specifications are better than typically expected.

Building fabric

Element	$U_{i\text{-}Typ}$	$U_{i\text{-}Min}$	Surface where the minimum value occurs*
Wall	0.23	0.19	0G000001:Surf[0]
Floor	0.2	0.2	B1000001:Surf[0]
Roof	0.15	0.16	0G000001:Surf[5]
Windows, roof windows, and rooflights	1.5	1.6	B1000001:Surf[2]
Personnel doors	1.5	-	No Personnel doors in building
Vehicle access & similar large doors	1.5	-	No Vehicle access doors in building
High usage entrance doors	1.5	-	No High usage entrance doors in building

$U_{i\text{-}Typ}$ = Typical individual element U-values [W/(m²K)] $U_{i\text{-}Min}$ = Minimum individual element U-values [W/(m²K)]

* There might be more than one surface where the minimum U-value occurs.

Air Permeability	Typical value	This building
$m^3/(h.m^2)$ at 50 Pa	5	3

Appendix D.3

GREEN

BRUKL Output Document

HM Government

Compliance with England Building Regulations Part L 2013

Project name

UKHM Green

As designed

Date: Fri Sep 28 15:53:41 2018

Administrative information

Building Details

Address: Victoria Tower Gardens, Westminster, London, SW1P 3GE

Certification tool

Calculation engine: Apache

Calculation engine version: 7.0.10

Interface to calculation engine: IES Virtual Environment

Interface to calculation engine version: 7.0.10

BRUKL compliance check version: v5.4.b.0

Owner Details

Name: Homes and Communities Agency

Telephone number: Phone

Address: Street Address, City, Postcode

Certifier details

Name: George Sigalas

Telephone number: 0117 930 6263

Address: 1 Queen Street, Bristol, BS2 0HQ

Criterion 1: The calculated CO_2 emission rate for the building must not exceed the target

CO_2 emission rate from the notional building, $kgCO_2/m^2$.annum	32.2
Target CO_2 emission rate (TER), $kgCO_2/m^2$.annum	32.2
Building CO_2 emission rate (BER), $kgCO_2/m^2$.annum	27
Are emissions from the building less than or equal to the target?	BER =< TER
Are as built details the same as used in the BER calculations?	Separate submission

Criterion 2: The performance of the building fabric and fixed building services should achieve reasonable overall standards of energy efficiency

Values which do not achieve the standards in the Non-Domestic Building Services Compliance Guide and Part L are displayed in red.

Building fabric

Element	$U_{a-Limit}$	U_{a-Calc}	U_{i-Calc}	Surface where the maximum value occurs*
Wall**	0.35	0.19	0.19	B1000001:Surf[3]
Floor	0.25	0.2	0.2	B1000001:Surf[0]
Roof	0.25	0.16	0.16	0G000001:Surf[5]
Windows***, roof windows, and rooflights	2.2	1.6	1.6	B1000001:Surf[2]
Personnel doors	2.2	-	-	No Personnel doors in building
Vehicle access & similar large doors	1.5	-	-	No Vehicle access doors in building
High usage entrance doors	3.5	-	-	No High usage entrance doors in building

$U_{a-Limit}$ = Limiting area-weighted average U-values [W/(m²K)]

U_{a-Calc} = Calculated area-weighted average U-values [W/(m²K)]

U_{i-Calc} = Calculated maximum individual element U-values [W/(m²K)]

* There might be more than one surface where the maximum U-value occurs.

** Automatic U-value check by the tool does not apply to curtain walls whose limiting standard is similar to that for windows.

*** Display windows and similar glazing are excluded from the U-value check.

N.B.: Neither roof ventilators (inc. smoke vents) nor swimming pool basins are modelled or checked against the limiting standards by the tool.

Air Permeability	Worst acceptable standard	This building
$m^3/(h.m^2)$ at 50 Pa	10	3

Building services

The standard values listed below are minimum values for efficiencies and maximum values for SFPs. Refer to the Non-Domestic Building Services Compliance Guide for details.

Whole building lighting automatic monitoring & targeting with alarms for out-of-range values	NO
Whole building electric power factor achieved by power factor correction	>0.95

1- Underfloor Heating with Supply and Extract

	Heating efficiency	Cooling efficiency	Radiant efficiency	SFP [W/(l/s)]	HR efficiency
This system	5	-	0.5	0	0.68
Standard value	2.5*	N/A	N/A	N/A	0.45
Automatic monitoring & targeting with alarms for out-of-range values for this HVAC system					YES
* Standard shown is for all types >12 kW output, except absorption and gas engine heat pumps. For types <=12 kW output, refer to EN 14825 for limiting standards.					

2- Trench Heating with Supply and Extract

	Heating efficiency	Cooling efficiency	Radiant efficiency	SFP [W/(l/s)]	HR efficiency
This system	5	5	0	2.24	0.68
Standard value	2.5*	3.2	N/A	1.6^	0.45
Automatic monitoring & targeting with alarms for out-of-range values for this HVAC system					YES
* Standard shown is for all types >12 kW output, except absorption and gas engine heat pumps. For types <=12 kW output, refer to EN 14825 for limiting standards. ^ Limiting SFP may be extended by the amounts specified in the Non-Domestic Building Services Compliance Guide if the system includes additional components as listed in the Guide.					

3- Underfloor Heating with Extract only

	Heating efficiency	Cooling efficiency	Radiant efficiency	SFP [W/(l/s)]	HR efficiency
This system	5	-	0.5	0	0.68
Standard value	2.5*	N/A	N/A	N/A	0.45
Automatic monitoring & targeting with alarms for out-of-range values for this HVAC system					YES
* Standard shown is for all types >12 kW output, except absorption and gas engine heat pumps. For types <=12 kW output, refer to EN 14825 for limiting standards.					

"No HWS in project, or hot water is provided by HVAC system"

Local mechanical ventilation, exhaust, and terminal units

ID	System type in Non-domestic Building Services Compliance Guide
A	Local supply or extract ventilation units serving a single area
B	Zonal supply system where the fan is remote from the zone
C	Zonal extract system where the fan is remote from the zone
D	Zonal supply and extract ventilation units serving a single room or zone with heating and heat recovery
E	Local supply and extract ventilation system serving a single area with heating and heat recovery
F	Other local ventilation units
G	Fan-assisted terminal VAV unit
H	Fan coil units
I	Zonal extract system where the fan is remote from the zone with grease filter

Zone name	SFP [W/(l/s)]									HR efficiency	
ID of system type	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**		
Standard value	0.3	1.1	0.5	1.9	1.6	0.5	1.1	0.5	1	**Zone**	**Standard**
0_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
0_Staircase	-	-	-	2.2	-	-	-	-	-	-	N/A

Zone name	SFP [W/(l/s)]									HR efficiency	
ID of system type	A	B	C	D	E	F	G	H	I		
Standard value	0.3	1.1	0.5	1.9	1.6	0.5	1.1	0.5	1	Zone	Standard
B1_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Staircase	-	-	-	2.2	-	-	-	-	-	-	N/A
B1_Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B1_Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B1_WC	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Acc WC/Shower	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Bin Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Circulation	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Cloakroom	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Corridor	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Corridor	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Kitchen	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Lift Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Lockers	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Showers/Changing	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_Staircase	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Stairs	-	-	-	2.2	-	-	-	-	-	-	N/A
B2_Store	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_WC	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_WC	-	-	1.1	-	-	-	-	-	-	-	N/A
B2_WC Lobby	-	-	-	2.2	-	-	-	-	-	-	N/A

General lighting and display lighting	Luminous efficacy [lm/W]			
Zone name	Luminaire	Lamp	Display lamp	General lighting [W]
Standard value	60	60	22	
0_Lift Lobby	-	100	-	48
0_Staircase	-	100	-	45
B1_Cafe and Retail	-	100	40	204
B1_Circulation	-	100	-	126
B1_Circulation	-	100	-	138
B1_Learning Centre	-	100	40	280
B1_Lift Lobby	-	100	-	32
B1_Lift Lobby	-	100	-	47
B1_Staircase	-	100	-	52
B1_Store	100	-	-	11
B1_Store	100	-	-	14
B1_WC	-	100	-	133
B2_Acc WC/Shower	-	100	-	28

General lighting and display lighting	Luminous efficacy [lm/W]			
Zone name	Luminaire	Lamp	Display lamp	General lighting [W]
Standard value	60	60	22	
B2_Bin Store	100	-	-	10
B2_CCTV	100	-	-	96
B2_Circulation	-	100	-	231
B2_Circulation	-	100	-	34
B2_Cloakroom	100	-	-	25
B2_Corridor	-	100	-	102
B2_Corridor	-	100	-	242
B2_Info Desk	-	100	40	73
B2_Kitchen	-	100	-	182
B2_Learning Centre	-	100	40	3560
B2_Lift Lobby	-	100	-	42
B2_Lift Lobby	-	100	-	57
B2_Lockers	100	-	-	16
B2_Meeting Room 1	100	-	-	98
B2_Meeting Room 2	100	-	-	75
B2_Office	100	-	-	455
B2_Plant	100	-	-	1078
B2_Showers/Changing	-	100	-	43
B2_Staircase	-	100	-	64
B2_Stairs	-	100	-	162
B2_Store	100	-	-	32
B2_WC	-	100	-	174
B2_WC	-	100	-	55
B2_WC Lobby	-	100	-	19

Criterion 3: The spaces in the building should have appropriate passive control measures to limit solar gains

Zone	Solar gain limit exceeded? (%)	Internal blinds used?
B1_Cafe and Retail	N/A	N/A
B1_Learning Centre	NO (-91.2%)	NO
B2_CCTV	N/A	N/A
B2_Info Desk	N/A	N/A
B2_Learning Centre	NO (-97.5%)	NO
B2_Meeting Room 1	N/A	N/A
B2_Meeting Room 2	N/A	N/A
B2_Office	N/A	N/A

Criterion 4: The performance of the building, as built, should be consistent with the calculated BER

Separate submission

Criterion 5: The necessary provisions for enabling energy-efficient operation of the building should be in place

Separate submission

EPBD (Recast): Consideration of alternative energy systems

Were alternative energy systems considered and analysed as part of the design process?	YES
Is evidence of such assessment available as a separate submission?	NO
Are any such measures included in the proposed design?	NO

Technical Data Sheet (Actual vs. Notional Building)

Building Global Parameters

	Actual	Notional
Area [m²]	2652.7	2652.7
External area [m²]	7225.8	7225.8
Weather	LON	LON
Infiltration [m³/hm²@ 50Pa]	3	3
Average conductance [W/K]	1403.88	0
Average U-value [W/m²K]	0.19	0
Alpha value* [%]	10.08	10

* Percentage of the building's average heat transfer coefficient which is due to thermal bridging

Building Use

% Area	Building Type
3	**A1/A2 Retail/Financial and Professional services**
	A3/A4/A5 Restaurants and Cafes/Drinking Est./Takeaways
1	**B1 Offices and Workshop businesses**
	B2 to B7 General Industrial and Special Industrial Groups
	B8 Storage or Distribution
	C1 Hotels
	C2 Residential Institutions: Hospitals and Care Homes
	C2 Residential Institutions: Residential schools
	C2 Residential Institutions: Universities and colleges
	C2A Secure Residential Institutions
	Residential spaces
	D1 Non-residential Institutions: Community/Day Centre
96	**D1 Non-residential Institutions: Libraries, Museums, and Galleries**
	D1 Non-residential Institutions: Education
	D1 Non-residential Institutions: Primary Health Care Building
	D1 Non-residential Institutions: Crown and County Courts
	D2 General Assembly and Leisure, Night Clubs, and Theatres
	Others: Passenger terminals
	Others: Emergency services
	Others: Miscellaneous 24hr activities
	Others: Car Parks 24 hrs
	Others: Stand alone utility block

Energy Consumption by End Use [kWh/m²]

	Actual	Notional
Heating	1.83	3.27
Cooling	1.4	3.02
Auxiliary	14.48	11.99
Lighting	21.22	35.37
Hot water	14.41	15.83
Equipment*	52.54	52.54
TOTAL**	53.33	69.47

* Energy used by equipment does not count towards the total for consumption or calculating emissions.
** Total is net of any electrical energy displaced by CHP generators, if applicable.

Energy Production by Technology [kWh/m²]

	Actual	Notional
Photovoltaic systems	0	0
Wind turbines	0	0
CHP generators	0	0
Solar thermal systems	0	0

Energy & CO_2 Emissions Summary

	Actual	Notional
Heating + cooling demand [MJ/m²]	53.53	71.29
Primary energy* [kWh/m²]	165.1	187.76
Total emissions [kg/m²]	27	32.2

* Primary energy is net of any electrical energy displaced by CHP generators, if applicable.

HVAC Systems Performance

System Type		Heat dem MJ/m2	Cool dem MJ/m2	Heat con kWh/m2	Cool con kWh/m2	Aux con kWh/m2	Heat SSEEF	Cool SSEER	Heat gen SEFF	Cool gen SEER
[ST] Chilled ceilings or passive chilled beams and displacement ventilation, [HS] Heat pump (electric): ground or water so										
	Actual	19.3	41.8	1.2	2.5	14	4.54	4.55	5	5
	Notional	0	0	0	0	0	0	0	----	----
[ST] Central heating using water: floor heating, [HS] Heat pump (electric): ground or water source, [HFT] Electricity, [CFT]										
	Actual	51.2	0	3	0	14.9	4.7	0	5	0
	Notional	19.6	74.8	2.1	5.5	16.5	2.56	3.79	----	----
[ST] Central heating using water: floor heating, [HS] Heat pump (electric): ground or water source, [HFT] Electricity, [CFT]										
	Actual	95.7	0	5.7	0	39.7	4.7	0	5	0
	Notional	52.8	0	5.7	0	4.8	2.56	0	----	----
[ST] No Heating or Cooling										
	Actual	0	0	0	0	0	0	0	0	0
	Notional	83.1	0	9	0	21.9	2.56	0	----	----

Heat dem [MJ/m2]	= Heating energy demand
Cool dem [MJ/m2]	= Cooling energy demand
Heat con [kWh/m2]	= Heating energy consumption
Cool con [kWh/m2]	= Cooling energy consumption
Aux con [kWh/m2]	= Auxiliary energy consumption
Heat SSEFF	= Heating system seasonal efficiency (for notional building, value depends on activity glazing class)
Cool SSEER	= Cooling system seasonal energy efficiency ratio
Heat gen SSEFF	= Heating generator seasonal efficiency
Cool gen SSEER	= Cooling generator seasonal energy efficiency ratio
ST	= System type
HS	= Heat source
HFT	= Heating fuel type
CFT	= Cooling fuel type

Key Features

The Building Control Body is advised to give particular attention to items whose specifications are better than typically expected.

Building fabric

Element	$U_{i\text{-}Typ}$	$U_{i\text{-}Min}$	Surface where the minimum value occurs*
Wall	0.23	0.19	0G000001:Surf[0]
Floor	0.2	0.2	B1000001:Surf[0]
Roof	0.15	0.16	0G000001:Surf[5]
Windows, roof windows, and rooflights	1.5	1.6	B1000001:Surf[2]
Personnel doors	1.5	-	No Personnel doors in building
Vehicle access & similar large doors	1.5	-	No Vehicle access doors in building
High usage entrance doors	1.5	-	No High usage entrance doors in building

$U_{i\text{-}Typ}$ = Typical individual element U-values [W/(m²K)] $U_{i\text{-}Min}$ = Minimum individual element U-values [W/(m²K)]

* There might be more than one surface where the minimum U-value occurs.

Air Permeability	Typical value	This building
m³/(h.m²) at 50 Pa	5	3

Kings Orchard
1 Queen Street
Bristol
BS2 0HQ

wsp.com