ARUP

Imperial College London

South Kensington Zero Emission Neighbourhood Heat Network

Feasibility study

Reference: LEA Project. Reference: GLA 81635 Local Energy Framework

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1. Executive summary

Imperial College London ('Imperial'), the Natural History Museum ('NHM'), the Science Museum ('ScM') and the Victoria and Albert Museum ('V&A'), collectively the 'institutions', were once all fed heat from the same heat network, which was installed in circa 1959, and operated as one network until circa 1999.

Arup were appointed under the GLA's Local Energy Framework to investigate the existing heat network installed at the four institutions, with the aim of decarbonising the heat supplied from it. This is ultimately required to assist the institutions achieve their net zero carbon emission ambitions.

Three of the institutions, Imperial, NHM and V&A, still use the heat network to supply heat to their buildings, only the ScM is no longer connected to it. The heat network is operated as two networks, one at Imperial and one at NHM and V&A. Imperial, which has the largest heat demand of the four institutions, operates their heat network with their own Energy Centre, and the other part of the network operates from the NHM's Energy Centre, which also feeds heat to the V&A. This study has found that reconnection of the ScM and connection of the two heat networks is technically feasible.

At the present time, decarbonisation of heat via heat networks generally has two pathways:

1. Electrification of heat;
2. Recovery of rejected or wasted heat.

The UK government is also investing in research for hydrogen to be made available via the gas network, but timescales for this are uncertain, so a decarbonisation strategy based on hydrogen availability would have a timescale outside the control of the institutions.

Once reconnected, the heat supplied from the network needs to be provided without the burning of fossil fuels. This study found four opportunities to utilise recovered heat or renewable heat at a heat network scale. These are:

1. Recovery of the heat from water pumped out from Transport for London's ('TfL') South Kensington station;
2. Recovery of renewable heat from the Serpentine and Long Water lakes in Hyde Park;
3. Recovery of the heat within the sewer under the Natural History Museum; and,
4. Recovery of heat from the aquifer underneath the institutions.

A further option of recovering heat from some large chillers situated around the institutions was found to be hydraulically very complicated and more suitable for individual buildings to reduce their load on the heat network.

Table 1 below shows a summary of the four options. The carbon emission reductions are all against a base line of the heat being provides by gas fired boilers.

The reason the electrification of heat is a decarbonisation pathway, is that the electricity grid is decarbonising. For this reason, Table 1 includes the carbon emissions in 2023 and 2035 (with the 2035 emissions factors coming from government projections[1]).

Table 1: Summary of the potential recovered and renewable heat options

Option	Description	Carbon reduction and key issues
TfL rejected water	Using the rejected water pumped from the South Kensington station to extract heat through a combination of heat exchangers and Water Source Heat Pumps (WSHP) in the NHM Energy Centre, with the potential of circa 1.4MW heat output.	Potential to reduce annual carbon emissions by 9% in 2023, and 13% in 2035. Subject to agreeing commercial terms and pipe routing with TfL. Environmental permissions may be required from the Environment Agency. Subject to agreeing plant location.
Sewer source	Heat from the sewer located on the corner of Cromwell Road and Queen's Gate is extracted through a pumping well in the NHM's Wildlife Garden. This feeds WSHPs in the NHM Energy Centre. The range of heat available is between 3.1 to 15.3MW, but the higher number is subject to further studies and 3.1MW is used in this report.	Potential to reduce annual carbon emissions by 19% in 2023, and 27% in 2035. Subject to agreeing commercial terms with Thames Water. Environmental permissions may be required from the Environment Agency. Subject to agreeing plant location, particularly with the NHM as it would be located on their site.
Imperial aquifer	Extraction and injection wells are bored into the Imperial aquifer located in Prince's Gardens, where a new pump house is required. This water passes through a heat exchanger and into the Imperial service tunnel to WSHPs located in the Energy Centre where circa 0.9MW is recovered. This option could also be undertaken across the institutions to give a higher output of circa 4MW, but this is subject to further studies, and this study focuses on the 0.9MW available.	Potential to reduce annual carbon emissions by 5% in 2023, and 8% in 2035. Subject to agreeing commercial terms and pipe routing within the institutions. Environmental permissions will be required from the Environment Agency. Subject to agreeing plant location.
Serpentine	Heat from the Serpentine Lake is extracted through lake source heat exchangers, which leads to a local pump house in Hyde Park, feeding to the Imperial energy centre which increases the heat output to circa 4.5MW through WSHPs.	Potential to reduce annual carbon emissions by 27% in 2023, and 40% in 2035. Subject to agreeing commercial terms with the Royal Parks. Environmental permissions will be required from the Environment Agency. Subject to agreeing plant locations with Royal Parks and the institutions.

[1] Greenhouse gas reporting: conversion factors, Department for Energy Security and Net Zero, Retrieved from: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022 , [Accessed 7th of July 2023].

Whilst it would be possible to utilise more than one of the options above, the carbon emissions are not as much as adding the options together, as the heat demands for the institutions are seasonal.

As can be seen from the carbon emissions, further heat load reduction (from the 2018 baseline used) or supplementary heating will be required from other low carbon technologies to completely decarbonise the heating supplied. Suitable technologies for this are, for example, Air Source Heat Pumps or electric boilers.

The feasibility level capital and operational costs are shown in Table 2 and Table 3 below.

As Imperial and NHM have gas-fired CHP plants, and as gas and electricity prices are inherently unstable at present since the removal of Russian gas from several countries' gas networks in 2022, energy costs have been used as supplied by the Department for Energy Security & Net Zero[2]. For the Base Case, it was also assumed that the heat pumps would operate when CHP plants are not operating, with all heat supplied from gas fired boilers.

Whilst costs have been requested and therefore produced, a very important part of recommended further studies is to identify for which of the government grants the schemes qualify to reduce the cost paid by the institutions.

Table 3 illustrates the typical costs associated with the options. For all options, the electrical consumption of the gas boilers, and their plant replacement and labour and materials costs are excluded from the table as they are costs that would always be incurred, as the solutions are not large enough to completely omit the need for gas fired boiler plant.

All costs presented exclude the costs for commercialisation (i.e., the costs TfL, Thames Water or Royal Parks) could charge for heat being taken from them. Only the aquifer solution has less risk of costs being requested by a landowner or utility, though the Environment Agency may make a charge.

Table 2: Capital cost figures for the potential options

Cost estimate	TfL rejected water	Sewer source	Imperial aquifer	Serpentine
Mechanical costs	£4.8M	£17.8M	£4.4M	£10.4M
Electrical costs	£0.2M	£1.0M	£0.2M	£0.4M
Civil costs	£0.1M	£0.3M	£0.9M	£2.4M
Subtotal	**£5.1M**	**£19.1M**	**£5.5M**	**£13.3M**
Testing & Commissioning @5% Capex	£0.3M	£0.7M	£0.3M	£0.7M
Contractor's Preliminaries @15% Capex	£0.8M	£2.2M	£0.8M	£2.0M
Contractor's OH&P @10% Capex	£0.5M	£1.9M	£0.5M	£1.3M
Project / Design Team Professional Fees @6% Capex	£0.3M	£0.9M	£0.3M	£0.8M
Contingency @40% Capex	£2.8M	£10.0M	£3.0M	£7.2M
Total	**£9.7M**	**£34.9M**	**£10.4M**	**£25.2M**

[2] Quarterly Energy Prices from June 2023 and Prices of fuels purchased by non-domestic consumers in the United Kingdom by the Department for Energy Security & Net Zero (https://www.gov.uk/government/statistics/quarterly-energy-prices-june-2023),

Table 3: Annual operational cost figures for the potential options

Cost estimate	Base case (gas boiler only)	TfL rejected water	Sewer source	Imperial aquifer	Serpentine
Energy					
Energy (Gas)	£8.3M	£7.2M	£5.8M	£7.5M	£4.8M
Energy (Electricity)	N.A.	£0.9M	£2.1M	£0.8M	£3.2M
Operation & Maintenance					
Plant replacement (additional cost over gas-fired boilers and heat network costs)	N.A.	£0.4M	£1.5M	£0.3M	£0.7M
Labour and materials (additional cost over gas fired boilers and heat network costs)	N.A.	£24.3K	£51.5K	£31.5K	£45.9K
Financing					
Capital finance (15 years @ 6%)	N.A.	£1.0M	£3.5M	£1.1M	£2.6M
Total	**£8.3M**	**£9.5M**	**£13.1M**	**£9.7M**	**£11.2M**

1.1 Way forward

It recommended that the institutions:

1. Obtain a commitment from each of the institutions that they wish to proceed to investigate being connected to the same low carbon heat network. Should one or more institution not wish to progress, some of the options may still be available, depending on the institution that is not connecting.
2. Agree a desired timeline for the implementation of the technical solution. This will help to fix the scope for the future studies and give a firm basis on which the costs and financial modelling are to be presented. It will also provide an understanding of the plant spaces available, especially in Energy Centres where plant is already installed.
3. Agree Heads of Terms for working together and the approvals process. This document would, in the fullness of time and once the technical solution is more certain and nearer approval, evolve through a revision into the Heads of Terms for the supply of heat to the institutions.
4. Agree which solutions to pursue to the next stage and obtain funding for the studies. It is possible, depending on the scope, that this would come from the GLA's LEA programme, or the Salix administered Low Carbon Skills Fund (LCSF). It should also be decided if multiple options would be considered (e.g., the aquifer and the sewer source solutions) as space needs to be found for each of the options for the plant.
5. Obtain a concept design (e.g., RIBA Stage 2 level of detail) for each of the solutions and undertake any required testing to maximise the scale of the solution and heat recoverable.
6. Continue to discuss permissions to access the heat sources from the relevant parties (e.g., TfL, Thames Water, Royal Parks or other organisations required to recover heat from their land or systems).
7. Consider getting some planning permission and environmental permitting advice on each of the selected solutions.
8. Agree the metrics by which the solutions will be measured, accepting that measuring the project using the traditional financial mechanisms is likely to be challenging in a period of high inflation and with significantly fluctuating gas and electricity prices. Changing the Base Case should be

considered at the next stage, to appraise the solutions found against another all-electric heat option, rather than against a gas-fired solution.

9. For each of the solutions chosen to be progressed:

    a. Undertake all necessary tests to maximise the opportunity, for example, for the aquifer, consider a cross site/institution solution.

    b. Continue the application for increased electrical capacity from the DNO.

10. Should thermal storage be needed on the solution chosen, a location should be found for it. The consideration of the underground oil tanks at the NHM should be considered, subject to the statutory guidance on decommissioning underground oil tanks.

11. For the options taken forward to the next stage, undertake a more detailed cost model that considers the existing heat network and energy centre heating plant assets in more detail, breaking them down equitably amongst the four institutions.

12. The four institutions all have plans to achieve net zero carbon emissions by, or before, 2040. The heating technologies to be used by the institutions to reduce their carbon impact should be identified at the next stage to ensure the design of the solutions is done correctly.

2. Introduction

The Natural History Museum (NHM), the Science Museum (ScM), the Victoria and Albert Museum (V&A) and Imperial College London (Imperial), co-located in South Kensington, were once supplied heat by a single heat network installed in the late 1950s. Imperial and ScM disconnected from the heat network in the late 1990s to early 2000s. The only connection remaining is between NHM and V&A, where the V&A receives space heating from the NHM network. Both Imperial and NHM have a gas fired CHP plant that feeds their heat networks. The buildings and wider site can be seen in Figure 2.

The institutions (along with additional buildings in the South Kensington area) undertook a Carbon Reduction Masterplan for the 1851 Estate in 2011, this report focused on the specific carbon reduction targets of each institution.

In order to heat and cool the sites, Aquifer Thermal Energy Storage (ATES) was identified in the early stages of that masterplan as a potential significant contributor to carbon reduction. This led Imperial to dig a test borehole within their campus, though an ATES was not progressed further though the measured flow rates indicated the feasibility for heat extraction.

Since the report, the electricity grid has experienced significant decarbonisation over recent years and the Department for Energy Security and Net Zero (‘DESNZ’) projections show a continuation of this trajectory. However, the future improvement of the natural gas network carbon emissions factor, through hydrogen adoption for example, is more uncertain.

A graph showing projections for the carbon factor of electricity and gas can be seen in below. This represents the projections published by DBEIS Green Book[3] Supplementary Guidance 2022. These carbon emission factors are an industry recognised source of data.

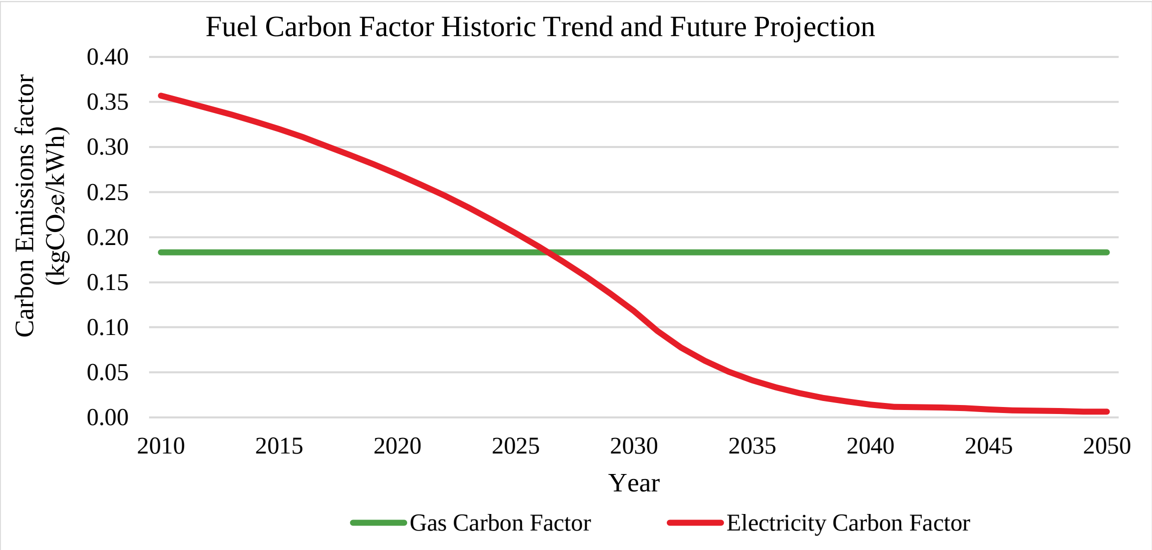

Figure 1: DESNZ (formerly BEIS) projected carbon emission factors

Due to these projections, industry has followed suit with the rapid development of high efficiency electric heat pumps. Heat pumps can utilise various heat sources such as air and water. Water sources can be found through a variety of external opportunities to recover heat from sources that would have otherwise been wasted.

[3] Greenhouse gas reporting: conversion factors, Department for Energy Security and Net Zero, Retrieved from: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022 , [Accessed 7th of July 2023].

The main scope objectives for this feasibility study include:

- Assess the feasibility of re-instating historic network connections and propose solutions for a zero or low carbon heat supply (including cooling) to meet demand from all institutions.
- Explore feasibility of having a single Energy entre facility or smaller shared facilities across each institution to meet heat (including cooling) demand.
- Assess feasibility for utilising waste heat between institutions or other organisations within the area.
- Consider opportunities for improving electricity resilience through battery storage and renewables, or other technologies that will help minimise the impact of electrifying the heat networks.
- Assess opportunities for hydrogen gas, high temperature heat pumps, and other medium to long terms solutions that will put beneficiaries on a clear pathway to achieving their carbon targets

This feasibility level study has focussed on wasted heat sources, and several opportunities have been identified in the area for recovering heat that would have been wasted and also using renewable heat. These opportunities include groundwater pumped from the underground rail system (the ‘tube’) at the South Kensington station, an aquifer located in Princes’ Gardens, the sewer systems running underneath Queen’s Gate and Cromwell Road and the iconic Serpentine and Long Water Lake in Hyde Park.

The following contacts are the lead representatives at each of the institutions:

- Andy Hammond, Head of Engineering, Energy and Environment at Imperial
- Jude Hughes, Energy Manager at NHM
- Paul Rees, Senior Estate Manager (South) at ScM
- Melissa Painter, Head of Sustainability at V&A.

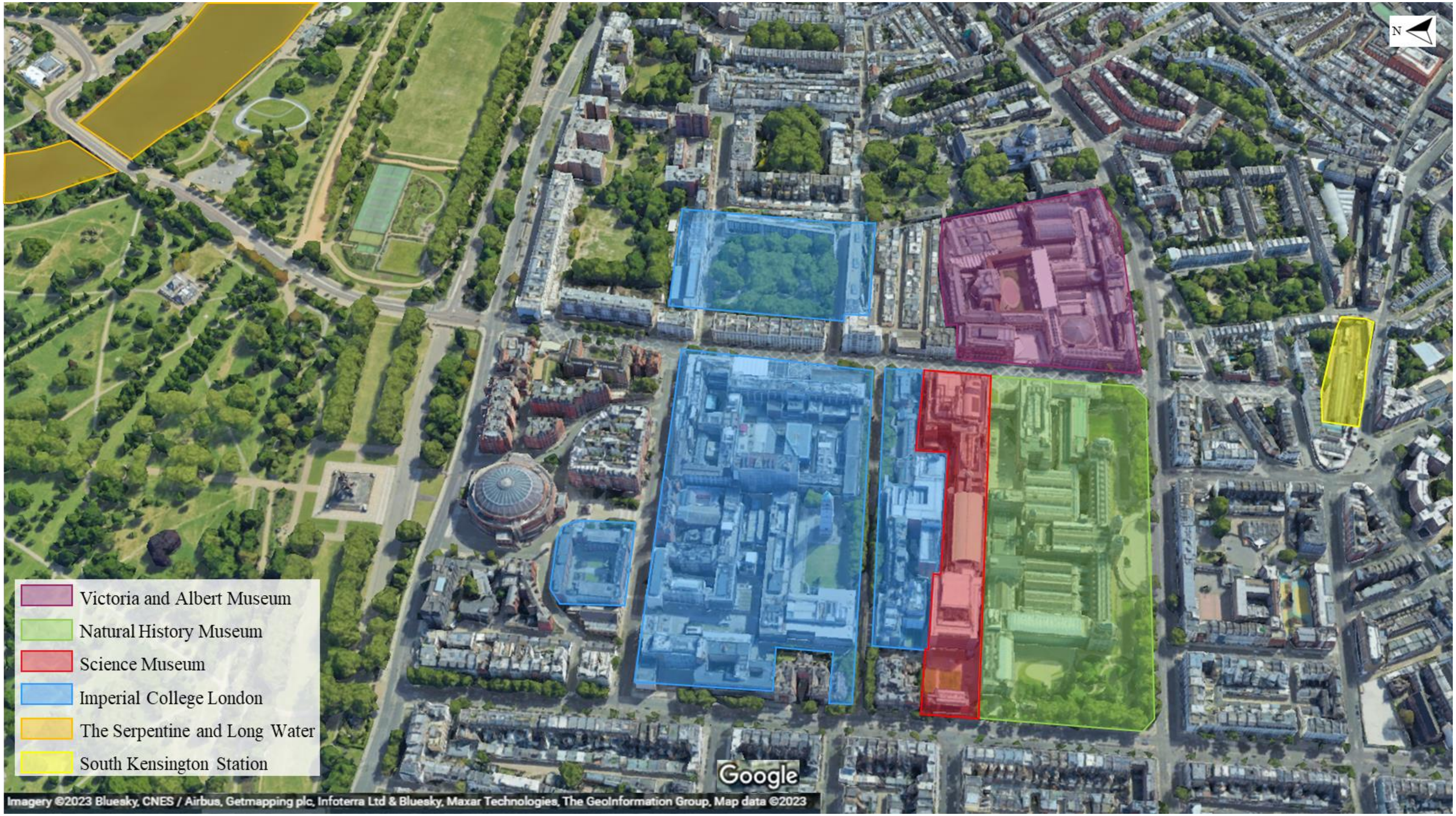

Figure 2: South Kensington institutions to potentially reconnect to a single heat network and wider site context

3. Institution background

The Baseline report in Appendix A, provides a thorough background on all institutions considered. The following offers a summary of the institution including the main heating equipment, ongoing works and listed status.

3.1.1 Imperial College London

Imperial College London was founded in 1907 as a public research university undertaking high impact research. They have approximately 17,000 students and 8,000 staff. Their main campus is in South Kensington.

Figure 3: Imperial College London

The site was served by 3 × 12MW gas-fired steam boilers and a 2 × 4.5MWe CHP plants which provided electricity as well as direct steam and hot water (through use of plate heat exchangers) to the majority of the campus. Some buildings on site have their own individual gas-fired boilers.

Imperial is currently (expected completion Q4 2023) undergoing significant works under the Public Sector Decarbonisation Scheme to remove all steam on site by replacing the gas-fired steam boilers with higher efficiency gas-fired LTHW boilers, of the same rating.

The CHP plants are expected to remain as they were only brought online in 2017.

3.1.2 Natural History Museum

The Natural History Museum is one of three museums situated on Exhibition Road. The museum focuses on exhibitions pertaining to the natural world and nature sciences including palaeontology. The museum was established in 1881. The Natural History Museum, Front Lodge and Gates, Gate Piers and Railings are Grade I listed buildings, whereas the West Lodge is a Grade II listed building.

Figure 4: Natural History Museum

The site is served by 2 × 10.5MW gas-fired LTHW boilers and a 1.8MW CHP plant. The NHM is undertaking several energy saving projects, as part of their refurbishment of the Energy Centre. The project is expected to be completed in 2023. The project includes the replacement of the gas-fired CHP plant as well as the addition of an Air Source Heat Pump, Water Source Heat Pump and rooftop photovoltaic panels.

3.1.3 Victoria and Albert Museum

The Victoria and Albert Museum focuses on the applied arts, decorative arts and design. The museum was established in 1852 and the main building (referred to as the Victoria and Albert Museum) is a Grade I listed building, while the Cole Wing is a Grade II listed building.

The V&A museum heating is supplied through and existing heat network connection to the NHM, running underneath Exhibition Road. This heat comes from the gas-fired CHP plant and boilers.

Figure 5: Victoria and Albert Museum

3.1.4 Science Museum

The Science Museum houses significant artifacts pertaining to the human engineering and understanding. The museum was established in 1857 as part of the Great Exhibition of the Works of Industry of All Nations. The museum is currently served by 5 × 0.895MW gas-fired LTHW boilers. The museum is not currently connected to the other sites; however, the historical connection has been verified and can be traced from the NHM Energy Centre. The museum has its own entrance to the NHM Energy Centre as this part of the building was built at the same time as the heat network was installed.

There are four incomers for electricity to the museums and the NHM manages and charges the institutions accordingly.

Figure 6: Science Museum

4. Investigation of relevant technologies

The following section discusses a selection of the technologies relevant to decarbonising the heat provision on the sites.

4.1 Solar

4.1.1 Photovoltaics

Photovoltaic (PV) systems work by converting solar energy directly into electricity. PV panels generate Direct Current (DC) electricity and are arranged in modules that include inverters to convert electricity into Alternating Current (AC) that can be used by the building systems. The panels should be mounted in a location that receives good access to the sun and is not overshadowed by surrounding parts of the building, adjacent buildings or other PV Panels. This technology, combined with battery storage, can be implemented in the future to provide electrical resilience for the chosen heat pump technology.

A desktop rooftop area study was undertaken as can be seen in Appendix D which shows the existing PV installations as well as the potential available space. As PV is an option that can be added independently of the thermal solutions, it is not included in the final option analysis.

4.1.2 Solar thermal

Solar water heating has the potential to make a significant contribution to the Domestic Hot Water ('DHW') demand. Solar water heaters are able to convert around 60% of the incoming solar radiation into hot water. It is typical to design solar collectors to provide DHW, as heat demand in summer is generally very low, and designing panels for winter heating demands will lead to problems with overheating in summer, and possibly require heat to be rejected. Panels are therefore typically sized to satisfy as much of the DHW demand as possible by utilising all of the sun's energy at the time of the year when the solar irradiation is highest.

Given that the hot water demand will only be met in summer conditions, it will be necessary to top-up hot water demand with boilers or heat pumps all year round. Solar thermal is ideally suited to buildings with full time residential occupancy, which makes it very suitable for Imperial which has student accommodation onsite. As per the PV above, solar thermal could be undertaken independently of the larger DHN thermal solutions to reduce building heat demands and as such is not included in the final option analysis.

4.2 Hydrogen

Hydrogen is being considered by the government as a solution to thermal combustion plant carbon emissions. As pure hydrogen gas has no carbon in it, the combustion of it does not cause carbon dioxide emissions at source. In the future, hydrogen may become available through the natural gas network, but it is not currently available, and a significant investment in production of it is required to provide the significant quantities of it that are required.

The use of hydrogen on site would therefore require compression of the gas and transmission via road haulage, and storage on site.

As 'green' hydrogen is produced from renewable electricity, and the yield is significantly less than the electricity put in, it is likely that even if it could be sourced, it would be significantly more expensive to buy, and have higher associated carbon dioxide emissions, than having heating systems using resistive heating. As it is not currently available in the gas grid, it is not considered further in this report.

4.3 Heat pumps

A heat pump is a refrigerant based machine which uses a heat source such as air, water, or the ground as an energy source for heating, or an energy sink if cooling. It is a low carbon technology, as the heat or cold is just moved from one place to another, meaning very high efficiencies can be achieved. Whilst being moved, it is possible to upgrade the temperature of the fluid. Heat pumps are unique in being able to produce these high levels of efficiency and as they are electric, carbon emissions will reduce even further as grid electricity decarbonises.

Heat pumps efficiency is measured using the coefficient of performance (CoP). This is a ratio of the useful heating/cooling output with the work (usually electrical) that was required to be put in. Depending on the conditions of the heat source and sink, heat pumps have typical CoPs in the range of 2 to 8. All thermal plant on the same basis would be less than 1.

4.3.1 Air source heat pump

ASHPs use air as a heat source, when in heating, and heat sink when in cooling. Since ASHP's use heat energy in external environments, their efficiencies (CoP) can vary significantly with outside temperature, reducing during colder ambient temperatures. Efficient ASHPs deliver low temperature hot water (LTHW), typically around 55/45°C (flow and return temperature, although some ASHPs can reach higher temperatures, but commercially not up to 90°C which is required), which is lower than typical gas boiler systems. For this reason, supplementary heating methods are usually required for domestic hot water, and buildings can often need heat emitters and pipework upgrades to operate effectively on these lower temperatures.

Air source heat pumps can operate within a wide range of external air temperatures. They can extract heat from air at -20°C and below if specially designed and they can reject heat (providing cooling) to air up to 40°C. The efficiency and performance will be greatly reduced when operating at these extreme conditions. A heat pump in a London climate should operate efficiently throughout the year.

For the context of this study, ASHPs were only considered where they could recover heat rejected by other processes, rather than from the air more generally, due to funding timeline and budget constraints.

4.3.2 Water source heat pump

A water source heat pump (WSHP) uses water for its source of heating or sink when cooling. Water is much more energy dense than air and is used in temperatures above the freezing point. As such, WSHPs are usually more efficient than ASHPs. They have the added advantage of being smaller (heat exchangers do not need the same surface area to achieve the same rate of heat transfer) and they can be located in internal plant spaces.

Unlike ASHPs that need an exposed location as they need access to the air WSHPs can be placed in energy centres or enclosed areas. However, a water source is not abundant in most locations and distribution networks to provide the source is often required. WSHPs can produce LTHW up to 90°C, which is specifically useful when there is a need to maintain a higher building side temperature. This circumvents the need to upgrade heat emitters and pipe sizes that would be required using a low temperature air source heat pump.

4.4 Boilers

4.4.1 Gas-fired boilers

Gas fired boilers are currently the primary source of heat on site and can be used to generate steam or LTHW. To decarbonise, there is a need to move away from fossil fuels and as such a gas-fired primary heat source in the long term is not preferred. Gas-fired boilers can however provide space efficient resilience to alternative, more sustainable heat sources, for example, in times during extreme weather conditions or in the event of an electrical power outage. They also remain a solution when top-up heating is required in peak times or if ASHPs are part of the solution, provide heating during defrost cycles, during the period before the sites fully decarbonise.

4.4.2 Electric boilers

Electric boilers have high thermal efficiency (~99%), fast ramp-up times, and low downtimes. They can be used to generate both steam and LTHW and have an even smaller footprint compared to conventional oil/gas-fired boilers. There is no requirement for onsite pollution abatement or combustion accessories, such as tanks and fuel links as there are for oil/gas fired boilers. They do not require a flue; however, they do require a steam pressure safety valve and vent. Compared to other electrically driven heat sources, such as ASHPs, they require a greater electrical load if used as a primary heat source. This increases the need for larger electrical network reinforcement works and often national grid supply upgrades. They are a relevant technology for supplying peak heating demands.

4.5 Energy storage

4.5.1 Battery storage

Battery storage offers two primary functions, firstly it can store electricity produced from low carbon sources onsite such as photovoltaics. The second main use is storing electricity when the demand on the grid is low, which allows for a reduction in cost and potentially carbon.

The inclusion of it in this study was for the former, however as can be seen later in this report, the site does not have sufficient roof space to install PV systems that are larger than the base electricity demand, so are not required. Any PV generated on site, would be used on site without any need for battery storage.

4.5.2 Thermal storage

A thermal storage system can be used to efficiently store, and release heat energy as needed. It typically consists of a large, insulated tank capable of storing heated water. During periods of low demand or when excess heat is available, the system heats and stores the energy in the tank. When heat demand increases, the stored thermal energy is released and distributed to the central heating system. This allows the plant to operate more efficiently by reducing the need for constant heat generation, optimizing energy usage, and providing a buffer for peak demand periods.

5. Investigation of relevant opportunities

Due to the location of the site and the built-up nature of the four institutions, various external opportunities for low carbon heat provision were considered. This required engagement with external partners including Transport for London (TfL), Thames Water, United Kingdom Power Networks (UKPN) and Royal Parks. The opportunities investigated are laid out in the following sections.

The water source heat pumps described in Section 4.3.2 require a heat source. This section explores five different heat sources that have the potential to reduce the energy consumption for the site. Two of the options come from a heat source that would otherwise be wasted; and two are naturally occurring sources that could be utilized. One source, from the building chillers, was deemed technically challenging and more sensibly done during a building's refurbishment or chiller replacement.

The first step was to determine what heat demand was required. This was done in the Baseline report that can be found in Appendix A.

5.1 Baseline

5.1.1 Heat load duration curve

The heat load duration curve shown below shows the heat load and indicates the individual peak loads for each of the four sites. The heat load duration curve also indicates the time for which a load occurs, preventing oversizing of equipment. The cumulative peak load for the combined sites was estimated at 33.3MW (this being the addition of the four institutions' peak demands). As the data for the museums was only available monthly, this assumes that the highest demands happen at the same time (as they are primarily used for space heating).

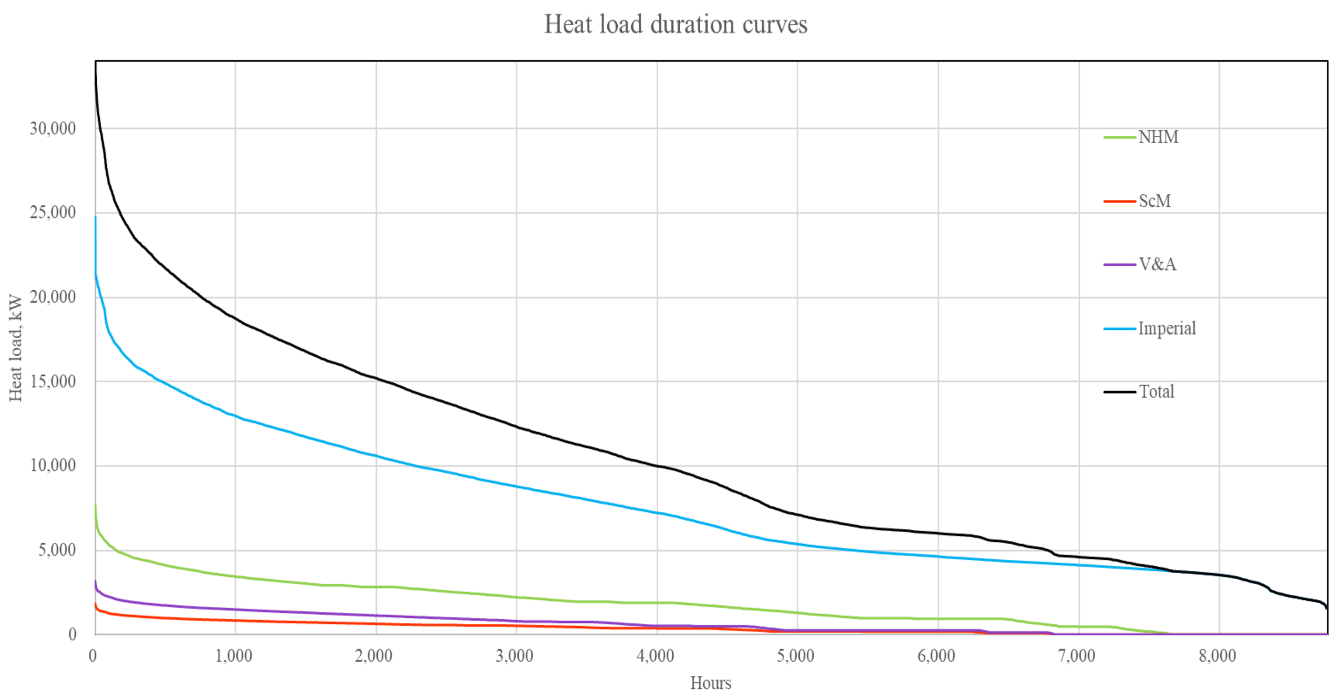

Figure 7: Heat load duration curves for the four sites

5.1.2 Thermal storage analysis

In order to reduce the size of the heating plant that is required to meet the peak demand, the feasibility of thermal storage has been assessed based on the hourly energy demand. The option was investigated to meet 10% of the peak load, equivalent to 3.33MW, through the use of thermal storage tanks.

To achieve this, a thermal storage tank with a volume of 620m³ would be required. Using a realistic tank height of 3.5m, a diameter of 16.5m would be required, or an equivalent of 44 × 2.5m diameter tanks. Due to insufficient space on the existing site and the high cost associated with strengthening the plant room foundations, the thermal storage system is not included in the proposed solutions. This is because the size of tank required to make a large change to the size of the heating plant in winter was very large indeed, due to Imperial's continuous large heating demand in winter. It can be seen in Table 4 below, a 10,000m³ tank being needed to reduce the peak by only 7.3MW.

The NHM underground fuel tanks do offer an opportunity to introduce a certain amount of thermal storage into the network if required. They would need to be lagged and redesigned, and all statutory requirements should be met with regards to the repurposing of underground oil tanks. The tanks have a combined volume of 847.5m³, it is not known if this includes ullage. These could be connected to the NHM Energy Centre with relative ease due to their location.

Table 4: Thermal storage options investigated

Peak demand	Heating plant output reduced size	Thermal storage volume	Required tanks
33.3MW	30MW	620m³	44 × (2.5m diameter by 3.5m height) tanks
33.3MW	28MW	1,800m³	127 × (2.5m diameter by 3.5m height) tanks
33.3MW	25MW	10,000m³	706 × (2.5m diameter by 3.5m height) tanks

Thermal storage is required to be used in conjunction with WSHPs to provide buffer to allow constant flow with regulated temperatures, however this is a different function than storing the water for use at a different time, this instead just keeps the WSHPs operating without large fluctuations in demand.

5.1.3 Heat network

The Baseline report, given in Appendix A, shows how to reconnect the network of the four institutions. This will form the basis of all potential solutions investigated in this report. The solutions will connect into a single heat network. The following table discusses the benefits and drawbacks of reconnecting the institutions via a single heat network.

Whilst the NHM heat network currently operates at a maximum temperature of 95°C, Imperial currently operates theirs at 90°C. This study has assumed that NHM and V&A (connected to NHM) could operate at 90°C so that they can all be connected. Any possible reduction of this temperature would improve the efficiency of the scheme, both increasing the CoPs of the heat pumps and lowering heat distribution losses.

Table 5: Benefits and drawbacks of reconnecting the institutions

Benefits	Drawbacks
Potential to utilise surrounding opportunities to provide low carbon heating to all institutions. Heat from local opportunities (identified in 5.2 to 5.5) have the potential to meet the full summer demand.	There would be single network operating temperature, suggested as 90°C. This temperature is suitable for the Imperial network as well as the NHM network which currently operates between 85-95°C. (i.e., reduced temperature flexibility for the network).
There is an additional resilience to sharing a heat network, by connecting multiple heat sources and energy centres.	A single network means that all buildings will have to decarbonise at the same time to be able to operate at a single network temperature.
Potential higher operational efficiencies and long-term cost reduction.	There is a significant cost to re-establishing the network (over £250K as discussed in the Baseline Report).

5.1.4 CHP plant operation

As was demonstrated in Figure 1, the projected emission factors related to gas and electricity indicate that electric options are the primary way to decarbonise buildings and sites. The NHM and Imperial both currently have gas-fired CHP plants which in recent years have operated at very high spark spreads. High spark spread, that is the difference between electricity price and gas price, creates a very favourable case for the gas-based CHP plant solutions. Conversely, low spark spreads are helpful towards heat pump solutions.

The decision as to when to run CHP plants was traditionally an economic one, but now companies are starting to assess the environmental aspects as well. As the institutions plan to decarbonise by targeting net zero carbon emissions (ScM by 2033, NHM and V&A by 2035 and Imperial by 2040), this study has considered the case of the CHP plants not running so as not to confuse the CHP plant financials within the choice to run heat pump plant that will be required in the future.

Therefore, all analysis has been made on the basis of a single heat network being supplied heat by one of the solutions presented below, with the existing gas fired boilers making up the demand not met by the solution. The bundling of options is possible, where space, capital and electrical supply etc. permits, but the savings cannot be added, due to the heat demand changing throughout the year. The baseline comparison was taken to be a gas-boiler systems (as existing) without CHP plant running.

5.2 TfL rejected water – London Underground

5.2.1 Opportunity background

Since much of the London Underground is under the water table, Transport for London (TfL) are continuously pumping ground water from their stations to prevent flooding of the stations. The pumped water is discharged directly to the Thames Water sewer network.

The South Kensington Underground station has a pumping house adjacent to Thurloe Square bridge. This pumping house removes an average of 74,214m^3 [4] of water each month. The instantaneous rate will fluctuate depending on the weather conditions. The most common occurring flow rate is not known however the average flow rate over the month is 28 l/s. The water temperature was measured in December 2020 at 16°C which is warmer than average UK ground water for that time of year.

5.2.2 Proposed solution

It is proposed that this pumped ground water could be used as a source of heat for a nearby consumer, such as the Natural History Museum. By supplying the water, via a heat exchanger, to a heat pump, the otherwise wasted energy could be used as a heat source for the LTHW network.

The proposed solution is to install a self-cleaning drum filter within the TfL pump room to clean the water. This clean water would go to a small buffer tank and then be pumped to the NHM Energy Centre where, having passed through a plate heat exchanger, it will be discharged to sewer. The plant space required is shown in Figure 10. The TfL source combined with a dual-stage high-temperature heat pump could produce 1.3MW of heat at 90°C.

The ground water is pumped via two TfL owned and controlled sump pumps to the inlet of the NHM controlled pump which will boost the pressure enough to overcome the long pipe run. If there is more ground water flow than is required by the WSHP, or if it is offline, the excess (or total) TfL flow will be immediately discharged to sewer, as it does currently.

A single insulated DN150 pipe will be required to transfer the source water to the NHM Energy Centre. The pipe run from the TfL pump room will pass through the station to the ticket hall where it will enter the pedestrian tunnel beneath Exhibition Road. At an appropriate location, the route will turn left, following the tunnel nearest Museum Lane. From here it will either pipe directly into the Energy Centre or first into the adjacent staff carpark. Once in the Energy Centre, the water will pass through a plate heat exchanger

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[4] Rundle et al., TfL Energy Strategy Waste Heat – Pumped Water Heat Recovery Feasibility Study, Transport for London, 2021.

(duty/standby) transferring its heat into the secondary medium before being rejected to a sewer of at least 0.25m diameter.

It is likely that this will have to be at Exhibition Road or Queens Gate. The water could also be used as a potable supply, subject to agreement with the Environment Agency. (It should be noted that the NHM have a borehole for their water supply that uses less water annually, understood to be some 50,505m³, than this supply rejects to the sewer.)

5.2.3 Electrical requirements

The Imperial aquifer scheme requires power for the pumps to thermal storage (7.5kW), evaporator water pump (5.5kW) & water source heat pump (449kW). A single line diagram has been developed to illustrate the design intent to provide power connections to the required equipment. Indicative LV switchgear required can be seen in Figure 8.

Figure 11 illustrates the proposed room and equipment layouts including the LV switchboard and dimensions. Ancillary systems such as fire detection, lighting, containment, and small power have not been shown at this stage however these will be required.

It has been assumed that a new LV connection will be provided to a position in close proximity to the LV switchboard. Furthermore, it is assumed is that all electrical rooms will be naturally ventilated i.e., no mechanical cooling is required. Please note, the LV switchgear has been shown in a separate room to all other equipment which is to be confirmed once mechanical plantroom layouts have been progressed to a further design stage.

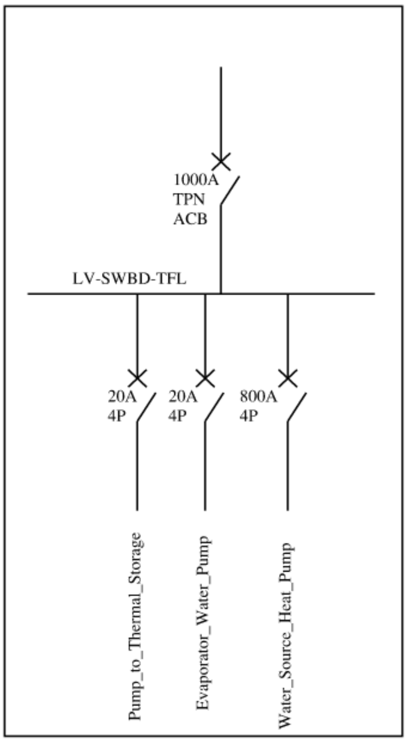


Figure 8: Single line diagram for the TfL rejected water opportunity

5.2.4 Evaluation of the TfL rejected water opportunity

This option includes the use of the rejected water pumped from the South Kensington station under the management of TfL. The water is pumped into a single DN150 pipe leading to the NHM Energy Centre through the TfL pedestrian tunnel underneath Exhibition Road. Once in the Energy Centre, the potential heat in the rejected water (which was extracted at approximately 15°C) is passed through heat exchangers, prior to feeding into WSHPs from a thermal store. The WSHPs, with high COPs extract the maximum amount of heat from the water, which feeds into the heat network from the NHM Energy Centre at 90°C. The operational figures for this option are summarised in Table 7. The following table provides an overview of the primary drawbacks and benefit associated with this solution.

Table 6: TfL rejected water heat opportunity – benefits and drawbacks

Benefits	Drawbacks
Water from TfL source appears to be of higher-than-average temperature for ground water yielding higher efficiency from the heat pumps.	Instantaneous flow rate is not known, although the source is constantly available, the flow rate at any one time will likely vary depending on weather conditions. A buffer vessel may be required at a future design stage.
Opportunity to use the water extracted, though this would need to be agreed with the Environment Agency. This water would be colder than normal tap or borehole water.	Long pipe run from source to NHM Energy Centre. Permissions for installation of the pipework and pump room equipment required.
TfL have considered this as a viable option, and planning risks are minimal, with no road blockages required for works. The proposed tunnel is TfL owned.	TfL pricing scheme for the source is not known, however they have indicated that they would charge for the facility.
	Location for drainage connection for discharging 'used' water needs to be agreed. It is not known if the NHM Energy Centre one could be used. It may need to be taken back to a main Thames Water sewer. This needs to be downstream of any potential sewer source heat extract.
	There is a risk associated with permission and project timescales.

Table 7: Summary of the TfL rejected water heat opportunity

Performance measure	
Heat available at source	Circa 1.0MW
Potential maximum heat (after WSHP)	Circa 1.4MW
Electrical input required	0.46MW
Overall System COP (estimated)	3.0

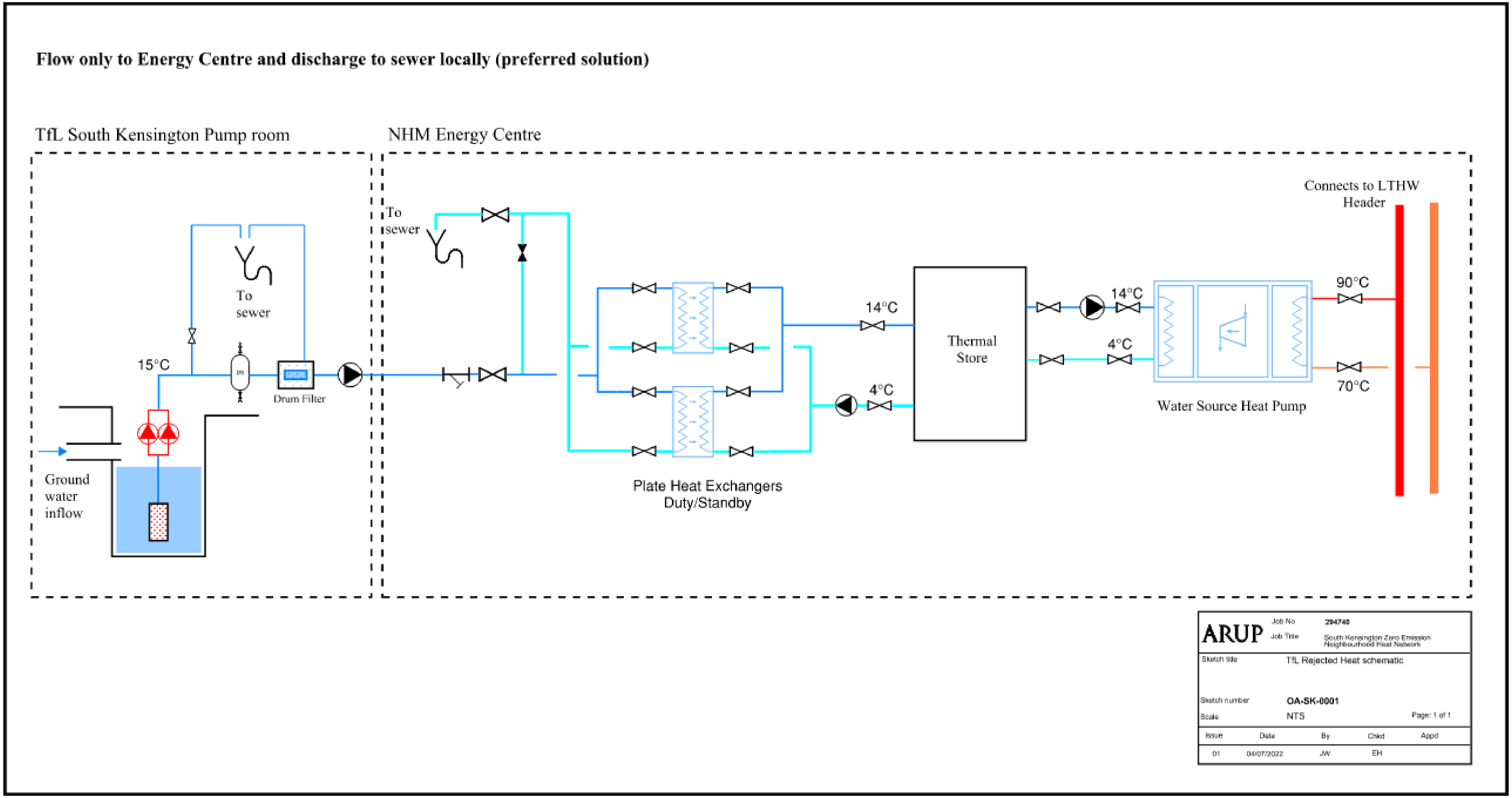


Figure 9: Schematic showing the operation of the TfL rejected water opportunity,

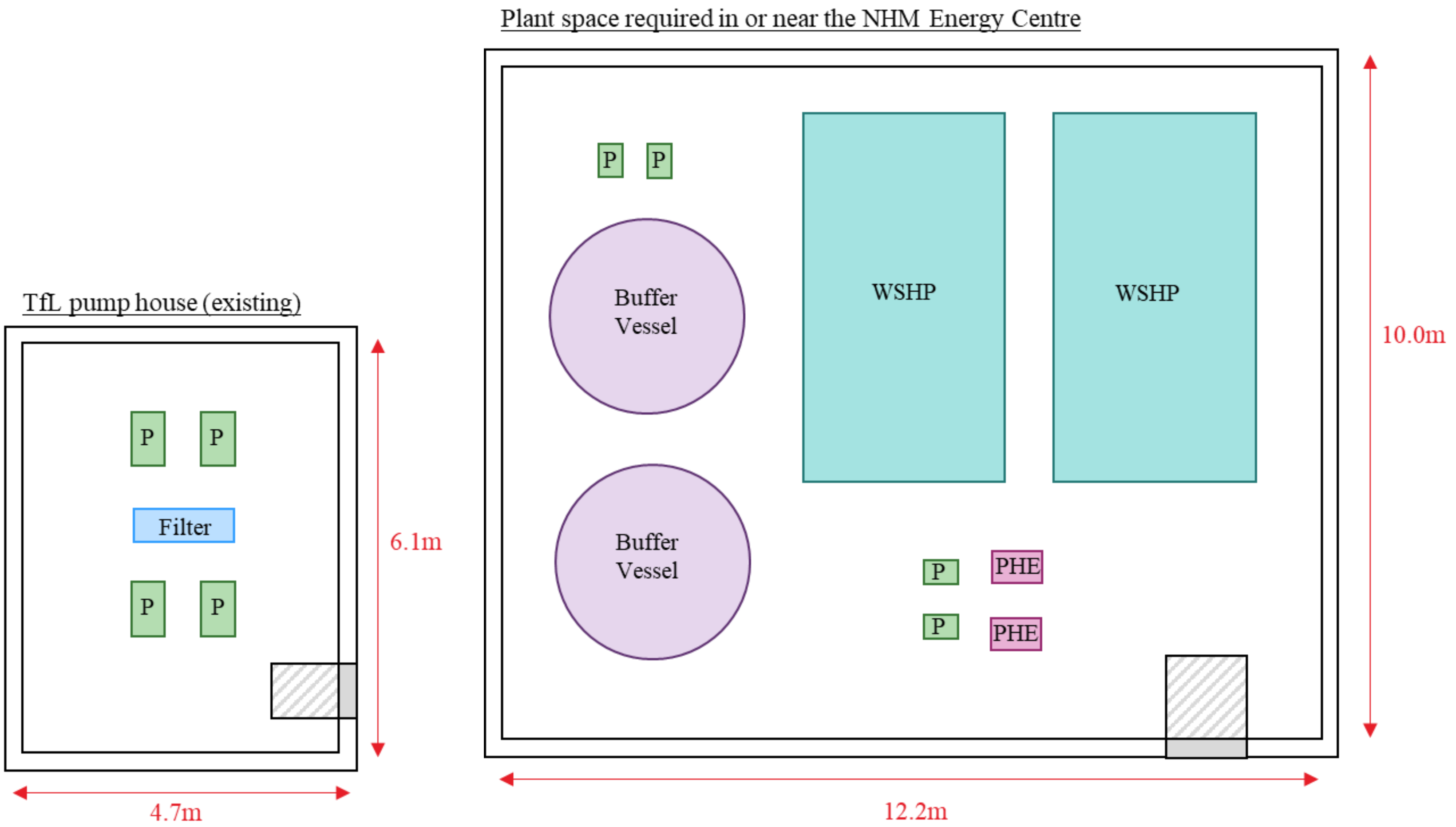


Figure 10: Mechanical space requirements for the TfL rejected water opportunity

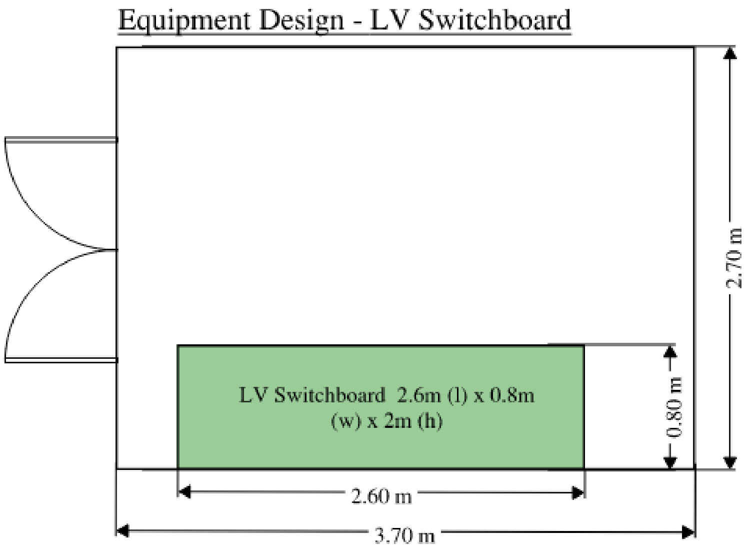
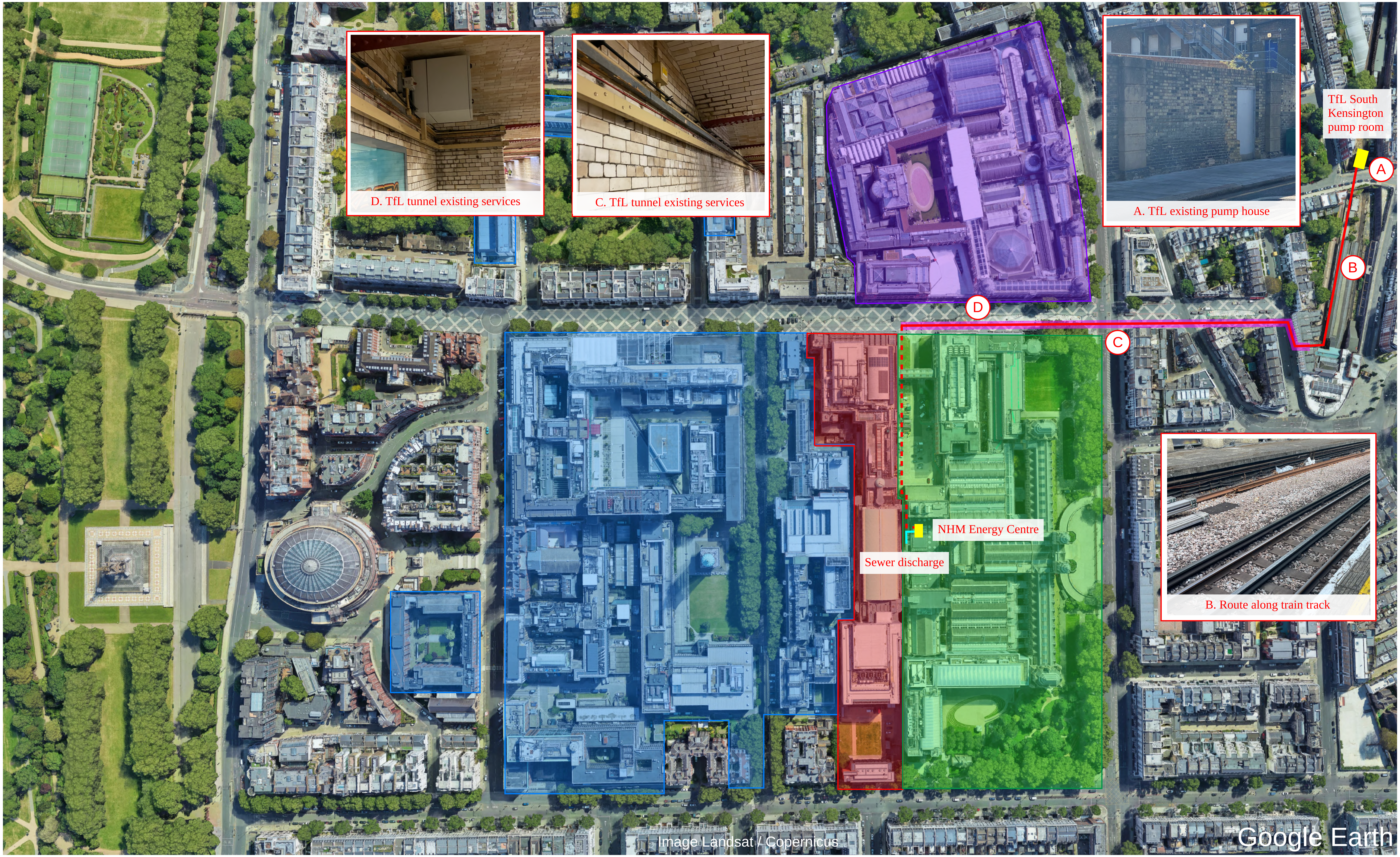


Figure 11: Electrical space requirements for the TfL rejected water opportunity



Legend	
Victoria and Albert museum	Pipework (flow)
Natural History museum	Pipework (return)
Science museum	Buried pipework (flow)
Imperial College London	Buried pipework (return)
	Pipework in tunnel

ARUP	Job No	294740		
	Job Title	South Kensington Zero Emission Neighbourhood Heat Network		
Sketch title	TfL groundwater			
Sketch number	OA-SK-0005			
Scale	NTS		Page: 1 of 1	
Issue	Date	By	Chkd	Appd
01	04/07/2022	AdT	EH	

Figure 12: Layout of TfL rejected water heat opportunity

5.3 Serpentine – Royal Parks

5.3.1 Opportunity background

The Serpentine and Long Water Lake (shown in Figure 13) is a 16.2-hectare man-made recreational lake in Hyde Park, London which opened circa 1730[5]. The lake is currently supplied by three boreholes drilled into the Upper Chalk. The first borehole is located at the Italian Gardens, the second at the Princess Diana Memorial and the third, drilled in 2012 to a depth of 132m (433 ft), is within 50m (160 ft) of the memorial. The boreholes supply approximately 660,000m^3/year (this flow is not constant and varies throughout the year, it is typically used for algae control). The maximum depth is estimated at 5.3m, while the average depth is 4.5m. The water temperature typically follows the air temperature, albeit at a lag, and not to the same extremes. The annual range fluctuates between 2.3°C and 25.3°C.[6]

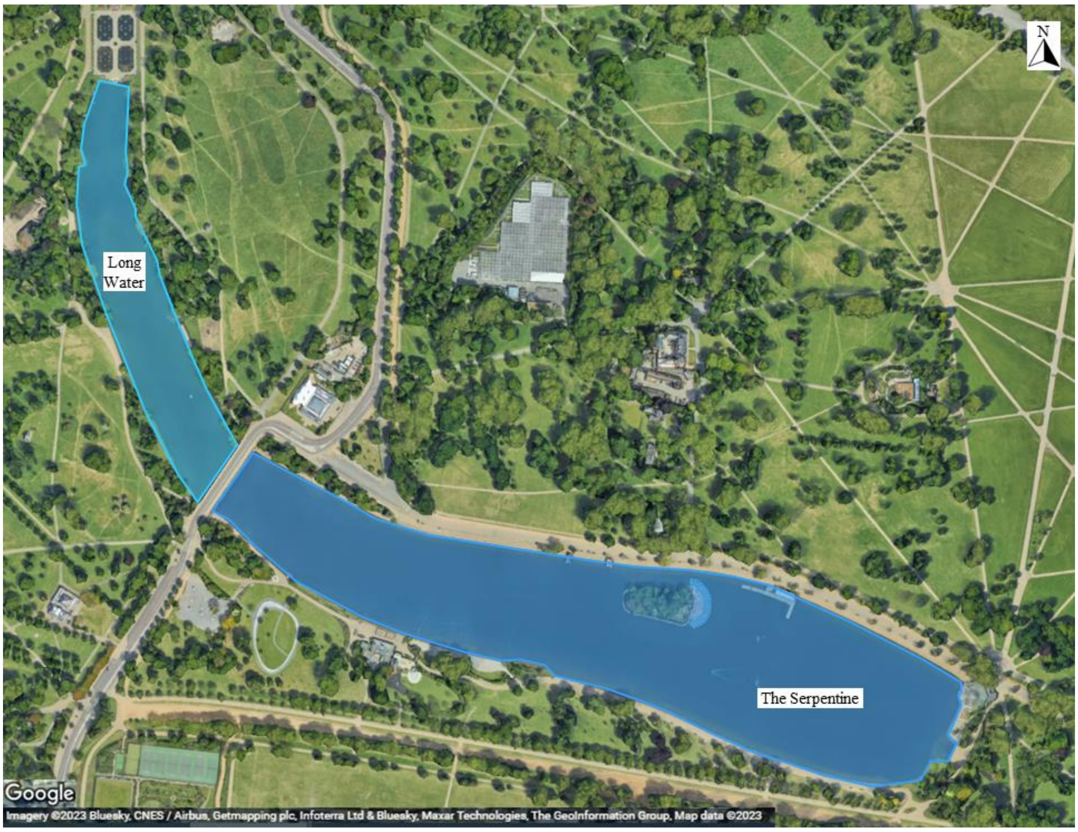


Figure 13: Aerial view of the Serpentine and Long Water in Hyde Park, London

5.3.2 Proposed solution

A surface water closed-loop ground source heat pump system is an efficient method of harnessing the natural heat to provide heating for buildings. This system utilizes a closed loop of pipes and heat exchangers that are submerged into the lake. The pipes and the heat exchangers (which look similar to domestic radiators) are made of durable, corrosion-resistant materials such as HDPE, stainless steel, titanium and are designed to circulate a heat transfer fluid. The term "surface water" in this solution means a body of water above ground, instead of in a below ground aquifer.

The Serpentine heat pump solution involves circulating a heat transfer fluid (water) through pipes and heat exchangers submerged in the water. As the fluid passes through the heat exchangers, it absorbs heat energy from the water. To implement this solution, flow and return headers need to be installed along the banks on

[5] The Royal Parks webpage, Retrieved from: https://www.royalparks.org.uk/parks/hyde-park/about-hyde-park/landscape-history , [Accessed 7th of July 2023].

[6] Meteor ESNET data provided by Royal Parks for 2022/2023.

the south side of the lake, connecting the heat exchangers to the pump house. The required plant space is depicted in Figure 16. Subsequently, the fluid will be pumped to the heat pump system located in the Energy Centre at Imperial College London. The main pipework, which will be approximately 2.5km long, can be installed along any location on the south banks subject to the complexity of underground utilities. The layout of this solution can be referred to Figure 18. The heat pump system utilizes a compressor and refrigerant to further increase the temperature of the captured heat, making it suitable for space heating or producing domestic hot water.

One of the key advantages of a surface water closed loop ground source heat pump system is its high efficiency. Water temperatures in the deeper parts of the lake have a temperature higher than the air on cold days, which allows the system to consistently extract heat energy. This stability improves the overall performance of the heat pump and reduces energy consumption, resulting in lower operating costs and carbon emissions.

It is important to note that the installation of a surface water closed loop ground source heat pump system requires careful consideration of factors such as site conditions, water quality and approval from Royal Parks and the Environment Agency. Detailed design, environmental assessment and submission are required in the next design stages.

5.3.3 Electrical requirements

The Serpentine proposal requires power for the secondary water pump (15kW), primary water pump to energy centre (15kW), chilled water pump (15kW), water source heat pump (608kW) & condenser water pump (15kW). A single line diagram has been developed to illustrate the design intent to provide power connections for the required equipment. Both LV and MV infrastructure will be required as illustrated in Figure 14.

Figure 17 shows the equipment layout which includes a layout of the MV room housing the MV switchgear, battery tripping unit and remote switching panel. A layout of the transformer room, including dimension, can be seen as well as the LV room layout which includes an LV switchboard and a battery tripping unit. The fire detection, lighting, containment, and small power within the room has not been shown in the layout but will be required.

It has been assumed that a new MV connection will be provided for this option due to the large load required. Discussions with UKPN are ongoing to determine how and from where this supply will be fed.

Furthermore, it is assumed is that all electrical rooms will be naturally ventilated i.e., no mechanical cooling is required. Please note, the LV switchgear has been shown in a separate room to all other equipment which is to be confirmed once mechanical plantroom layouts have been finalised.

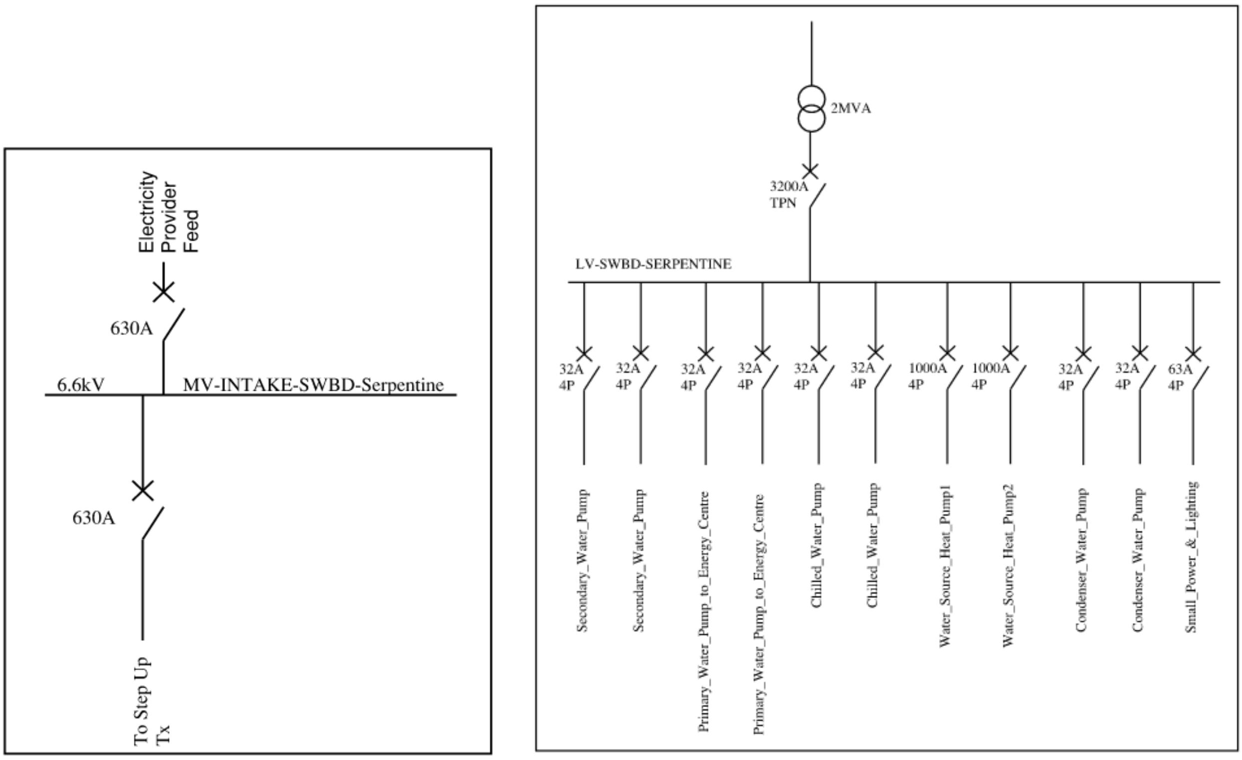


Figure 14: Single line diagram for the Serpentine opportunity

5.3.4 Evaluation of the Serpentine opportunity

This option utilises the heat contained within the Serpentine Lake body of water, through the use of lake source heat exchangers. This heat is extracted to a proposed pump house in Hyde Park where it passes through another heat exchanger before being pumped to the Imperial Energy Centre. The pipework will run underground adjacent to West carriage Road, which leads onto Exhibition Road. From here it will enter the existing Imperial service tunnel underneath Exhibition Road.

From the Imperial Energy Centre, the heat flow will be passed through WSHPs. The WSHPs, with very high COPs extract the maximum amount of heat from the water, which feeds into the heat network from the Imperial Energy Centre at 90°C. The operational figures for this option are summarised in Table 9. The following table provides an overview of the primary drawbacks and benefit associated with this solution.

Table 8: Serpentine Lake heat opportunity – drawbacks and benefits

Benefits	Drawbacks
The closed-loop heat exchanger allows for efficient heat transfer, enabling the heat pump to maintain consistent performance and high energy efficiency.	The effect of reducing the water temperature in the lake will require Environment Agency approvals, especially as the lake has wildlife living in it.
Closed-loop systems have minimal impact, other than temperature, on the water source itself since no water is directly withdrawn or discharged. This makes them environmentally friendly and reduces the potential for ecological disturbances to aquatic ecosystems.	Permits and approval from Royal Parks, the planning department of Westminster City Council, and public consultation is required to confirm the minimum acceptable impact to ecosystems and public, including boaters and swimmers.
Since no water is directly pumped, the risk of fouling or scaling in the heat exchanger is lower. Maintenance primarily involves periodic checks on the heat pump components and the closed-loop circulation system.	New pumping and heat exchanger station will be required in Hyde Park next to the water source.
	High pumping losses through the very large lake source array and heat network between the lake and Imperial.

Table 9: Summary of the Serpentine Lake heat opportunity

Performance measure	
Heat available at source	Circa 3.0MW
Potential maximum heat (after WSHP)	Circa 4.5MW
Electrical input required	1.7MW
Overall System COP (estimated)	2.7

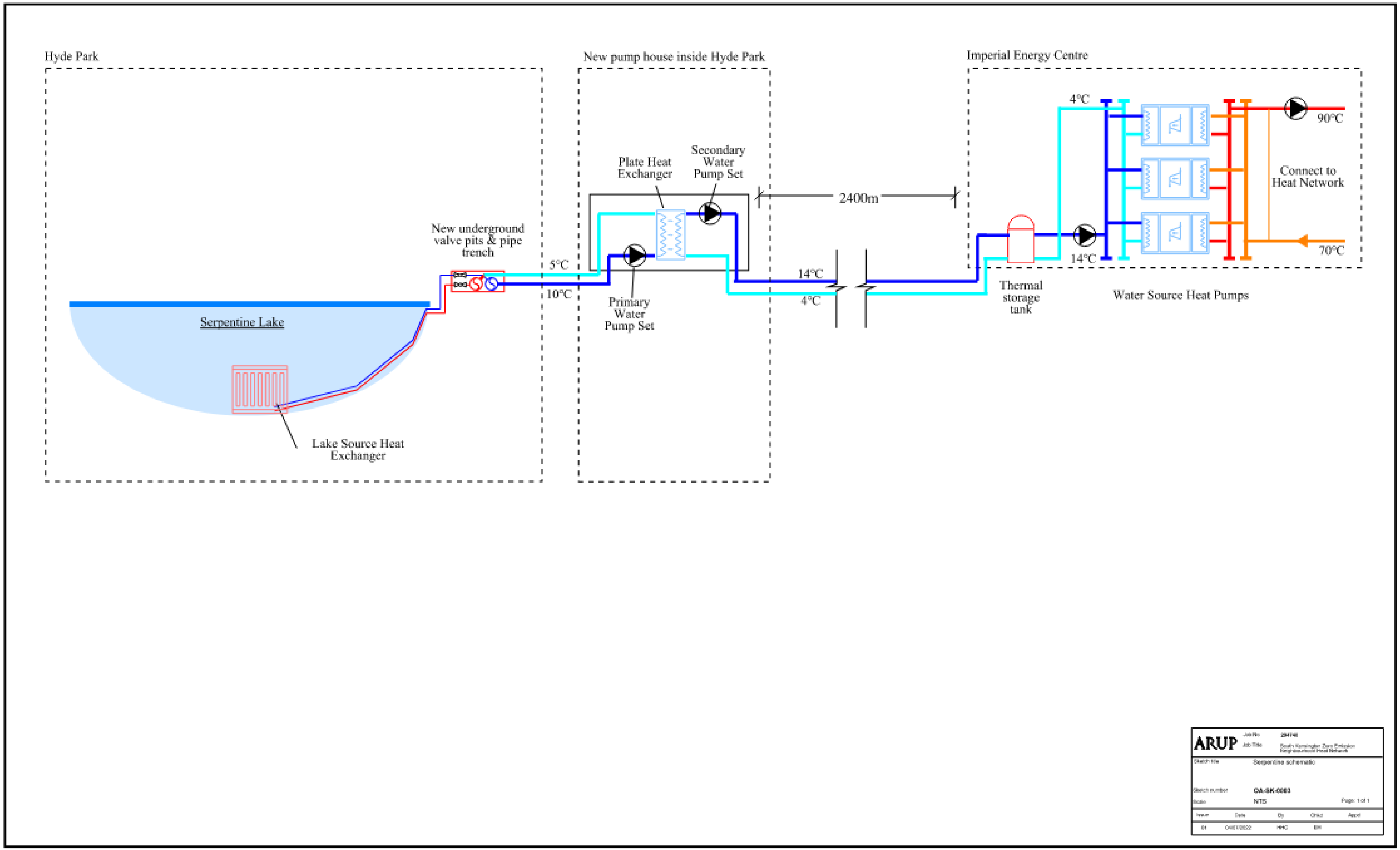


Figure 15: Schematic showing the operation of the Serpentine opportunity

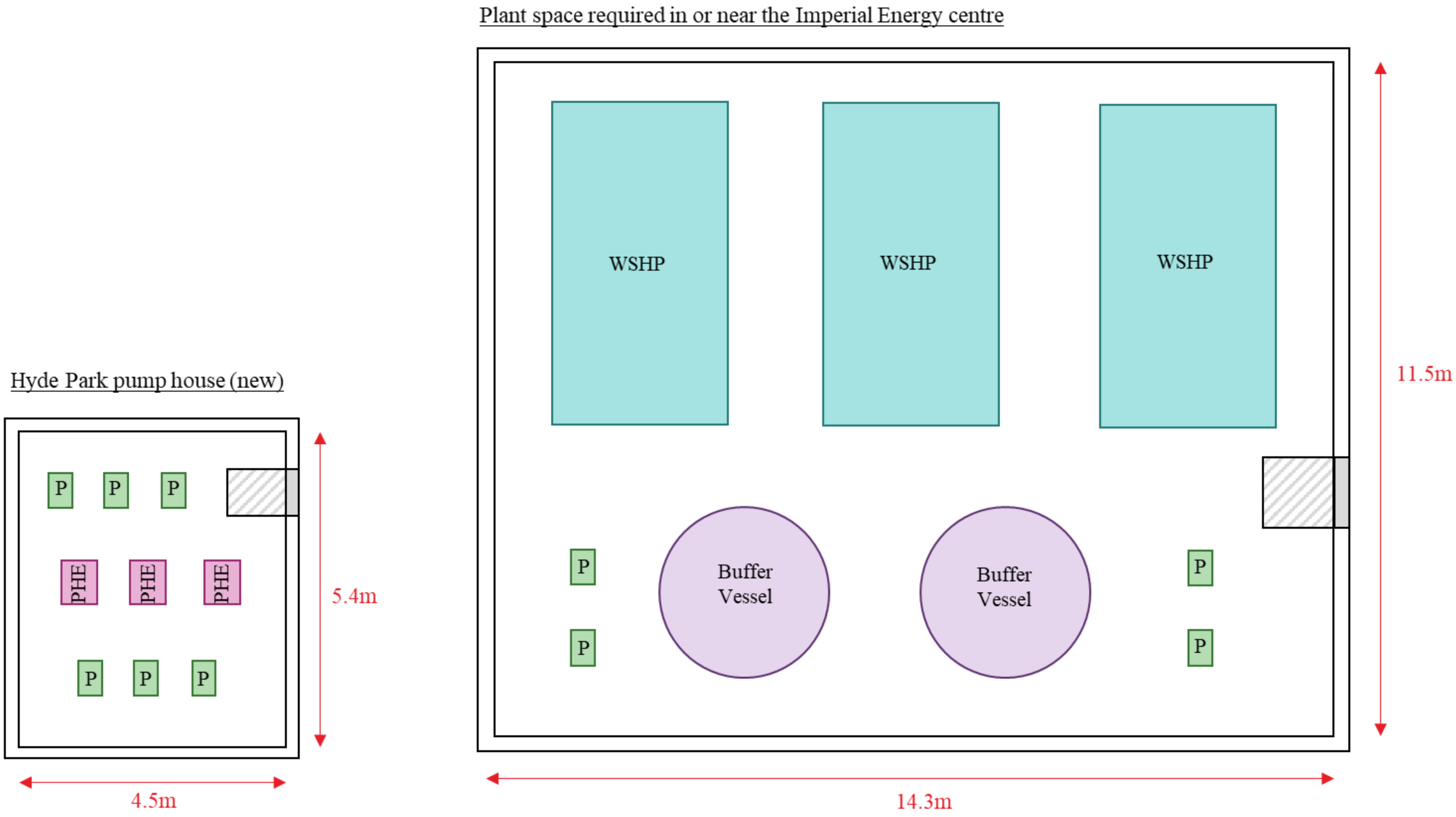


Figure 16: Mechanical space requirements for the Serpentine opportunity

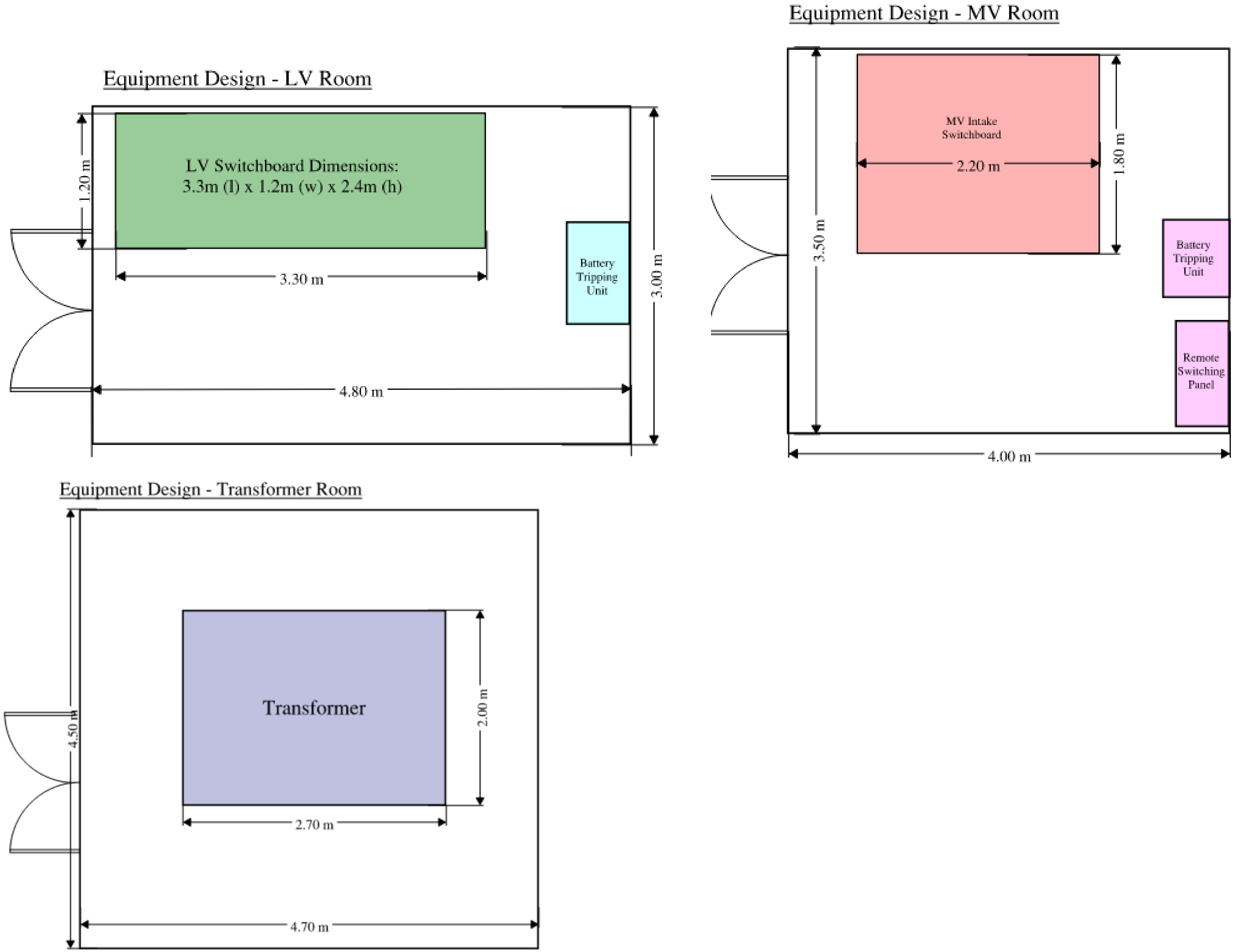
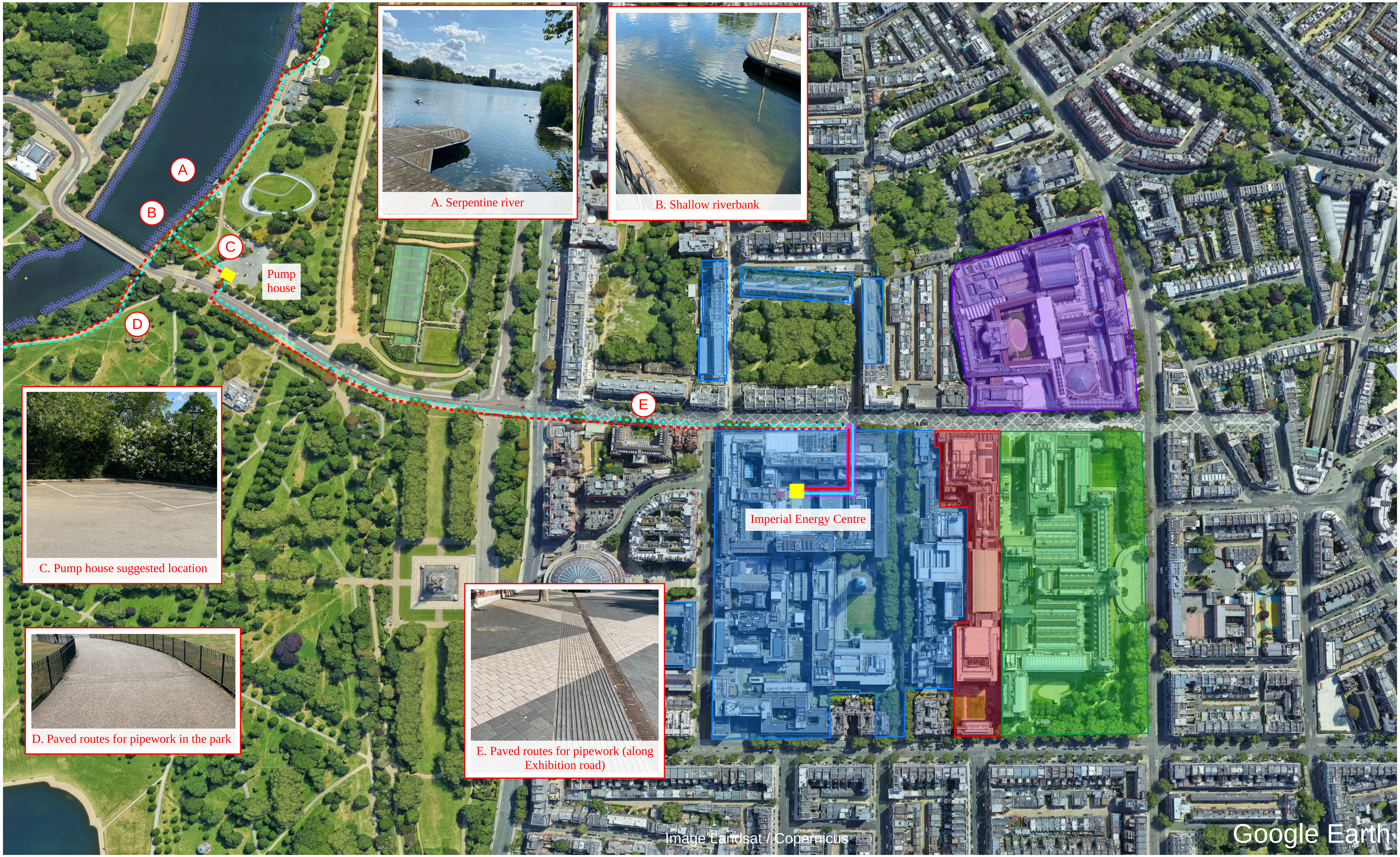


Figure 17: Electrical space requirements for the Serpentine opportunity



Victoria and Albert museum	Pipework (flow)
Natural History museum	Pipework (return)
Science museum	Buried pipework (flow)
Imperial College London	Buried pipework (return)
	Pipework in tunnel

ARUP	Job No	294740		
	Job Title	South Kensington Zero Emission Neighbourhood Heat Network		
Sketch title	Serpentine Lake Water Source Heat pump			
Sketch number	OA-SK-0008			
Scale	NTS	Page: 1 of 1		
Issue	Date	By	Chkd	Appd
01	04/07/2022	AdT	EH	

Figure 18: Layout of potential Serpentine heat opportunity

5.4 Sewer source – Thames Water

5.4.1 Opportunity background

The sewer network is a consistent source of heat year-round. Sewers in built up areas are full of flowing fluid at a temperature reliably warmer than the ambient air. The fluid is a mixture of warm discharge (from human washing (showers/baths), dishwashers, washing machines, and multiple other sources) and towns mains water. The fluid is sheltered from the atmospheric conditions and can be warmed further by the surrounding earth as it passes through the network.

5.4.2 Proposed solution

Wastewater thermal energy recovery is a system designed to retrieve thermal energy from wastewater in a sewer network. These energy systems, normally linked to a heat pump (as is the case in this proposal), can be used as a source of low carbon and low temperature thermal energy to provide heating to buildings. Heat from sewage is passed to another medium, such as clean water or glycol through a heat exchanger. This heated medium is then received by the evaporator side of a water source heat pump. This heat is pumped to the condenser side of the heat pump and used to heat the return low temperature hot water (LTHW) used for building heating and cooling. The cooled sewage is returned to the sewer. This technology has been pioneered in Germany and used on tens of projects in Europe.

There are currently two proprietary methods of extracting this heat for useful means: an online and offline system. The principle remains the same in each. An online system situates the heat exchanger in line with the effluent, keeping it inside the pipe. The heat exchanger can be either a flat plate in the bottom of the sewer or a coil wrapped around the outside of the sewer. These are simple to operate with little impact on the flow but are a less popular commercial option as they are less effective at extracting heat and require extremely long lengths of heat exchangers. The offline system involves separating a portion of the flow from the sewer and pumping it to a separate chamber where the heat exchanger and heat pump are located. The majority of grit, rags and solids are removed upstream of the heat exchanger, to prevent fouling and then returned to the sewer. Both systems utilise a solids separator, heat exchanger and heat pump although the type varies between different products. This is the considered option for this report.

Online system – Uhrig

German company Uhrig has been investigated as a possible solution for sewer waste heat recovery. The available linear (per metre) heat output is highly dependent on the flow rate and the size of the sewer however, a rule of thumb is 0.5m to 2m per kilowatt. This suggests that by taking a figure towards the better performing end of this range (1m per kW), approximately 100 metres of sewer pipe is needed to serve as a 100kW source. This yield is not practical for the South Kensington DHN and because of the age and construction of London sewers, this solution has not been further considered.

Offline system – Huber with Landmark (UK)

German company Huber, who’s agent in the UK is Landmark, offer a different solution. Their solution withdraws a proportion of the sewer flow, filters out solids, and then passes it through a heat exchanger to impart heat on the ‘clean side’ which is then the source water for the heat pump. The water exiting the heat exchanger on the ‘dirty side’ is then returned to the sewer (crucially downstream of the withdraw point) along with any extracted solids. Typically, the proportion of the sewer flow extracted is between 10 and 50%. To represent the upper limit of what could be obtained for this study, 50% of the flow has been assumed. This system relies on a ‘wet well’ being dug adjacent to the sewer (in the general vicinity) to house the filter system, solid extraction system and pumps. The heat exchanger and heat pump can then be located remotely.

Connecting the heat exchanger with the wet well in the case of the Natural History Museum will require digging a trench for the pipework through the Wildlife Garden to the Energy Centre. The layout of this solution is shown in Figure 23 and the plant space required is shown in Figure 21. It is estimated that the wet well would have a diameter of 2m and could be effectively level with the surrounding ground however it would need to remain visible and accessible for maintenance.

5.4.3 Electrical requirements

The sewer source proposal requires power for the sewer extract screw lift motor (9.3kW), pumps to heat exchanger (18kW), primary water pump (20kW) & water source heat pump (1,006kW). A single line diagram has been developed to illustrate the design intent to provide power connections for the required equipment. Both LV and MV infrastructure will be required as illustrated in Figure 19.

Figure 22 shows the equipment layout which includes a layout of the MV room housing the MV switchgear, battery tripping unit and remote switching panel. A layout of the transformer room, including dimensions, can be seen as well as the LV room layout which includes an LV switchboard, a distribution board to feed the small power and lighting within the three rooms and a battery tripping unit. This can all be seen in Figure. Ancillary systems such as fire detection, lighting, containment, and small power have not been shown at this stage however these will be required. It has been assumed that all three rooms will be in close proximity to one another.

It has been assumed that a new MV connection will be provided for this option due to the large load required. Discussions with UKPN are ongoing to determine how this supply will be fed and where it will be fed from.

Furthermore, it is assumed is that all electrical rooms will be naturally ventilated i.e., no mechanical cooling is required. Please note, the LV switchgear has been shown in a separate room to all other equipment which is to be confirmed once mechanical plantroom layouts have been finalised.

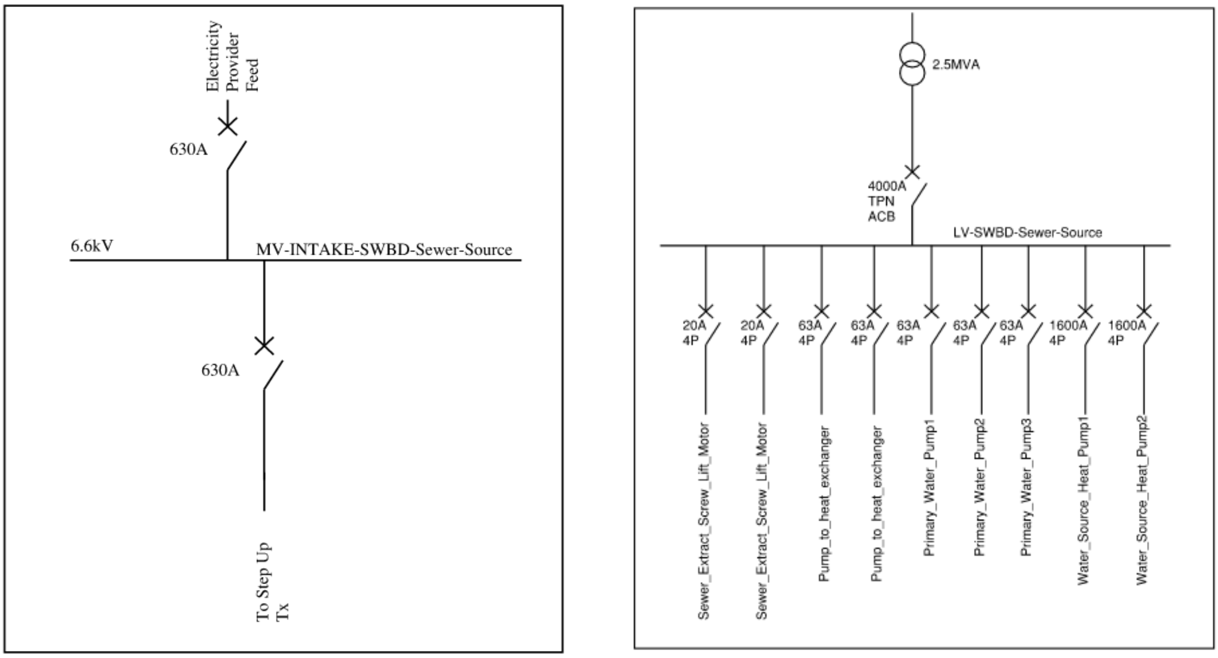


Figure 19: Single line diagram for the Sewer source opportunity

5.4.4 Evaluation of the Sewer source opportunity

Heat is extracted from the main sewer pipe on the corner of Cromwell Road and Queen's Gate, through an underground pumping well in the NHM wildlife Garden. This extraction is done with a Sewer Extract Screw Lift Motor and pumps. The flow leads to the NHM Energy Centre through an underground pipe along the path in the Wildlife Garden and then along Museum Lane.

Inside of the NHM Energy Centre, the heat flow will be passed through WSHPs. The WSHPs extract the heat from the water, which feeds into the heat network. The operational figures for this option are summarised in Table 11. The following table provides an overview of the primary drawbacks and benefit associated with this solution.

Table 10: Sewer Source heat opportunity – drawbacks and benefits

Benefits	Drawbacks
Consistent warm source of heat.	Ground works and permanent manhole in NHM Wildlife Garden, which will require careful planning to ensure no damage to local ecosystem.
Due to high flow rates on a sewer main, there is a significant amount of heat that can be extracted.	Significant digging through Wildlife Garden to provide trench for pipework to Energy Centre.
Potential for significant heat provision and carbon reductions.	Maintenance on filtration systems and potential blockages.
	Large plant room space required to utilise heat. This is not feasible in the current NHM Energy Centre. Refer to plant room layouts. Additional or alternative space will be required.
	Commercial and technical arrangements to be agreed with Thames Water may impact viability and timelines for implementation.
	Odour control may require consideration depending on pumping well arrangement.
	There is currently no proposal from Thames Water for the cost of utilising their energy nor has it been confirmed that the sewer in question (LL2) would be acceptable to tap into.
	There is a risk that the sewer source will be utilised upstream of the proposed connection point by another customer thereby diluting the heat source for NHM use ultimately reducing the heating output potential.

Table 11:Summary of the Sewer Source heat opportunity

Performance measure	
Heat available at source	Circa 2.1 (up to 10.3MW subject to further design)
Potential maximum heat (after WSHP)	Circa 3.1 (up to 15.3MW subject to further design)
Electrical input required	1.1 (up to 5.5MW for the 15.3MW case)
Overall System COP (estimated)	2.8

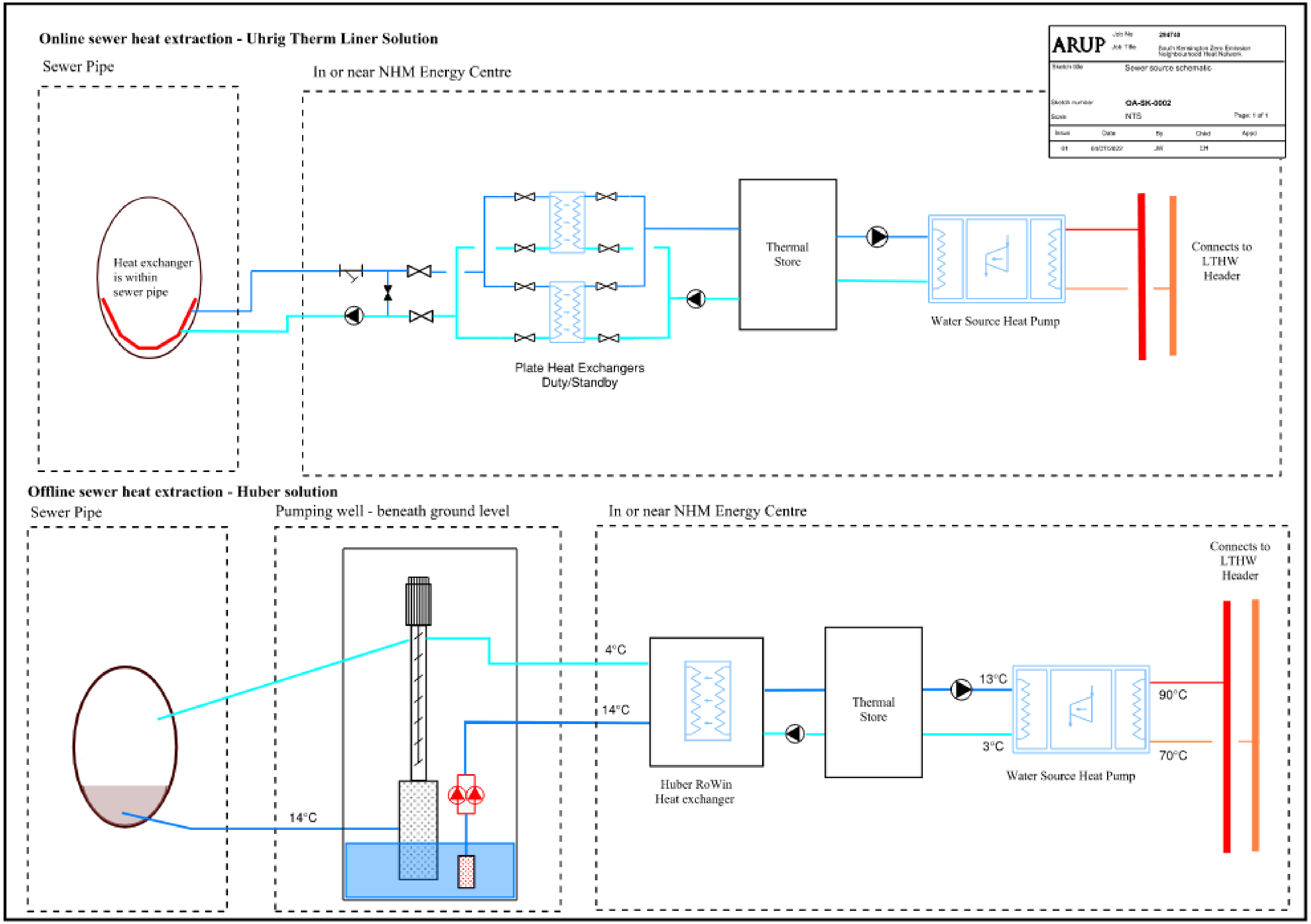


Figure 20: Schematic showing the operation of the Sewer source opportunity

Plant space required in or near the NHM Energy Centre

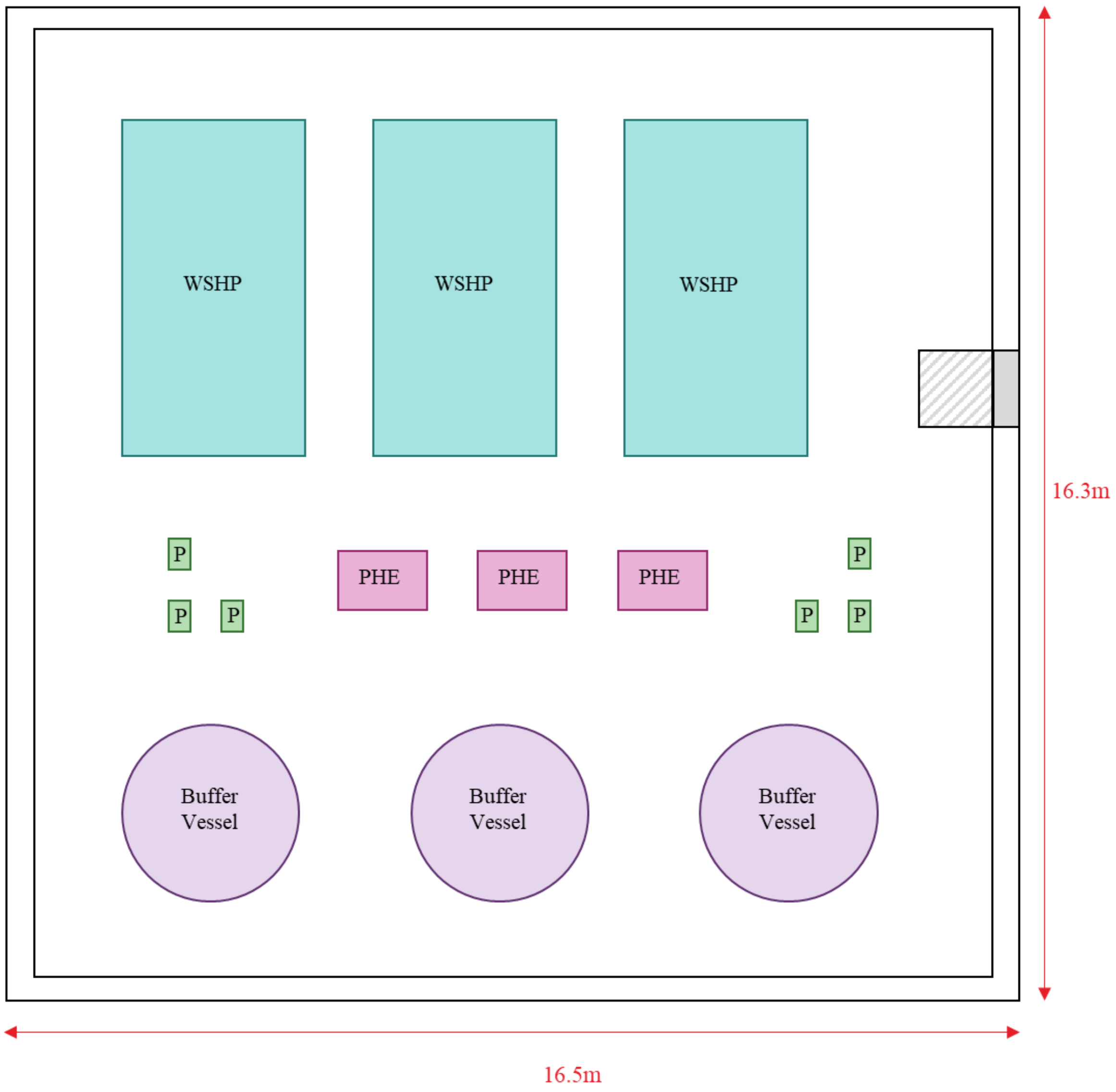


Figure 21: Mechanical space requirements for the Sewer source opportunity

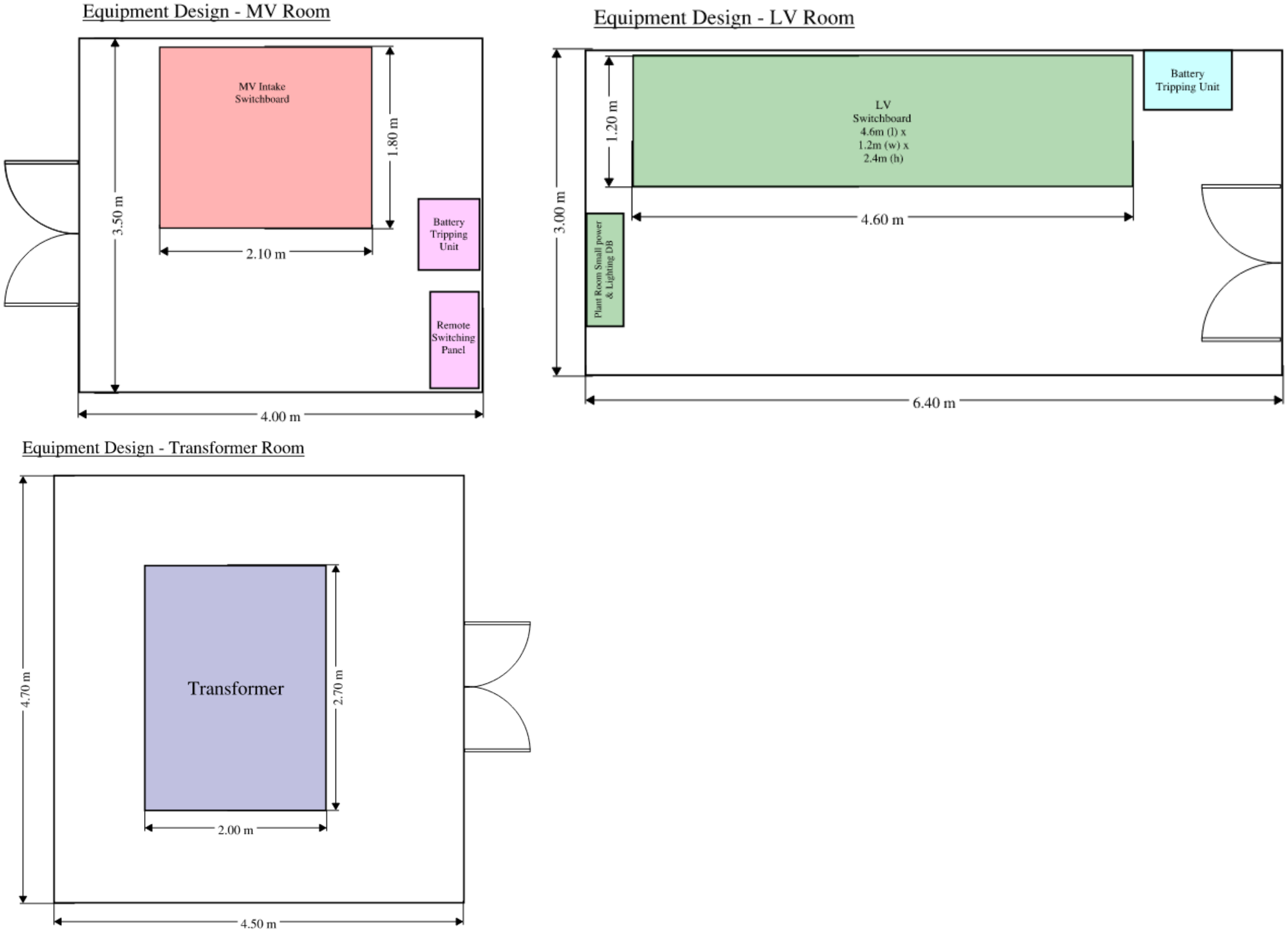
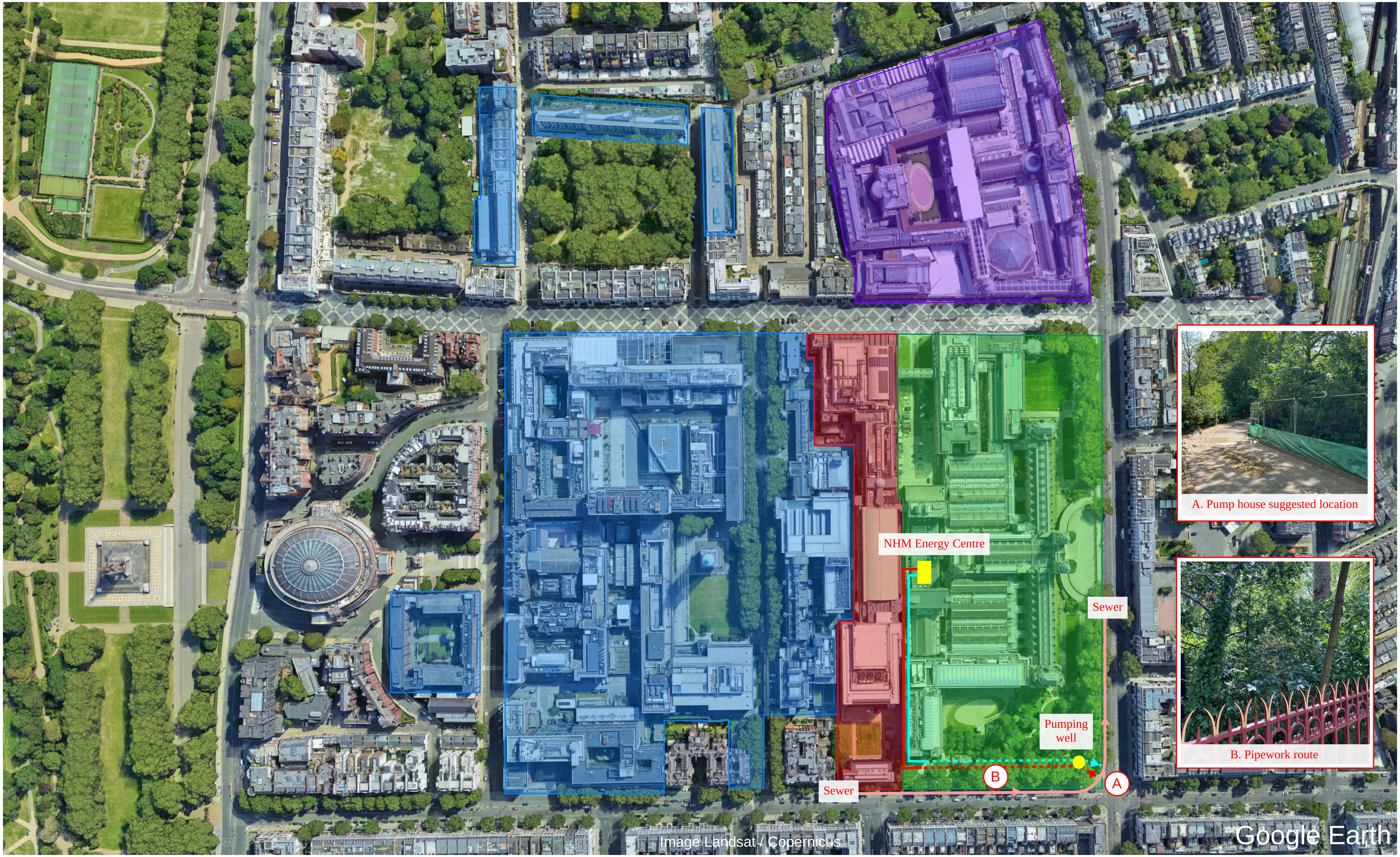


Figure 22: Electrical space requirements for the Sewer source opportunity



Legend	
Victoria and Albert museum	Pipework (flow)
Natural History museum	Pipework (return)
Science museum	Buried pipework (flow)
Imperial College London	Buried pipework (return)
	Pipework in tunnel

ARUP	Job No	294740		
	Job Title	South Kensington Zero Emission Neighbourhood Heat Network		
Sketch title	Sewer source heat			
Sketch number	OA-SK-0006			
Scale	NTS			Page: 1 of 1
Issue	Date	By	Chkd	Appd
01	04/07/2022	AdT	EH	

Figure 23: Layout of potential Sewer source heat opportunity

5.5 Imperial aquifer

5.5.1 Opportunity background

It is possible to utilise ground-source heat if there is an aquifer under the site. This involves digging a borehole into the ground to take out water, removing the heat through a heat pump, then reinjecting the water back into the ground.

It is also possible, where connected to a cooling system as well as a heating system, to use the aquifer as a thermal store, adding heat from space cooling in summer and harvesting it in winter for space heating. This system is called an Aquifer Thermal Energy Storage (ATES).

The pumping and reinjection wellfields must be spaced far enough apart to minimise thermal interference and short-circuiting. Open loop systems have flexibility, due to their dynamic nature, and can be run out of balance.

Imperial drilled a test borehole on Prince's Gardens in early 2015, to analyse the possibility of undertaking this, and the NHM already have a borehole used for water extraction. The report stated that a minimum flow rate of $50m^3$/hr (14 l/s) would be achievable. The results indicated that the geology in the area is suitable for either aquifer sourced heat or ATES. By analysing the data in the report, it was found that 30 l/s flow can be achieved with the addition of boreholes in Prince's Gardens.

It is recommended that an open loop test be undertaken going forward with the project, as well as a new pumping test with a higher capacity pump to fully test the well capacity.

Extracting water at one point and reinjecting it as far as possible from the extraction point, in the same aquifer, will allow for the maximum amount of heat extraction.

5.5.2 Proposed solution

The required spacing of abstraction and reinjection wells varies based on a range of site-specific factors; however, a typical rule of thumb is a spacing of around 250m between abstraction and reinjection wells. The layout of this solution is shown in Figure 28.

Characterisation of groundwater quality is required to properly specify equipment materials and to ensure abstracted groundwater is suitable for reinjection back to the aquifer (as contaminated groundwater should not be returned to its source). System considerations include:

- Aquifer yield needs to be proven during pump testing
- Operational costs include pump replacements and well workovers which occur roughly once every 5 to 10 years
- Can be designed to manage imbalanced loads
- Require a large enough site to separate the abstraction and reinjection wellfields. However, the footprint of the wells themselves is small
- Require an abstraction licence from the Environment Agency. This would be non-consumptive as the groundwater is returned to abstracted aquifer

The process begins with the extraction of water from borehole located in Prince's Garden and pumping it into the heat pump system. The aquifer, which maintains a relatively constant temperature throughout the year, serves as a stable and reliable heat source. To implement the aquifer solution, a small GRP building with dimensions of approximately 4.5m width, 3.5m length, and 3m height would be installed in Prince's Gardens. In order to connect the extraction well and reinjection wells, 150mm insulated pipes in a pipe trench would be laid underground. This trench would run from Prince's Garden to Imperial College via Watt's Way and across Exhibition Road. This piping system ensures the proper flow of water between the wells and the heat pump system.

The heat pump then extracts the heat from the water using a heat exchanger, which transfers the thermal energy to a refrigerant within the system. The water source heat pump will be installed inside Energy Centre of Imperial. The plant space required is shown in Figure 26. In the condenser side of the heat pump, it will increase the temperature of the water for space heating and domestic hot water use. In the evaporator side of the heat pump, it will extract the heat from the abstracted ground water. The cooled groundwater is then discharged back to the aquifer via a separate reinjection well. This ensures that the water supply remains constant, and that the system maintains a continuous heat source.

Maintaining an aquifer open loop heat pump system involves regular inspections, water quality monitoring, pump and piping maintenance, heat pump maintenance, system control checks, and occasional system flushing. Inspect components for damage or leaks, monitor water quality, clean and flush the piping system, and follow manufacturer guidelines for heat pumps and water pumps maintenance.

The open-looped aquifer heat pump system offers an efficient and renewable heating solution, as the groundwater provides a relatively stable heat source throughout the year. It is particularly suitable for locations where an abundant supply of clean groundwater is readily available, making it a sustainable alternative to traditional heating systems that rely on fossil fuels. Detailed thermal modelling is required to review the location of the extraction and injection wells/ boreholes.

5.5.3 Electrical requirements

The Imperial aquifer scheme requires power for the borehole extraction pump (90kW), primary water pump to energy centre (7.5kW) chilled water pumps (10kW), water source heat pumps (298kW) & condenser water pumps (11kW). A single line diagram has been developed to illustrate the design intent to provide power connections to the required equipment. Indicative LV switchgear required can be seen in Figure 24.

Figure 27 illustrates the proposed room and equipment layouts including the LV switchboard and dimensions. Ancillary systems such as fire detection, lighting, containment and small power have not been shown at this stage however these will be required.

It has been assumed that a new LV connection will be provided to a position in close proximity to the LV switchboard. Furthermore, it is assumed is that all electrical rooms will be naturally ventilated i.e., no mechanical cooling is required. Please note, the LV switchgear has been shown in a separate room to all other equipment which is to be confirmed once mechanical plantroom layouts have been finalised.

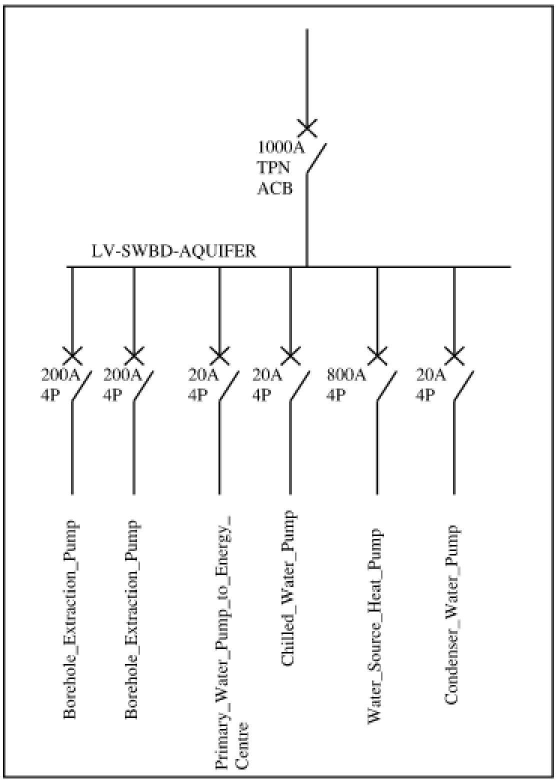


Figure 24: Single line diagram for the Imperial aquifer opportunity

5.5.4 Evaluation of the Imperial aquifer opportunity

The aquifer located in Imperial's Prince's Gardens will be used to extract heat through a borehole to a new pumping house located in the same garden. In this pump house, the extracted water passes through a filter and heat exchanger. This flows in an underground pipe to the existing Imperial service tunnel underneath Southside which leads to the Imperial energy Centre across Exhibition Road.

From the Imperial Energy Centre, the heat flow will be passed through WSHPs. The WSHPs, with high COPs extract the maximum amount of heat from the water, which feeds into the heat network from the Imperial Energy Centre at 90°C. The operational figures for this option are summarised in Table 13. The following table provides an overview of the primary drawbacks and benefit associated with this solution.

Table 12: Imperial Aquifer heat opportunity – drawbacks and benefits

Benefits	Drawbacks
Open-Loop Groundwater Source Heat Pumps can achieve higher levels of energy efficiency in comparison with a traditional air source heat pump.	Open-loop systems require permits and compliance with local regulations, such as obtaining permits for drilling wells and adhering to water usage restrictions.
An aquifer is a renewable energy source. It remains at a relatively constant temperature throughout the year, providing a stable heat source for the heat pump system.	Open-loop systems require regular maintenance and monitoring. The system's components, including the groundwater supply well, may require periodic cleaning, inspections, and repairs. These maintenance activities can add to the overall cost and effort involved in operating the system.
An aquifer open-loop heat pump system has minimal environmental issue since there is no impact on the wildlife and surrounding ecosystems. However, this needs to be investigated to ensure there are no sensitive surface water bodies, and associated aquatic environments, in continuity with the groundwater – this is considered unlikely for the confined London Chalk beneath the site.	A new pumping and heat exchanger station will be required inside Prince's Garden. Pipe routing shall be further confirmed by reviewing existing utilities underground in Prince's Garden.
	Groundwater flow rates need proving and high flow rates are not guaranteed. Poorly designed systems may thermally interfere with each other reducing system performance.
	Groundwater mounding around reinjection wells can lead to surface flooding – this is considered low risk given the confined and deep nature of the chalk aquifer.

Table 13: Summary of the Imperial Aquifer heat opportunity

Performance measure	
Heat available at source	Circa 0.6MW (up to 4MW subject to further design and testing using boreholes across the site instead of just on Prince's Gardens)
Potential maximum heat (after WSHP)	Circa 0.9MW
Electrical input required	0.4MW
Overall System COP (estimated)	2.2 (a combined cooling and heating aquifer is substantially higher but relies on a sitewide cooling system which at present is only installed at one site, NHM)

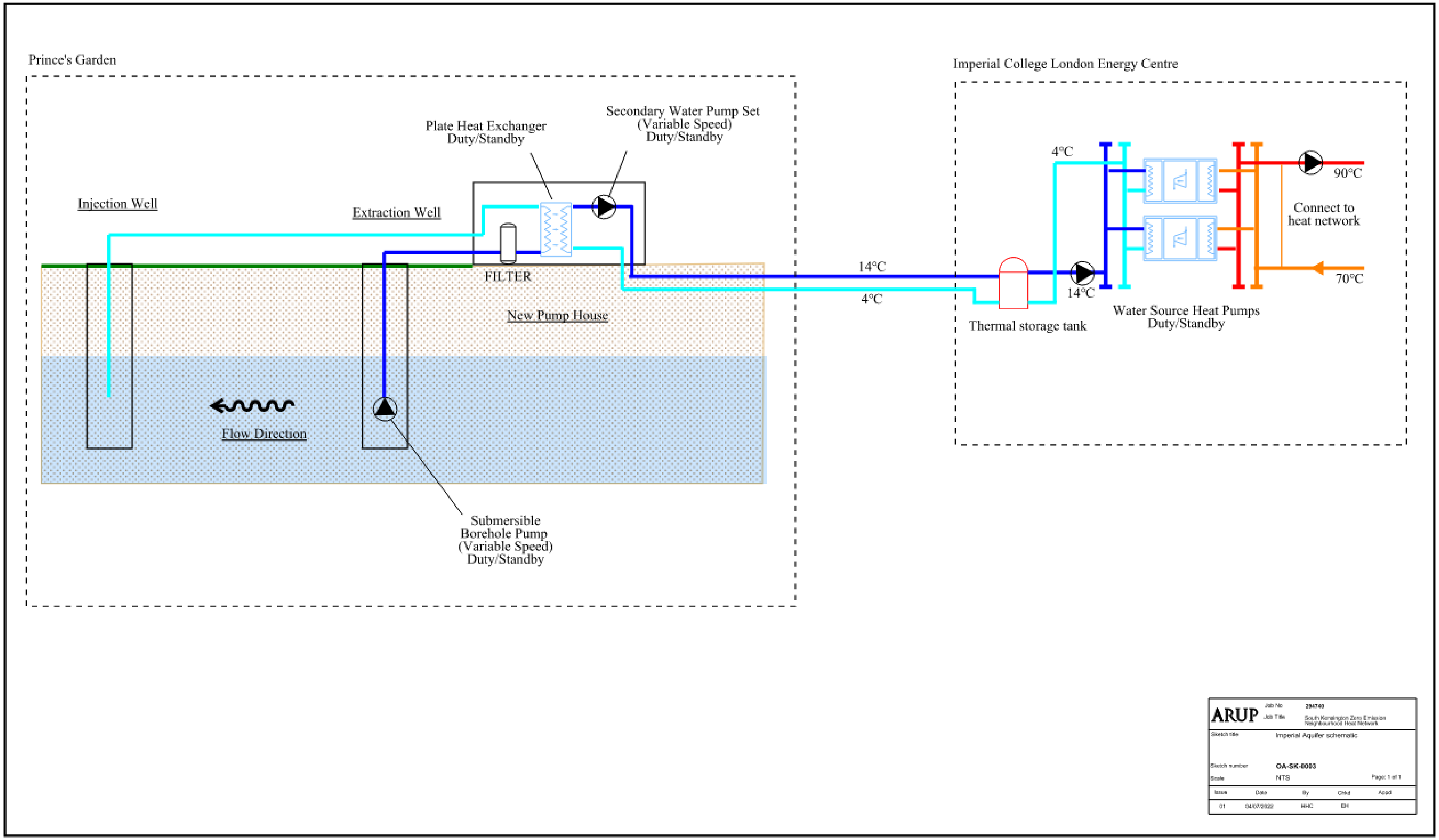


Figure 25: Schematic showing the operation of the Imperial aquifer opportunity

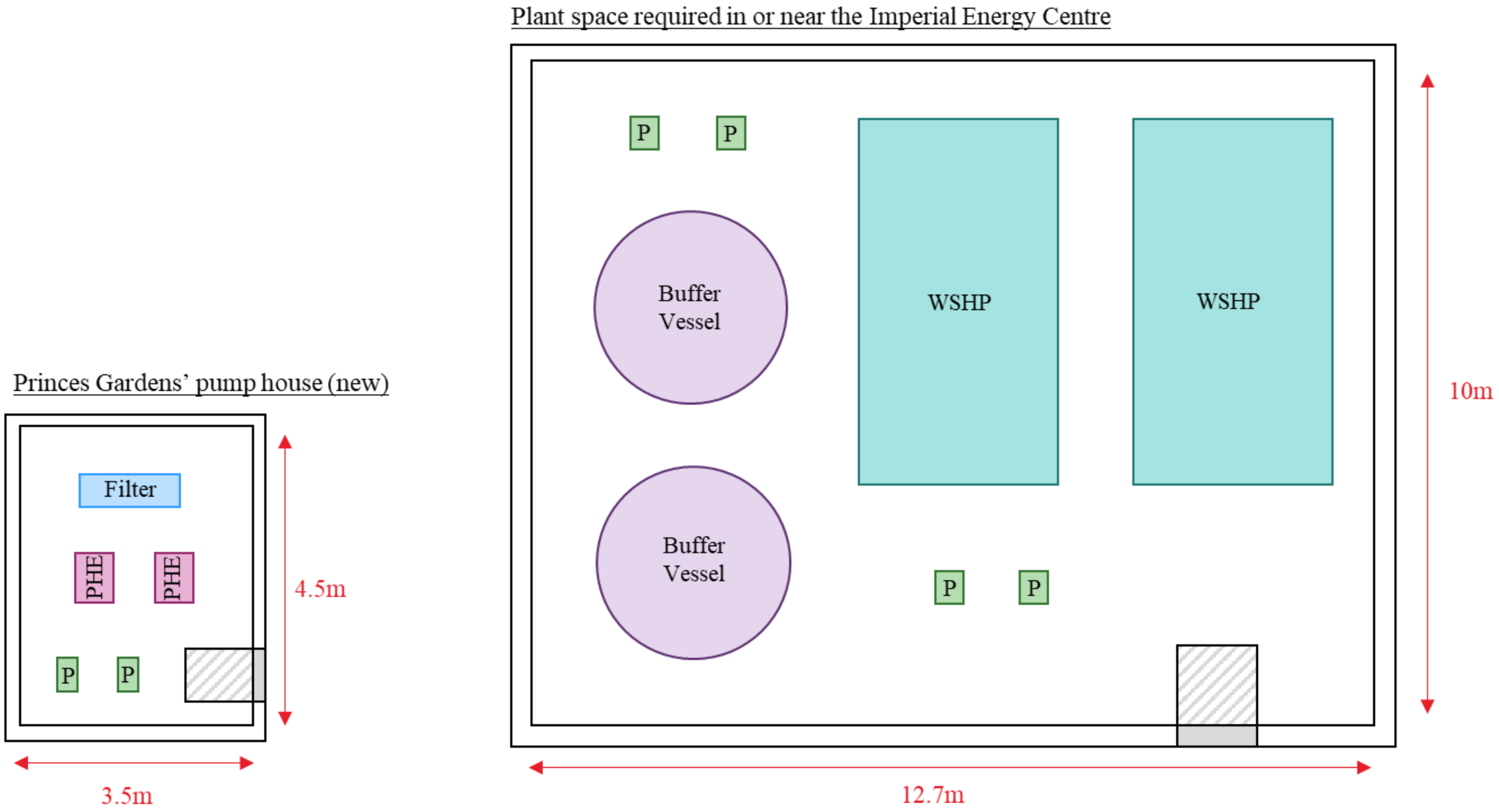


Figure 26: Mechanical space requirements for the Imperial aquifer opportunity

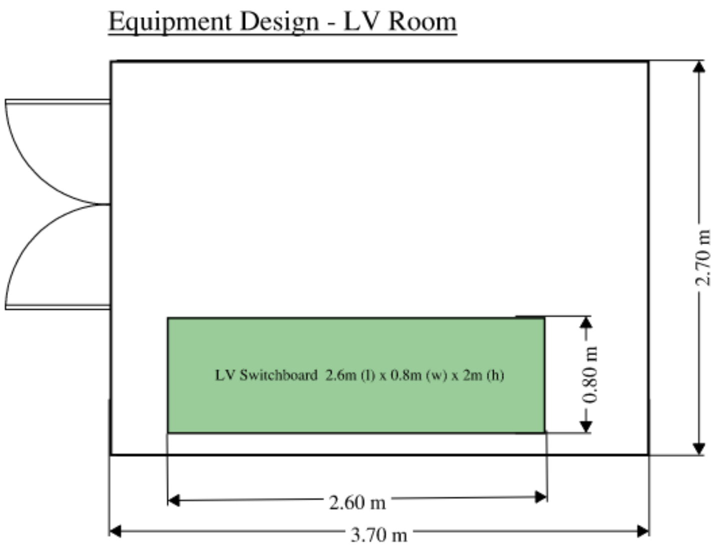
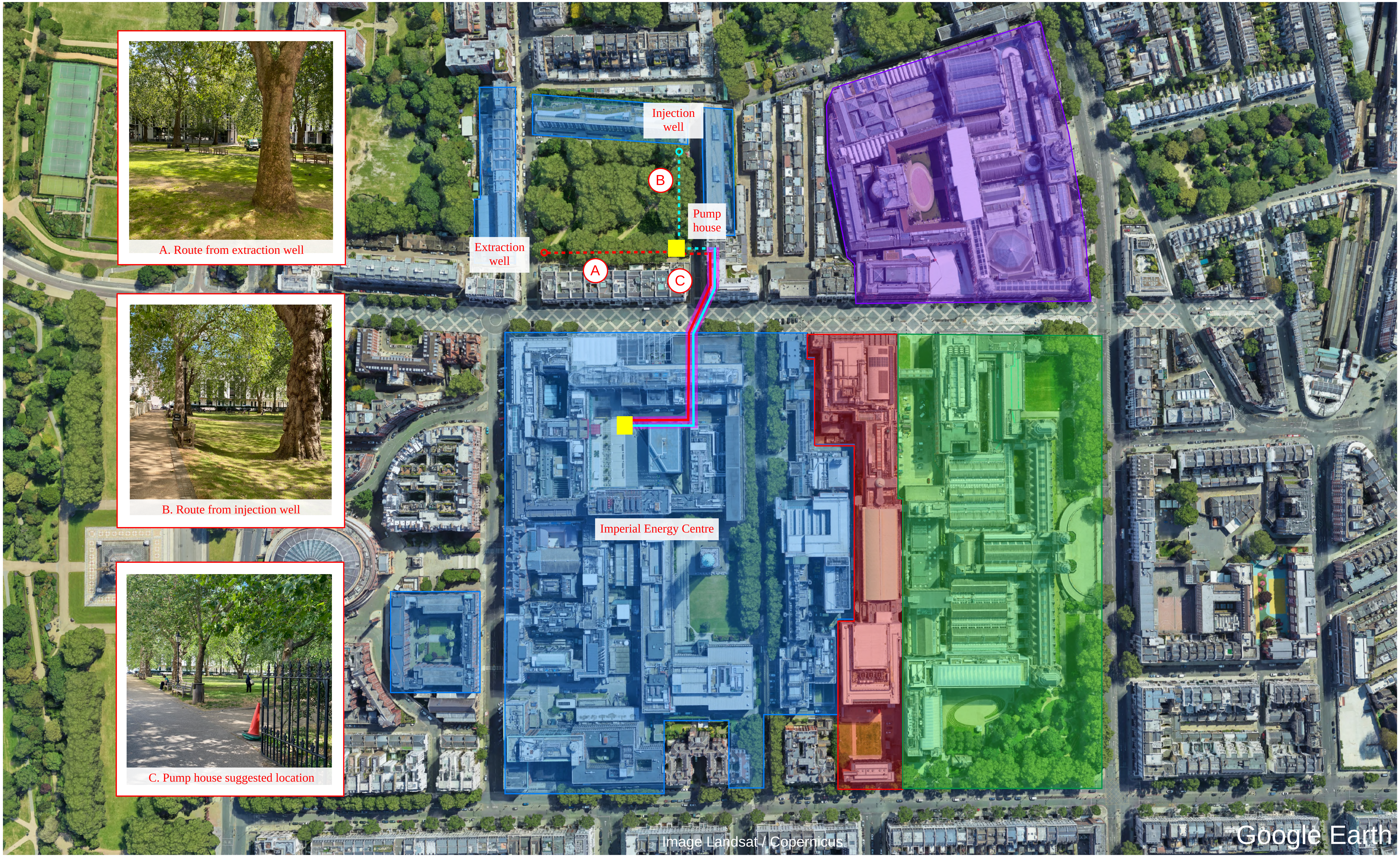


Figure 27: Electrical space requirements for the Imperial aquifer opportunity



Victoria and Albert museum
Natural History museum
Science museum
Imperial College London

Pipework (flow)
Pipework (return)
Buried pipework (flow)
Buried pipework (return)
Pipework in tunnel

ARUP	Job No	294740		
	Job Title	South Kensington Zero Emission Neighbourhood Heat Network		
Sketch title	Princes Gardens Aquifer			
Sketch number	OA-SK -0007			
Scale	NTS		Page: 1 of 1	
Issue	Date	By	Chkd	Appd
01	04/07/2022	AdT	EH	

Figure 28: Layout of potential Imperial aquifer heat opportunity

5.6 Heat recovery from larger chillers

Opportunity background

There are several chillers dispersed around the V&A, ScM, NHM and Imperial. Chillers are effectively heat pumps running in a cooling mode. The heat removed from the cooled spaces, along with the heat produced as a by-product of running the chiller, is rejected to atmosphere.

There are generally two uses for chillers on the sites:

- Cooling mode in summer
- In dehumidification mode all year round, but to a lesser degree in winter.

Whilst running chillers in summer for cooling limits the use of the heat rejected to DHW, the use of chillers for dehumidification in an air handling unit (AHU) provides more opportunity to recover the heat produced.

The temperature at which a chiller rejects heat depends on the specific design and application of the chiller. The chillers at the V&A, ScM and NHM were all surveyed and the majority of them were air-cooled systems positioned on roofs. The typical heat rejection temperature for air-cooled chillers can be as high as 43°C, depending on the ambient air temperature and design of the chiller.

In order to use the heat from the dispersed chillers, which typically serve local buildings, a local heat requirement would be needed (typically a DHW calorifier or an AHU). To use the heat for DHW, it would need to be upgraded to at least 60°C using a WSHP. This would also mean changing the air-cooled chillers to water-cooled chillers and is likely better done by instead replacing the chiller as a whole for a simultaneous heat pump, that produces heat and cold.

The use of the heat in the DHN could be done if the heat side temperature was boosted to at least 90°C and connected to the DHN. As the existing chillers are air-cooled, they are typically positioned on the roof of the building, making connection to the DHN more complicated as pipes would need to run to the tunnels through or outside of the building. They would also affect the hydraulic and thermal balance of the network if it were already running on central energy centres with heat pump technologies.

It is recommended that when replacing a chiller on any of the four sites that a simultaneous heat pump is considered instead. A simultaneous heat pump would allow for heating and cooling from the same equipment. This is likely to be of particular benefit where the heat pump is used for dehumidification as this usually involves cooling air and then reheating it in the same AHU. The following table provides an overview of the primary drawbacks and benefit associated with this solution.

Table 14: Heat recovery from large chillers – drawbacks and benefits

Benefits	Drawbacks
Recovery of heat rejected by chillers	Unless done for humidification, it is likely to be at times where there may be no use for the heat rejected, unless a DHW calorifier is nearby.
Opportunity, when chillers are replaced, to assess whether a simultaneous heat pump would provide a more efficient system.	Connection of lots of small heat loads into the DHN is likely to cause issues with pipe runs, hydraulic and thermal balancing issues.
Opportunity to reduce the amount of heat the building takes from the DHN by using wasted heat.	

5.7 Connecting the solutions

It is proposed that the solutions will connect into the main network through the Imperial and NHM Energy Centres. With the TfL rejected heat and the Sewer Source solutions feeding into the NHM Energy Centre, and the Aquifer and Serpentine solutions feeding into the Imperial Energy Centre. The network connection between the ScM and Imperial, as well as the ScM and NHM will act as a single DN250 balance line.

6. Techno-Economic feasibility

A techno-economic study has been undertaken for each of the four options. The energy, carbon and financial results are summarised in the following sections. All techno-economic results as well as the potential carbon reductions are based on the lower amount of heat that can be extracted (i.e., 0.6MW for the aquifer and 2.1MW for the sewer).

The basis for the techno-economic model assumes:

1. The CHP plants at NHM and Imperial are not operating
2. The cost of operating the heat network and gas-fired boilers (for peaking and standby) is already incurred so do not represent an additional cost.

At the next stage of the project, a more detailed model could be undertaken that considered the existing assets in more detail and broke down the costs more equitably amongst the four institutions. At present, the ScM is not connected to the heat network and therefore does not pay for its operation and maintenance. It is not known how the costs between the NHM, and V&A are split, and again this should be considered at the next stage of the project.

6.1 Technical evaluation

6.1.1 Energy

The energy output for each solution was determined, with the remaining heat assumed to be provided by the existing gas fired boilers. Table 15 below shows the summary of the results along with the breakdown between electricity and gas represented in Figure 29.

Table 15: Annual electrical and gas consumption based on heat output

Solutions	Heat generation by options (electric)	Heat generation by gas fired boiler	Electrical consumption (from solution)	Gas consumption (from boilers)
	MWh/year	MWh/year	MWh/year	MWh/year
Baseline	-	90,708	-	110,619
TfL rejected water	12,198	78,510	4,032	95,744
Sewer source	26,505	64,203	9,548	78,297
Imperial aquifer	8,099	82,609	3,637	100,742
Serpentine	38,231	52,477	14,083	63,996

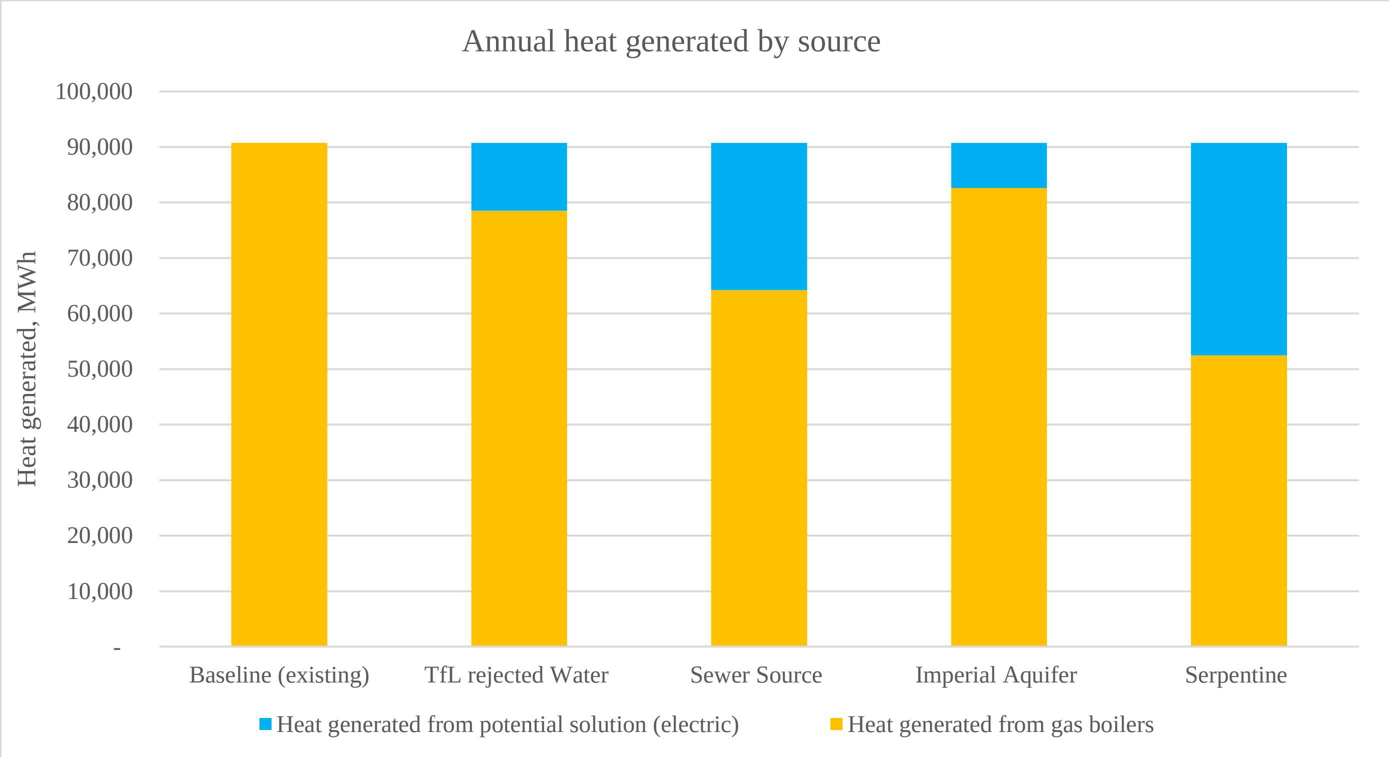


Figure 29: Annual heat generated by source for the potential options

6.1.2 Operational carbon emissions

The operational carbon emissions and savings were calculated for the present year (2023) and for a future scenario chosen as 2035 to align with the net zero ambitions of two of the institutions. Table 16 and Figure 30 represent the annual emissions and potential savings for each solution.

All carbon savings were estimated using the lower limit of the potential energy available from each option to show the minimum carbon saving achievable.

Table 16: Annual carbon emissions and savings compared to a gas-fired heat baseline

Solutions	Total carbon emissions 2023 (gas & electricity)	Total carbon emissions 2035 (gas & electricity)	Annual carbon savings over baseline, 2023	Annual carbon savings over baseline, 2035
	tonnesCO2/year	tonnesCO2/year	%	%
Baseline	20,192	20,192	NA	NA
TfL rejected water	18,330	17,626	9%	13%
Sewer source	16,220	14,646	19%	27%
Imperial aquifer	19,159	18,524	5%	8%
Serpentine	14,660	12,203	27%	40%

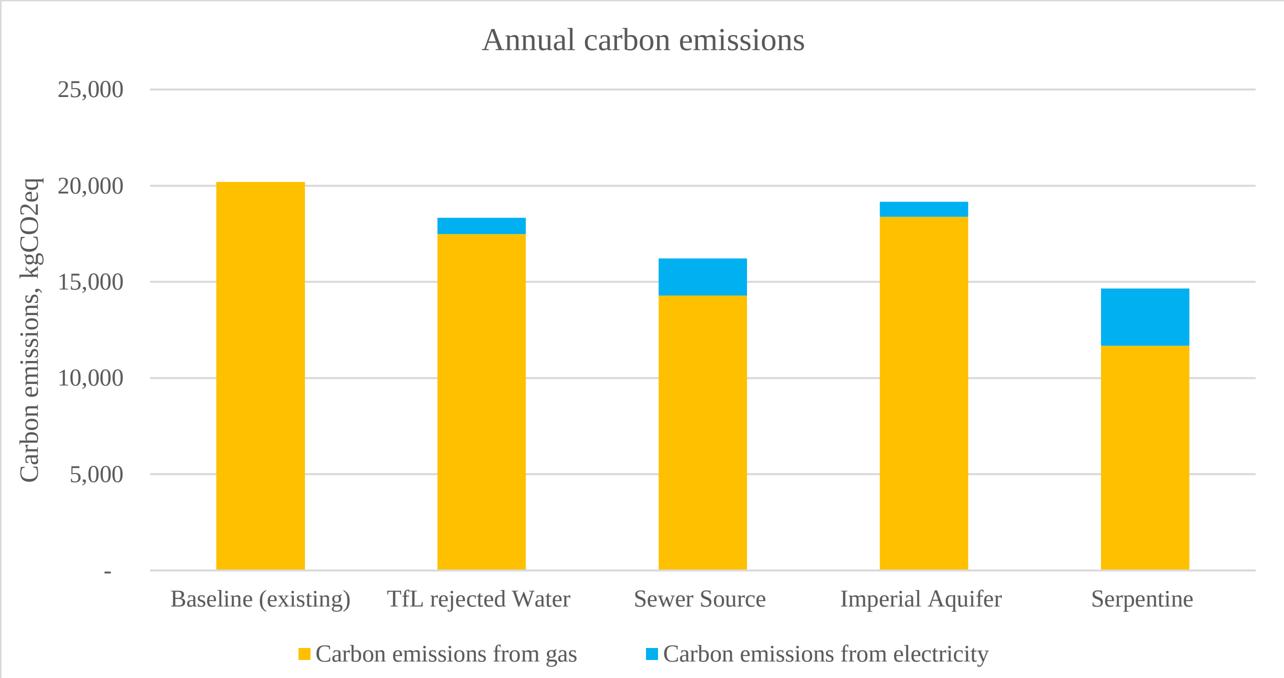


Figure 30: Annual carbon emitted by source for the potential options, based on 2023 carbon emission factors

6.1.3 Embodied carbon emissions and whole life carbon

A high-level estimation of the embodied carbon of the four options was considered. The objective is to assess whether the embodied carbon cost of implementing each option has a material impact in the operational carbon savings that have been estimated for each of the options. The balance of embodied carbon cost and operational carbon savings define the Whole Life Carbon savings.

The main conclusions of this assessment are:

- The embodied carbon impact for all options assessed range between 0.33-2% of the operational savings that can be achieved with each option.
- Therefore, embodied carbon cost only slightly reduces the operational savings, and it is not a decision driver for the selection of options. Whole life carbon savings are only 1-2% lower than the operational carbon savings.
- It is recommended that abatement cost (cost of carbon savings in £ per kg of carbon saved) is calculated, and decisions should be balanced between absolute Whole Life Cycle savings, absolute cost (£) of implementation and abatement cost.

Standards

This assessment follows as much as possible the Lifecycle Assessment (LCA) best practice, defined by the BS EN 15978:2011. This is the European standard for ‘Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method’. It is focused on the built environment (e.g., buildings) and provides the framework for appraising the environmental impacts of built environment assets.

BS EN 15978:2011 (explained in the previous section) had been subject to varying interpretations by professionals across the construction industry. To provide a consistent approach to the practical application of this standard, RICS (Royal Institution of Chartered Surveyors) published ‘Whole life carbon assessment for the built environment’ (also known as ‘RICS Professional Statement, RICS PS’) in November 2017. It is widely considered as best practice to follow this guidance in the UK.

Software

The LCA for the embodied carbon of the different options has been carried out using OneClick LCA software and is reporting emissions over building life cycle (modules A-C, 60 years).

Information sources

Information on the type, size and quantity of plant equipment and pipework has been taken from the high-level designs, as has any information on additional works associated with the options such as excavating and refilling trenches for pipework. When specific manufacturer data on the embodied carbon of plant items has not been available, discussions have been held with the Arup engineering team to inform assumptions on carbon modelling. In these cases, the capacity and weight of plant items has been used to scale up the carbon factors of similar products on OneClick, further details on the carbon modelling assumptions are provided in Appendix A. Information on the refrigerant charge and leakage rates have been provided by the Arup engineering team.

Simplified calculations

A conservative buffer factor of 1.3 has been applied to the results to provide an adjustment for the simplicity of the approach, in line with the basic calculation method in CIBSE TM65: 'Embodied carbon in building services: a calculation methodology'.

The whole life carbon savings with the constant grid carbon factor is shown in Table 17. This set of results are aligned with the RICS PS and imply that the electricity grid would not decarbonise in the future. They present the most conservative scenario evaluated.

Table 17: Whole life carbon savings over 60 years with no decarbonisation of the electricity grid

	Embodied Carbon - Materials	Embodied Carbon – Buffer factor (30%)	Total Embodied Carbon	Operational Carbon Savings	WLC Savings (operational – embodied)	Embodied Carbon/ Operational savings
	tCO_{2eq} over 60 years	tCO_{2eq} over 60 years	tCO_{2eq} over 60 years	tCO_{2eq} over 60 years	tCO_{2eq} over 60 years	%
TfL rejected water	1,068	320	1,389	111,840	110,772	1.24
Sewer source	2,324	697	3,021	682,020	679,696	0.44
Imperial aquifer	903	271	1,174	62,040	61,137	1.89
Serpentine	1,958	587	2,545	331,920	329,962	0.77

However, this conservative scenario is unlikely to happen as the electricity grid is expected to decarbonise to meet the commitments of the UK Government. This expected decarbonisation is estimated and revised annually by the Future Energy Scenarios (FES) by National Grid, source aligned with the requirements of the RICS PS. The whole life carbon savings calculated considering the future impact of the decarbonising UK electricity grid (FES 2022) is shown in Table 18.

Table 18: Whole life carbon savings over 60 years with decarbonisation of the electricity grid

	Embodied Carbon - Materials	Embodied Carbon – Buffer factor (30%)	Total Embodied Carbon	Operational Carbon Savings	WLC Savings (operational – embodied)	Embodied Carbon/ Operational savings
	tCO_{2eq} over 60 years	tCO_{2eq} over 60 years	tCO_{2eq} over 60 years	tCO_{2eq} over 60 years	tCO_{2eq} over 60 years	%
TfL rejected water	1,068	320	1,389	147,138	146,070	0.9
Sewer source	2,324	697	3,021	909,184	906,861	0.3
Imperial aquifer	903	271	1,174	93,866	92,963	1.3
Serpentine	1,958	587	2,545	455,009	453,051	0.6

As shown in Table 17 and Table 18, the following conclusions can be drawn:

Absolute embodied carbon cost

The Sewer Source solution has the greatest magnitude of embodied carbon. This is due to this option requiring more water source heat pumps (WSHPs) than the other options. The Serpentine solution has the second highest embodied carbon, largely due to this option requiring more pipework than other options. The embodied carbon of the TfL Rejected Water solution is slightly higher than the Imperial Aquifer solution due to it requiring more pipework and a larger plate heat exchanger (PHE).

The total embodied carbon of the options ranges between 0.33% and 2% of the operational savings that can be achieved, therefore whilst it slightly reduces the operational savings, the embodied carbon cost should not be a decision driver between the options.

Whole-life Carbon savings

The Sewer Source solution has the potential to save larger amounts of carbon, followed by the Serpentine solution, which delivers approximately half the carbon savings.

Abatement cost

It is recommended that abatement cost (cost of carbon savings in £ per kg of carbon saved) is calculated, and decisions should be balanced between absolute Whole Life Cycle savings, absolute cost (£) of implementation and abatement cost (£/kgCO2e saved).

6.2 Economic evaluation

6.2.1 Capital cost

The capital costs were estimated for mechanical components (which includes equipment and network material and installation costs), electrical components (which includes distribution upgrades) and civil works (such as plant room construction and boreholes) as well as design, overheads, contractor, and risks, allowing for a contingency of 40%. A full breakdown of the assumptions and exclusions can be found in Appendix C.

Grid capacity

The budget quote application to UKPN has been submitted, but the response has not been received at the time this report is prepared.

Table 19: Capital cost breakdown for each option

Cost estimate	TfL rejected water	Sewer source	Imperial aquifer	Serpentine
Mechanical costs	£4.8M	£17.8M	£4.4M	£10.4M
Electrical costs	£0.2M	£1.0M	£0.2M	£0.4M
Civil costs	£0.1M	£0.3M	£0.9M	£2.4M
Subtotal	**£5.1M**	**£19.1M**	**£5.5M**	**£13.3M**
Testing & Commissioning @5% Capex	£0.3M	£0.7M	£0.3M	£0.7M
Contractor's Preliminaries @15% Capex	£0.8M	£2.2M	£0.8M	£2.0M
Contractor's OH&P @10% Capex	£0.5M	£1.9M	£0.5M	£1.3M
Project / Design Team Professional Fees @6% Capex	£0.3M	£0.9M	£0.3M	£0.8M
Contingency @40% Capex	£2.8M	£10.0M	£3.0M	£7.2M
Total	**£9.7M**	**£34.9M**	**£10.4M**	**£25.2M**
Finance over 15 years at 6%	£1.0M	£3.5M	£1.1M	£2.6M

6.2.2 Operational cost

In order to determine the annual energy costs, the 'Quarterly Energy Prices' from June 2023[7] and 'Prices of fuels purchased by non-domestic consumers in the United Kingdom'[8] by the Department for Energy Security & Net Zero was used. The electricity price for medium size non-domestic consumers was found to be 22.81 pence per kWh and that of the gas price was 7.47 pence per kWh in year 2023, in the 1st quarter.

Table 20: Annual operational energy costs

Options	Estimated annual electrical heating cost	Estimated annual gas heating cost	Estimated total annual heating cost
Baseline (existing)	-	£8.3M	£8.3M
TfL rejected water	£0.9M	£7.2M	£8.1M
Sewer source	£2.1M	£5.9M	£7.9M
Imperial aquifer	£0.8M	£7.5M	£8.4M
Serpentine	£3.2M	£4.8M	£8.0M

[7] https://www.gov.uk/government/statistics/quarterly-energy-prices-june-2023

[8] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1166293/table_341.xlsx

The maintenance and replacement costs are highlighted in Table 21. The Reference service life (RSL) years was taken from Guide M[9].

The replacement cost annually was determined using the projected future value at the end of the specific equipment lifecycle, spread over the equipment service life.

Maintenance costs were based on specialist and general call out costs, with safety considerations included, such as no lone working while servicing tunnels, boreholes or while diving.

Table 21: Costs associated with maintenance, replacement, and labour

Options	Annual labour and materials (maintenance) cost of new plant	Annual replacement cost
TfL rejected water	£24K	£0.4M
Sewer source	£51.5K	£1.5M
Imperial aquifer	£33K	£0.3M
Serpentine	£46K	£0.7M

6.3 Phasing of works

In order to progress the project from a technical perspective, further tests will be required for all of the solutions identified. There will be costs for all of the testing and further development of the solutions, so it is important to progress with the options that the institutions want to pursue. Typical tests required include further borehole pumping tests and geological surveys (for the aquifer), and metering of sewage and monitoring of the sewage temperature (for the sewage solution).

As each solution will provide heat to more than one institution, once further design has been undertaken, there is a need to commercialise the solutions so costs are known by all institutions and heat off-takers.

The expected phasing of the future works is shown in Figure 31 below.

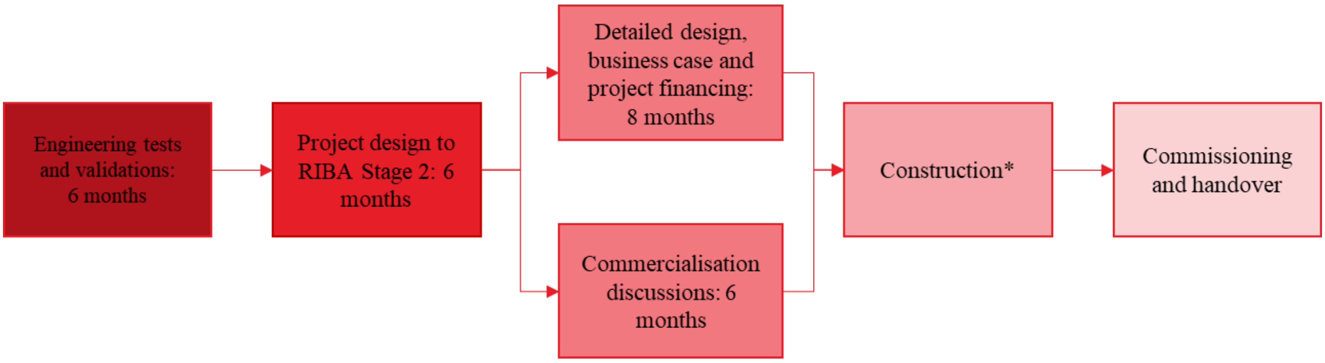


Figure 31: Typical next steps for each solution

*To be identified based on the surveys and subject to stakeholder and landowner agreements.

[9] Guide M Maintenance engineering and management (2014)

7. Conclusions

From this study it is concluded that:

1. It is possible to reconnect the current two heat networks together and form one heat network servicing each of the four institutions. This could be served by the existing Energy Centres at NHM and Imperial, though some controls would need changing to allow for it. The NHM Energy Centre, which once served all of the heat network, no longer has the correctly sized heat connection to serve all of the heat network, this is due to Imperial's heat demands increasing since the heat network was first built in the late 1950s (they have transferred most of their steam heat demands to the heating network).
2. The number of energy centres in the future would depend on the technologies being used and their locations, however ideally the number of energy centres would be kept to a minimum for control purposes.
3. There were no waste heat sources found at any of the institutions of any significance that justified sharing this heat between institutions. The installed dispersed chillers could have their heat recovered from them, but this was considered at a scale that each institution could use the heat from them at the building level to reduce their heating demand from the heat network.
4. The total potential for PV technologies was found to be 0.7MWe. As this was below the base electrical demand for the institutions, the use of battery technologies to store the electricity not used on site to prevent export is not required.
5. Four solutions were found to take heat from wasted heat or renewable heat, however even at their largest potential sizes, or using combinations of them, the heat network will not fully decarbonise through electrification of the heating supply using them. Further heat demand reductions will be required, in combination with further electrified heating solutions. These electrified heating solutions should be considered at the next stage of the project to ensure the solutions are connected in the most efficient manner hydraulically.
6. Decarbonisation using hydrogen rather than electrification may be possible in the future, but is not certain enough to plan for it currently.
7. Three of the sources of heat require permissions from others to install equipment in their land or connect to their systems. During the discussions with TfL, Royal Parks and Thames Water it was clear that all would charge for this, though none could at the currently say what that cost would be. Royal Parks made it clear that if they did allow connection of heat recovery systems to their land, they would very likely tender the opportunity.
8. It is likely that all four solutions will require permission from the Environment Agency, so they should be contacted at the next design stage.

8. Way forward

8.1 Potential for future expansion

The potential for future expansion should be studied in the next stage. The network can only expand to other sites once the baseload of the existing four institutions is met by a proposed solution or combination of solutions. Due to this, future expansion is based on identifying the maximum heat possible to be extracted from the solutions.

8.2 Route to achieve net zero

It is acknowledged that the waste heat proposals in this feasibility study do not, on their own, account for the heating demand of the South Kensington ZEN. To achieve net zero, a combination of the relevant opportunities will need to be utilised to reduce or eliminate the carbon emissions of the heat network.

Currently the only feasible way to reduce heating carbon emissions to near zero is to utilise electrically powered heat sources (heat pumps or direct electric boilers) albeit with limitations on physical space (for heat pumps) and the UKPN supply.

In the coming decades, combustion boilers fuelled by hydrogen may also prove part of the solution.

This study has detailed four different water sources available for heating. To come closer to net zero, air source heat pumps (ASHP) could also be utilised using available roof space. Specifically, the ASHPs would absorb heat from the air and produce LTHW at 45°C (for example). This source water would then be transferred to a plant room to become the water source for a WSHP that would generate LTHW at the elevated temperature required for the current networks.

The combined CoP of this system is still only approaching 2, however, this is nearly twice as efficient as heating purely from direct electric.

The practical limitation of this system in South Kensington surrounds the allowable pressure the existing building roofs can tolerate without significant reinforcing, and the internal plant space needed to house the WSHPs.

A desktop study of available roof space has outlined 4.7MW of air source heat could be installed at Imperial, and 3MW at the NHM. This assumes that the roofs can accept a loading 1.5kPa; the ASHPs were spaced and supported accordingly, and the ambient temperature was taken to be -5°C. It also assumes planning permission is granted, if required.

8.3 Funding opportunities

8.3.1 Funding opportunities

These are the funding opportunities that may be applicable to the South Kensington ZEN site to take the feasibility study forward. The Low Carbon Skills Fund as detailed below offers an opportunity for funding to develop a full Heat Decarbonisation Plan based on the outcomes of this study, and to further produce a RIBA Stage 3 design for it. Thereafter the Public Sector Decarbonisation Scheme offers an opportunity for funding to implement the potential solutions moving away from fossil fuel systems and implementing WSHPs. The investigation into restoring the historic heat network connection between the institutions open up another funding pathway through the Green Heat Network Fund.

Low Carbon Skills Fund (LCSF)[10]

The Public Sector Low Carbon Skills Fund offers grants to public sector organizations to access specialized expertise and skills necessary for developing a Heat Decarbonization Plan (HDP) or design up to RIBA Stage 3. This initiative aims to support the UK's goal of achieving Net Zero by 2050 by focusing on reducing carbon emissions in the heating of buildings. The funding is intended for the creation of a HDP, updating an existing plan, or, in cases where an up-to-

[10] Salix webpage, Retrieved from: https://www.salixfinance.co.uk/phase-4-public-sector-low-carbon-skills-fund, [Accessed 7th of July 2023].

date plan already exists, producing a standalone detailed design up to at least RIBA Stage 3. The grant specifically covers the expenses associated with acquiring specialist skills and expertise from the private sector, such as consultancy services, for eligible projects.

Public Sector Decarbonisation Scheme (PSDS)[11]

The Public Sector Decarbonisation Scheme (operated by DESNZ, formerly DBEIS), administered by Salix Finance, supports the objective of reducing emissions from public sector buildings by 75% by 2037, based on a 2017 baseline, in accordance with the 2021 Net Zero and Heat and Buildings strategies (published by DBEIS).

To be eligible for the scheme, applicants must currently utilize a heating system powered by fossil fuels, which should be nearing the end of its useful life.

Each application must propose a measure that contributes to decarbonizing heating in each building included, utilizing a low carbon heating source. The new low carbon heating system, in combination with energy efficiency measures, must be capable of meeting the heat demand of the existing fossil fuel heating system at the end of its life.

The funding allocated per project must not exceed £325 per tonne of direct carbon savings (tonneCO_{2eq}) over the project's lifespan, as per the Carbon Cost Threshold (CCT). It is important to note that the CCT may be subject to change in future funding rounds.

Direct low carbon measures encompass air source heat pumps, water source heat pumps, ground source heat pumps, electric heating and hot water systems, and solar thermal solutions. Indirect low carbon measures include solar photovoltaic (PV) systems, LED lighting, and energy-efficient ventilation.

Green Heat Network Fund (GHNF)[12]

The Green Heat Network Fund (GHNF) is a 3-year, £288 million capital grant fund that will support the commercialisation and construction of new low and zero carbon (LZC) heat networks (including the supply of cooling) as well as the retrofitting and expansion of existing heat networks.

The grant award can be up to 50% of the combined total commercialisation and construction costs (with an upper limit of £1 million for commercialisation). There are 4 rounds of submissions in a year and the last round will be 29 November 2024.

To qualify for the GHNF, full application documents should be provided to demonstrate the heat network can achieve the following key metrics (a) the carbon intensity of network consumer detriment, (b) annual thermal demand, (c) Social Internal Rate of Return (IRR), (d) subsidy control and (e) market transformation. GHNF application gated metrics summary is extracted from the Guidance for Applicants (Version: 5.0)[13] as below.

Table 22: GHNF relevant metrics

Metric	Limit
Carbon gate	100gCO_2e/kWh thermal energy delivered (lower is better).
Customer detriment	Domestic customers and micro-businesses must not be offered a price of heat greater than a low carbon counterfactual for new buildings and a gas/oil counterfactual for existing buildings.
Social IRR	Projects must demonstrate a Social IRR of 3.5% or greater over a 40-year period Note: The Investment Committee will also consider a maximum acceptable post-GHNF Grant project IRR, this is not made public for commercial purposes.

[11] Salix Phase 3b Public Sector Decarbonisation Scheme, Retrieved from: https://www.salixfinance.co.uk/Phase3bPSDS, [Accessed 7th of July 2023].

[12] Green Heat Network Fund (GHNF), Retrieved from: https://www.gov.uk/government/publications/green-heat-network-fund-ghnf , [Accessed 7th of July 2023].

[13] Green Heat Network Fund Guidance, Department for Energy Security & Net Zero, Retrieved from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1167773/green-heat-network-fund-r6-guidance.pdf , [Accessed 7th of July 2023].

Minimum demand	For urban networks, a minimum end customer demand of 2GWh/year (including existing customers). For rural (off gas grid) networks a minimum number of 100 dwellings connected. This is to be achieved within a 5-year window from the date of first connection.
Limit on award compared to eligible costs	Combined grant requested up to but not including 50% of the estimated eligible commercialisation and construction costs of the project.
Capped award	The total award may not exceed 4.5 pence of grant per kWh of heat delivered over the first 15 years of operation.
Non-heat/cooling cost inclusion	For projects including wider energy infrastructure in their application, the value of income generated/costs saved/wider subsidy obtained should be greater than or equal to the costs included.

If the scores of different projects are similar, adjustment metrics are used to prioritize the application. The adjustment metrics are as below:

- The extent to which a project is assessed to be deliverable
- The carbon abatement potential of the project
- Overall volume of thermal energy delivered to customers
- The expansion potential of the network
- Innovation and energy efficiency credentials of the project.

Local Energy Accelerator (LEA)[14]

The GLAs (Greater London Authority) started the LEA to enable clean and flexible local energy projects. The LEA aims to reduce carbon emissions in London by 20,000tonne$CO_{2eq.}$

The objective of this scheme is to support applicants in the development of flexible, locally generated energy projects while simultaneously reducing carbon emissions. The LEA Programme Delivery Unit (PDU) offers complimentary and personalized project management services, along with additional support, to all funding beneficiaries. This includes assistance with engagement, skills training, and other forms of tailored support.

To achieve this heightened ambition, the LEA programme team is dedicated to providing support for larger projects primarily during their advanced stages of implementation. The team aims to assist in overcoming obstacles and expediting the delivery of these projects.

The supported clean local energy projects may include various elements such as:

- Ground, water, and air-source heat pumps
- Secondary heat sources like geothermal, water and sewage, solar thermal, existing energy from waste facilities, London Underground, data centres, and industrial processes
- Clean local power networks and building-level electricity systems incorporating solar PV, fuel cells, or battery storage
- Energy system controls and management, such as demand side flexibility
- Integrated smart charging solutions for electric vehicles.

Heat Network Delivery Unit (HNDU)[15]

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[14] https://www.london.gov.uk/sites/default/files/local_energy_accelerator_-_information_brochure.pdf

[15] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1156827/hndu-r13-guidance.pdf

The Heat Network Delivery Unit (HNDU) scheme in its thirteenth round provides grant funding and guidance to Local Authorities in England & Wales, as well as specific non-Local Authority organizations. This support is aimed at facilitating the development stages of heat network projects. Round 13 opens for applications on Monday 15 May 2023, and will close no later than 31 December 2023.

In Round 13 of the Heat Network Delivery Unit (HNDU) scheme, funding is accessible to various types of organizations, including:

- Local Authorities in England and Wales
- Registered Social Landlords
- Property Developers
- Universities
- NHS Trusts
- Registered Social Landlords
- Property Developers
- Universities
- Other Government Departments

The grant funding provided by the Heat Network Delivery Unit (HNDU) can cover up to 67% of the estimated eligible external costs associated with heat network development studies. This funding can significantly support the financial aspects of conducting studies related to heat network development.

Funding varies from £20K to £250K depending on the project scale (small medium and large) and the stage of design such as Techno-Economic Feasibility (FES) and Detailed Project Development (DPD).

8.4 Next steps

It recommended that the institutions:

1. Obtain a commitment from each of the institutions that they wish to proceed to investigate being connected to the same low carbon heat network. Should one or more institution not wish to progress, some of the options may still be available, depending on the institution that is not connecting.
2. Agree a desired timeline for the implementation of the technical solution. This will help to fix the scope for the future studies and give a firm basis on which the costs and financial modelling are to be presented. It will also provide an understanding of the plant spaces available, especially in Energy Centres where plant is already installed.
3. Agree Heads of Terms for working together and the approvals process. This document would, in the fullness of time and once the technical solution is more certain and nearer approval, evolve through a revision into the Heads of Terms for the supply of heat to the institutions.
4. Agree which solutions to pursue to the next stage and obtain funding for the studies. It is possible, depending on the scope, that this would come from the GLA's LEA programme, or the Salix administered Low Carbon Skills Fund (LCSF). It should also be decided if multiple options would be considered (e.g., the aquifer and the sewer source solutions) as space needs to be found for each of the options for the plant.
5. Obtain a concept design (e.g., RIBA Stage 2 level of detail) for each of the solutions and undertake any required testing to maximise the scale of the solution and heat recoverable.
6. Continue to discuss permissions to access the heat sources from the relevant parties (e.g., TfL, Thames Water, Royal Parks or other organisations required to recover heat from their land or systems).
7. Consider getting some planning permission and environmental permitting advice on each of the selected solutions.

8. Agree the metrics by which the solutions will be measured, accepting that measuring the project using the traditional financial mechanisms is likely to be challenging in a period of high inflation and with significantly fluctuating gas and electricity prices. Changing the Base Case should be considered at the next stage, to appraise the solutions found against another all-electric heat option, rather than against a gas-fired solution.

9. For each of the solutions chosen to be progressed:

    a. Undertake all necessary tests to maximise the opportunity, for example, for the aquifer, consider a cross site/institution solution.

    b. Continue the application for increased electrical capacity from the DNO.

10. Should thermal storage be needed on the solution chosen, a location should be found for it. The consideration of the underground oil tanks at the NHM should be considered, subject to the statutory guidance on decommissioning underground oil tanks.

11. For the options taken forward to the next stage, undertake a more detailed cost model that considers the existing heat network and energy centre heating plant assets in more detail, breaking them down equitably amongst the four institutions.

12. The four institutions all have plans to achieve net zero carbon emissions by, or before, 2040. The heating technologies to be used by the institutions to reduce their carbon impact should be identified at the next stage to ensure the design of the solutions is done correctly. Incorrect hydraulic connection of the solutions could result in them not working correctly.

Appendix A – Baseline report

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South Kensington Zero Emission Neighbourhood Heat Network

Baseline Report

Imperial College London

LEA Project. Reference: GLA 81635 Local Energy Framework

Issue | 19 July 2023

Job number: 294740

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arup.com

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Document Verification

Revision	Reason for Issue	Prepared	Checked	Approved	Date
01	Draft for comment	Najlae Bouhi, Anni du Toit	Ertan Hataysal	Doug Walter	19/05/2023
02	Issue	Anni du Toit	Ertan Hataysal	Doug Walter	21/07/2023

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Contents

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1. Introduction

Project background

Arup was appointed by Imperial College London ('Imperial') to conduct a feasibility study on decarbonising the heat network by finding heat recovery options within the South Kensington Area as part of a holistic decarbonisation plan for the area.

The area was served by an original heat network which was installed in the late 1950s and originated in the Natural History Museum ('NHM') Energy Centre. This heat network supplied four institutions: Natural History Museum, Imperial College London, Science Museum ('ScM') and the Victoria & Albert Museum ('V&A').

Imperial and the ScM disconnected from the original heat network between 1999 and 2006. The V&A space heating is still provided by the NHM heat network.

There are two electrical supply points within the four institutions: one at Imperial, which feeds only Imperial, and one feeding all three of the Museums, located at the NHM.

Arup was appointed to investigate the technical possibilities to reconnect Imperial, ScM, NHM and V&A to the heat network, and to consider decarbonised heat sources to supply the heat network. Solutions such as waste heat recovery from underground stations, sewers and chillers will be considered.

A map of the wider South Kensington site comprising NHM, Imperial, ScM and V&A is shown in Figure 1.

This project is split into two main work packages, the first one being 'WP-I: Baseline review'. WP-I aims to investigate the current energy infrastructure within the four institutions, the existing connections to the heat network and to produce a baseline energy model of the demands.

The second Work Package 'WP-II: Feasibility Study' is dedicated to investigating opportunities to decarbonise the heat network and develop an energy model of the potential carbon and energy savings. Each scenario will be assessed against the following criteria:

- Energy performance
- Capital and operational costs
- Difficulty of implementation
- Whole life carbon emissions
- Available grid electrical capacity.

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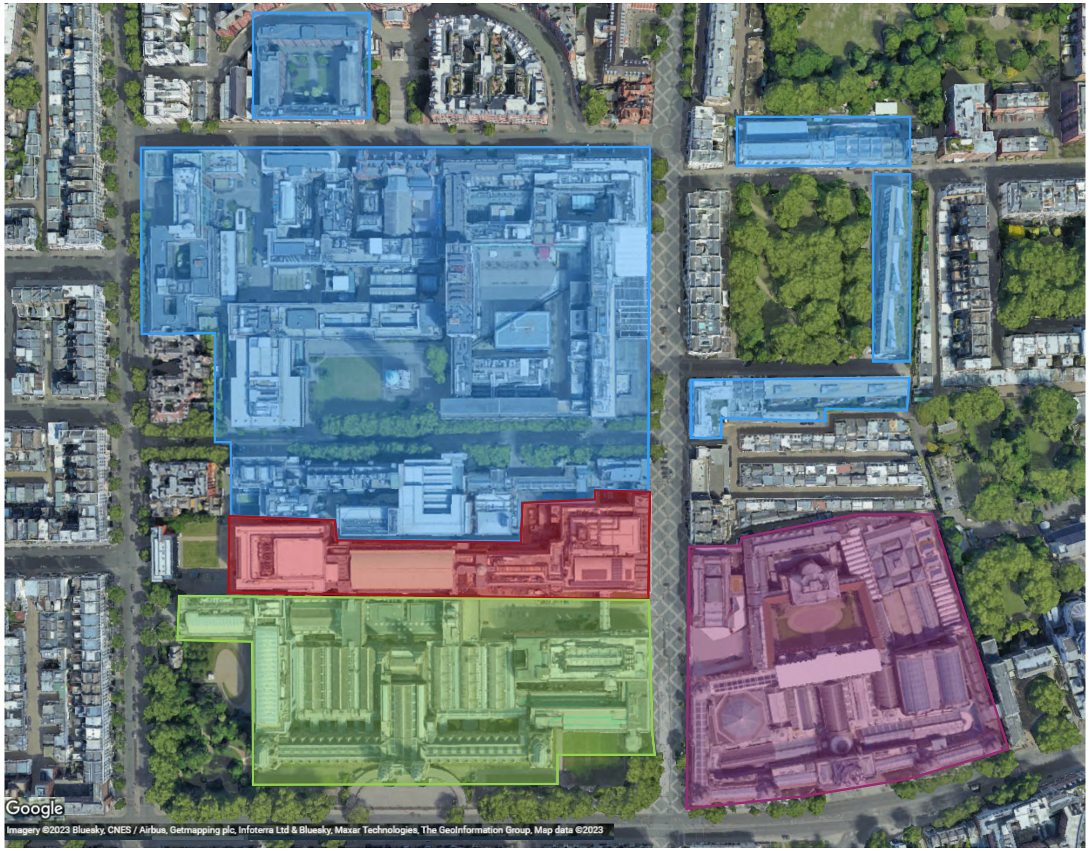
1. Introduction

Site overview



Victoria and Albert Museum

Natural History Museum

Science Museum

Imperial College London

Figure 1. South Kensington site map showing the relevant institutions

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2. Review of the existing information

Review of the previous works

Arup have undertaken a number of projects for Imperial regarding their energy strategy and heat network since 2013, and are currently assisting with their current energy infrastructure project, which is removing the centrally-provided steam system and removing steam from their buildings.

Arup have assisted the NHM since 2019 in a similar capacity. The team that have undertaken the majority of this work are also assisting on this project, to maximise the outputs over the short project duration.

In addition to supplying any relevant Arup reports to the team undertaking this work, the following reports were also provided and have been reviewed:

- "Carbon Reduction Masterplan for the 1851 Estate", Cynergin, 2011
- "Science Museum Heat Decarbonisation Plan", Buro Happold, 2022 (Revision P01 draft)
- Sustainability strategies for each institution from their respective websites (as available in April 2023).

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2. Review of the existing information

London Heat map

The London heat map was investigated to determine the presence of any existing heat networks in the area with a potential to connect into. As can be seen in Figure 2, the nearest heat network is in Pimlico, approximately 2.1km away. This concludes that there are no feasible nearby heat network connections for the site.

The heat map also indicates Transport for London (TfL) Potential Waste Heat Supply Sites, which can be seen intersecting with the SK ZEN site. This promising opportunity is further explored in the stakeholder engagement section under the 'Interface with external partners' section (on page 27). Arup have discussed this matter with TfL.

Proposed Heat Networks
Existing Heat Networks
South Kensington site
TfL Potential Waste Heat Supply Sites

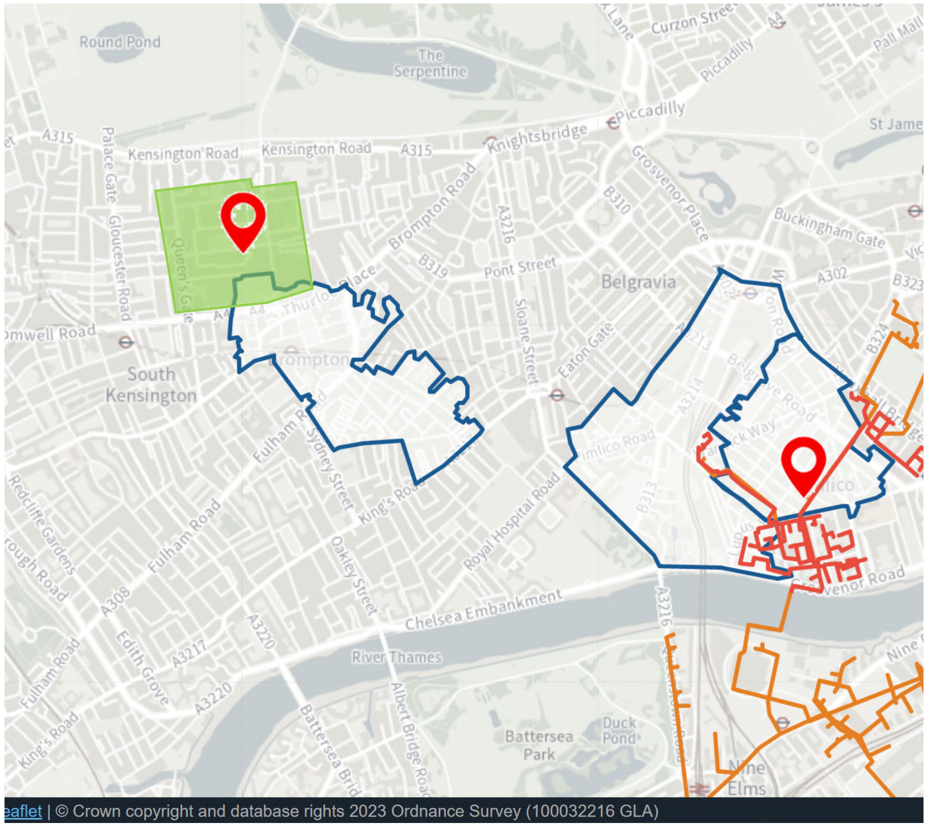

Figure 2. London heat map (https://maps.london.gov.uk/heatmap/)

3. Current energy infrastructure

Site investigations

Arup has undertaken several site visits as part of these works. These visits have enabled us to have a comprehensive understanding of the current energy infrastructure in the overall South Kensington site, as well as the existing connections to the heat network. By conducting these initial visits, potential solutions were identified that will be further explored in the subsequent phase of the project.

At the initial site visit to the V&A, ScM, and NHM, the focus was on examining the existing energy facilities. Each visit involved identifying the installed chillers and exploring the potential for recovering waste heat from the condenser side.

At the V&A, the location of the heat network connections to the NHM and the two LTHW plate heat exchangers in the basement were identified with the help of the V&A team. These are presented as #1 and #2 respectively in Figure 3.

The site visit to the ScM further clarified the installed capacities and historic connection with the help of the ScM team. The boiler house which is #3 in Figure 3 was inspected. Furthermore, the connection leading to the NHM boiler house is also identified.

The NHM visit enabled us to understand the Energy Centre and its historical connection to other institutions. There is a tunnel which is accessible from the NHM boiler house to the ScM and potentially to Imperial. This tunnel includes several hot water pipes and some other services. A photo taken from the entrance of the tunnel is presented in #4 of Figure 3. This connection was further investigated and it was found as a route to reconnect the network to all institutions.

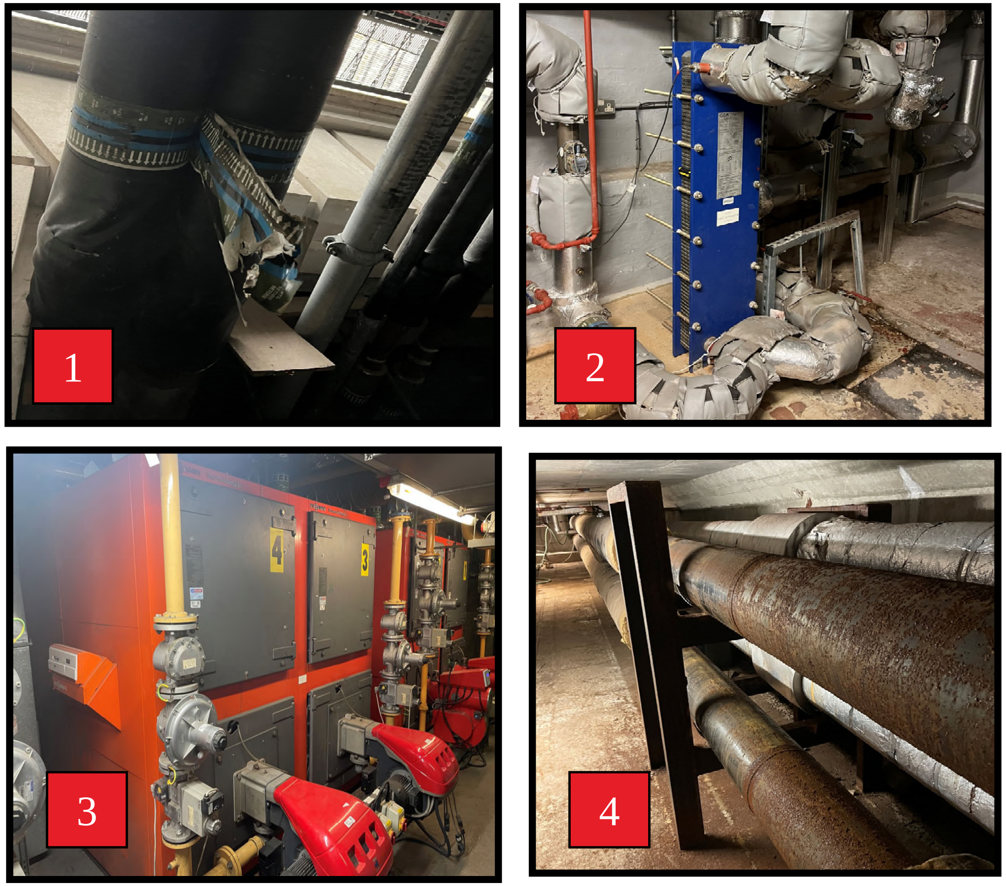

Figure 3. Key findings of the site visits

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3. Current energy infrastructure

Existing Energy Services Agreements (ESA)

A review of the current contracts that Imperial and NHM have with their Energy Services Companies (ESCos) has been undertaken to understand the opportunities and constraints for any future decarbonisation initiatives for each of the sites. They are referred to as Energy Services Agreements (ESA).

At both Imperial and NHM, the ESCo that runs each of their CHP plant facilities and heating infrastructure is Vital Energi.

Common features of both ESAs

Both ESAs have the following things in common:

- They cover the operation and maintenance of the Energy Centre energy plant and the associated heating networks. (In the case of the NHM, the heat network operation and replacement guarantee items only covers the NHM's heating system, not the V&A's.)

- Should any of the covered plant need replacement during the duration of the contract, this is covered by a replacement guarantee service.

- Performance Guarantees are in place such that Vital Energi are incentivised to ensure that the plant operates efficiently and achieves high availability. There is also the provision that the CHP plant should only be run when financially viable (e.g. when it saves them cost compared to turning it off and using boilers and imported electricity instead).

- Both contracts allow for voluntary termination by the client (Imperial or NHM as appropriate), however this is not at no cost, indeed the costs could be considerable, depending on several contractual variables.

Imperial ESA

The Imperial ESA started in August 2015, and terminates in June 2028. As a result of the current heat network and plant modifications being undertaken on the campus, it is currently being updated in line with the works.

The ESA does not specifically allow for low carbon technologies to be included within it. Indeed, the performance indicators are based around running the CHP plant for as long as possible whilst financially viable. However, the contract does allow for Imperial to request that the CHP plant is not run, as long as they pay the costs for the maintenance contract on it (sub-contracted to Clarke Energy).

As such, if any other heat provision was provided via new low carbon solutions, they would reduce the amount of heat provided by the CHP plant, and hence affect the financial impact of this ESA. In order to obtain best value, this ESA may need to be renegotiated, or if near to the termination date, tendered.

ARUP

3. Current energy infrastructure

Existing Energy Services Agreements (ESA)

NHM ESA

Vital Energi are currently replacing the CHP plant at NHM, and providing another energy plant as part of a refreshing of the Energy Centre plant. An air source heat pump (ASHP) is being provided with water source heat pumps (WSHP), to boost the temperature of the ASHP and CHP plant low grade heat circuits to provide heat to the heat network.

As the works are currently still being undertaken, the full agreement is yet to start. The expiry date of the contract is 15 years after the commencement of the full services, so it would be 2038 if commencement happens this year.

The performance guarantees within the ESA also incentivise the use of the CHP plant, but it allows for the heat pumps to be used instead. Both the CHP plant and the heat pumps have guaranteed efficiencies.

The NHM ESA was produced with decarbonisation in mind, the NHM having a target to be net zero carbon by 2035. An external source of low carbon heat was not necessarily considered though, so the options for this remain the same as for Imperial (if near to the termination date, retender, if not, renegotiate the ESA to reduce the CHP plant running hours and costs).

Summary of contract review

Both ESAs allow for the heat required from the Energy Centres to reduce as the site heat demands reduce. If the annual heat demands reduce below the outputs of the CHP plant output guaranteed, and this is because the site heat demand is being met by an offsite low-carbon source (or, for that matter, from the NHM or Imperial Energy Centres where the heat network between them is restored) it is likely that Vital Energi would request to vary the contract.

In any case, should the heat networks be reconnected, a more in-depth review of the ESAs should be undertaken.

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3. Current energy infrastructure

Current energy infrastructure

Table 1 provides a summary of the existing heating systems with their capacities. It also addresses the condition of these plants and any planned future upgrade. The expected lifecycle for this equipment is added based on CIBSE Guide M. For some of the items, further information is included.
There are various chillers on site of varying age and size, and we have surveyed some of them. When replacing the chillers that are approaching their end life, it would be advantageous for them to be replaced with a 4-pipe solution, to allow the recovery of the heat rejected into the LTHW heat network. It is recommended that this option is evaluated on a case-by-case basis for each chiller at the time of replacement.

Table 1. Main energy centres; asset details, expected lifecycles for replacement, and planned future changes

Energy Centre	Plant item	Current Capacity	Date installed	Expected lifecycle (per CIBSE Guide M)	Survey/ Condition	Planned Future Changes
Imperial	2 no. gas fired CHP engines	2 × JMS624 4.5 MW electrical output	2015	15 years	No problem identified. Maintenance strategy must be aligned with CIBSE Guide M.	Currently under consideration.
Imperial	3 no. gas fired steam boilers	3 × 12 MW steam boilers	1999	20 years	Currently being replaced – to be complete by end of 2023.	Replacement of steam boilers to LTHW boilers: 2 × combination boilers rated at 10MW (gas fired) + 2MW (heat recovery). 1 × 10MW gas fired only boiler.
ScM	5 no. gas fired boilers	5 × 0.895 MW	1998	20 years	No problem identified. Maintenance strategy must be alligned with CIBSE Guide M.	Currently under consideration.
NHM	1 no. gas fired CHP engine	1 × JMS612 1.8 MW electrical output (not yet operational nor commissioned)	2023	20 years	Currently being installed - not yet commissioned.	N/A
NHM	2 no. gas fired boilers	2 × 10.5 MW	1982	20 years (but under a 15 year warranty)	No problem identified. Maintenance strategy must be aligned with CIBSE Guide M.	Not planned within the next 15 years.
NHM	1 no. ASHP with associated WSHP temperature boost	1 × ASHP 456 kW and corresponding WSHP capacities (not yet operational or commissioned)	2023 (not yet commissioned)	15 years	Currently being provided – not yet commissioned.	N/A

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3. Current energy infrastructure

Current energy projects

Natural History Museum
The NHM is undertaking several energy-saving projects as part of their refurbishment of the Energy Centre, including the replacement of fans in their Air Handling Units. These measures also include replacing the existing CHP plant, installing photovoltaic panels and air-source and water-source heat pumps. The CHP plant will continue to operate in conjunction with the existing gas boilers. The project is expected to be completed during the summer of 2023.

Imperial College London
Imperial is in the process of extensive works under the Public Sector Decarbonisation scheme, which includes the removal of centrally-provided steam on site. The carbon savings will result from the new higher efficiency low temperature hot water boilers, a reduction in losses from the LTHW network due to network upgrades and the removal of significant losses associated with steam networks. The project is expected to be completed by the end of 2023.

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3. Current energy infrastructure

Feasibility of re-installing historical network connections

Visual evidence in the NHM energy centre, displayed on wall drawings (Figure 5), confirms that the four institutions were formerly interconnected to the heat network, receiving their heat supply from the NHM.

The connection tunnels were also observed during the site visit, which confirmed this situation. There is some evidence that steps have been undertaken by people unknown to prove that the network still works (this is evidenced by the removal of the Imperial and ScM connection from the NHM main header and installation of a pump). A photograph of the installation is shown in Figure 4.

Arup have also seen the 1961 heat supply contract between Imperial and the NHM.

There are two road access plates that need to be removed to visually inspect the network, and arrangements need to be made to finalise it. It is hoped this will be done by the time of the final report.

Connecting the institutions is considered feasible, but the following issues need to be considered:

- Imperial typically operate their heat network at 90°C flow, but have the ability to raise it to, nominally, 105°C in stress events (it should be noted that this was not required during the 'Beast from the East' cold weather event in March 2018).
- NHM's heat network operates at a flow temperature of between 85°C and 95°C, so is compatible with Imperial's.
- Imperial is increasing the capacity of their heat network, as they are moving the steam network loads to the LTHW network (and removing the steam network), so the pipes from the NHM to Imperial are likely to be undersized for the peak flow conditions if the Imperial Energy Centre were decommissioned. Indeed, it may be easier to supply the load the other way around (from the Imperial energy centre to the NHM).

Figure 4. Historical connection between NHM and ScM

3. Current energy infrastructure

Historical Pipe Route Diagram

The historic pipe route diagram is shown in Figure 5 opposite. It was drawn by Heating Ventilating Design Service (HVDS) and is dated October 1991. It is understood that the networks could be restored to a similar configuration, though geographically slightly different as some new buildings have been built over the top of some of the tunnels (for example the Sir Alexander Flemming Building in 1998). This is shown on the next page.

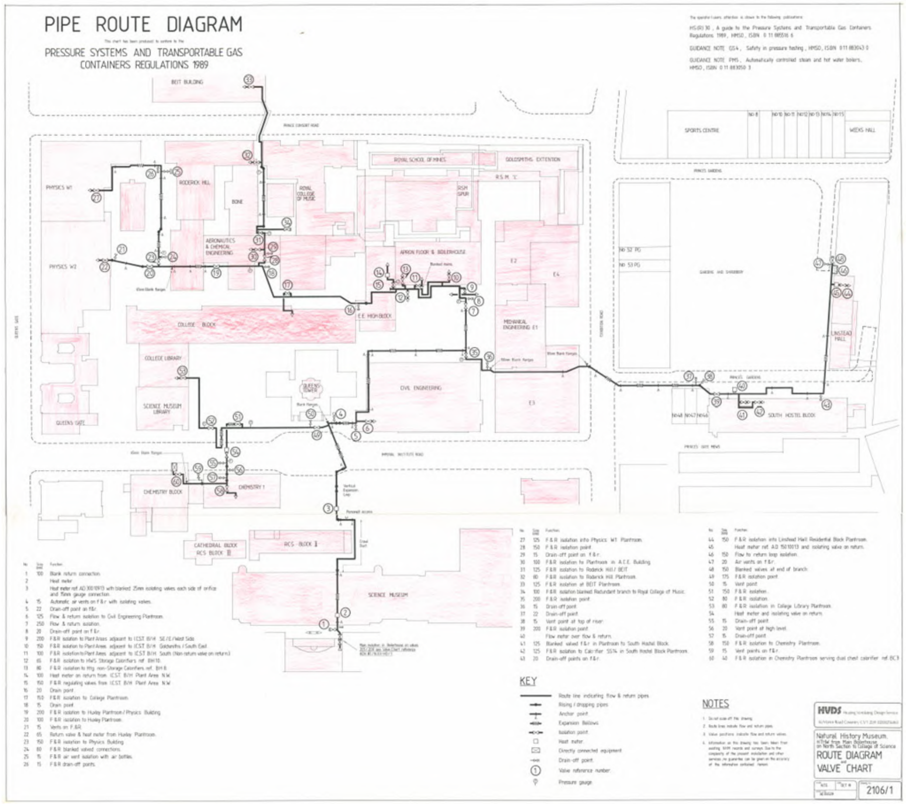


Figure 5. SK ZEN Historical connections between NHM – ScM – V&A (NHM wall drawing)

3. Current energy infrastructure

Current energy infrastructure diagram

After reviewing the existing documentation, record drawings and site visits; it can be seen how the four institutions were once connected.

Figure 6 presents the current connections in detail.

The connection between NHM, ScM and Imperial was investigated on-site and the existing sections of the previous connection between the ScM and NHM were identified, as can be seen in Figure 7.

Current LTHW works in progress

Existing LTHW heat network (verified on-site)

Existing LTHW Heat network (from record information)

NHM: VI 21 NHM LAY 001 - LTHW & Chilled Water Delivery & Termination Points
V&A: CHP-SCM-2 - High Temp Water Schematic
ICL: 50408-VEN-SW-XX-FA-M-5617- Steam &LTHW Site Distribution Layout

Historic LTHW heat network (verified on-site)

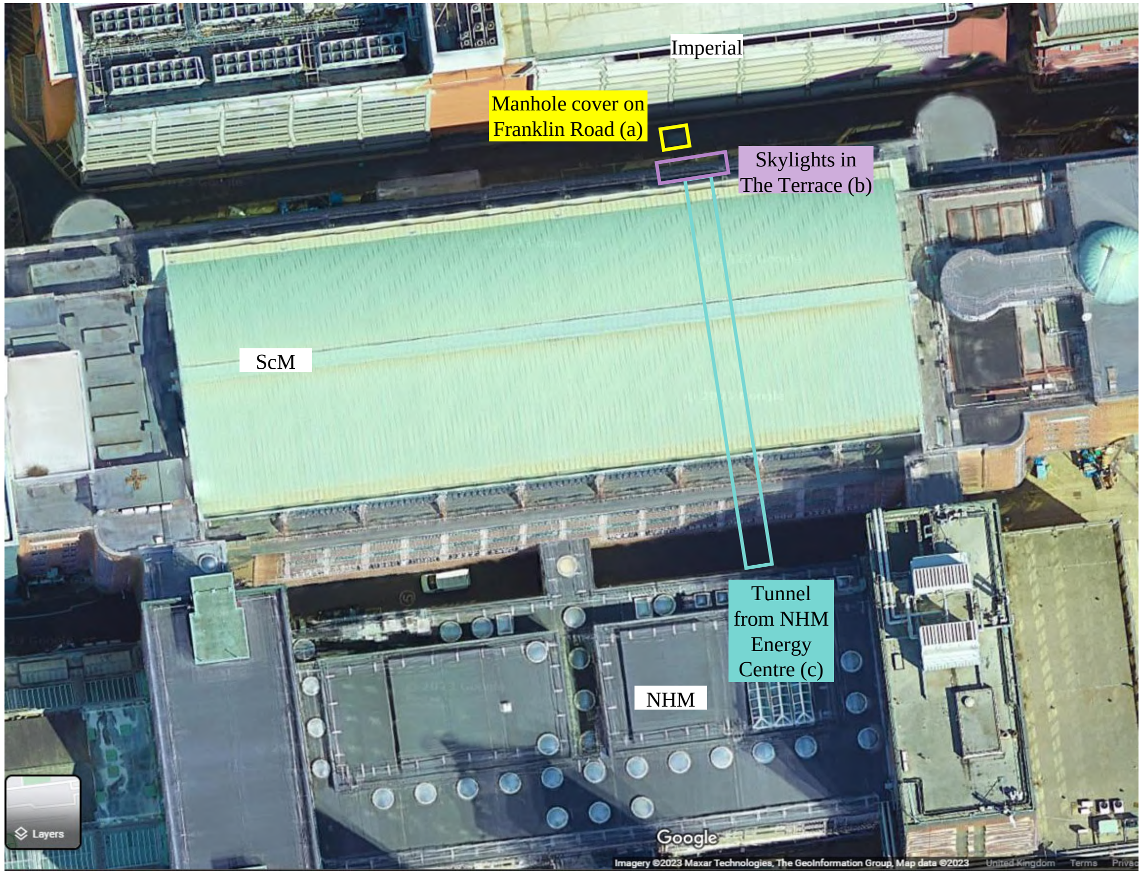
Figure 6. SK ZEN Heat Network – Existing Connections – All institutions

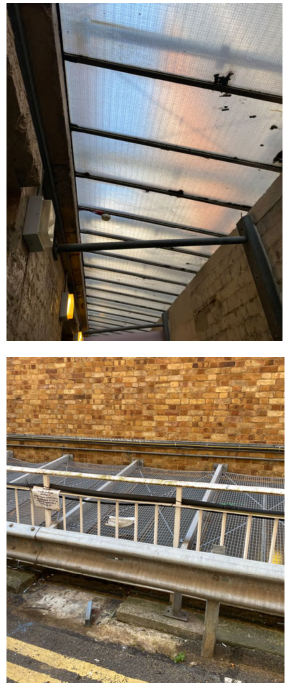
3. Current energy infrastructure

Re-establishing the network

Manhole cover on Franklin Road (a)

Tunnel (c)





Skylights in The Terrace (b)

Figure 7. Historic connection between NHM, ScM and Imperial

3. Current energy infrastructure

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Re-establishing the network

In order to reconnect the institutions, two connections are required:

1. Extending the current capped connection in the NHM Energy Centre to connect into the existing flow header.
2. Extending the pipework from the ScM "The Terrace" underneath Franklin Road into the existing SAF (Sir Alexander Fleming building) tunnel network connection.

Considerations:

1. The connection into the SAF tunnel is limited to a DN250 connection due to the existing Imperial network sizes. These sizes could be used to circumvent network upgrades from Franklin Road back to the Imperial Energy Centre underneath Electrical Engineering. However, careful control and hydraulic studies are required to balance the network connection.

2. A cost estimate of re-establishing this connection was done based on a DN250 pipe and found to be £250,000. This assumes that the existing pipework can be retained. This excludes penetrations into the SAF tunnel.

3. Road closures, traffic redirections and general disruptions were not included in this estimate.

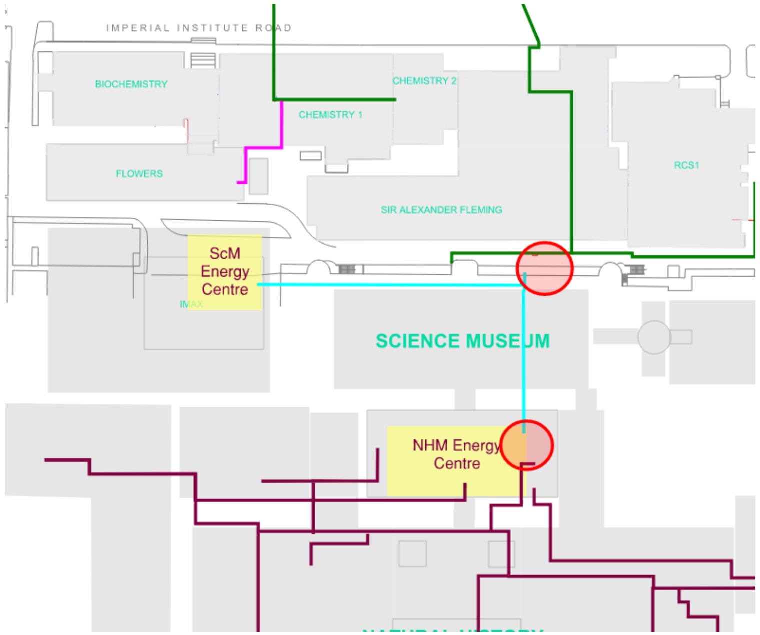

Figure 8. Heat network extensions to the existing infrastructure required

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4. Energy modelling

a. Methodology

To size plant at the next project stage, a heat load duration curve is required for each of the four connected institutions and a total one. As information was not available on an hourly basis for the institutions, it was needed to calculate a synthetic heating profile.

The modelling approach involved developing an energy model using a spreadsheet (MS Excel) to perform a comprehensive technical and financial evaluation of various decarbonization possibilities. The objective is to identify appropriately sized solutions for this project.

The first step of the energy modelling exercise was to assess data received from the institutions, including heating and electricity demands. For the museums, only monthly heat and gas consumption data was available.

Excel-based modelling is by nature a high-level modelling approach. To ensure maximum accuracy, it is essential to employ modelling based on hourly data. Converting monthly energy data into hourly data can be achieved through various methods. In this case, a regression analysis was conducted, specifically correlating heat consumption with heating degree days. Please refer to Figure 9 for a visual representation of this approach.

Detailed Imperial hourly data was available. The baseline period was fixed between August 2017 to July 2018.

To calculate the heating degree days (HDD), it was assumed that the base temperature at which the institutions turn heating on was 15.5 ºC. This is a typical assumption for museums and offices to reach an internal temperature between 17-19ºC. The outside dry bulb temperature for the period from August 2017 to July 2018 was provided by the Imperial weather station. Seasonal/local heating strategies adopted by the institutions were also taken into account to calculate the HDD. The assumptions used are summarized in Appendix B.

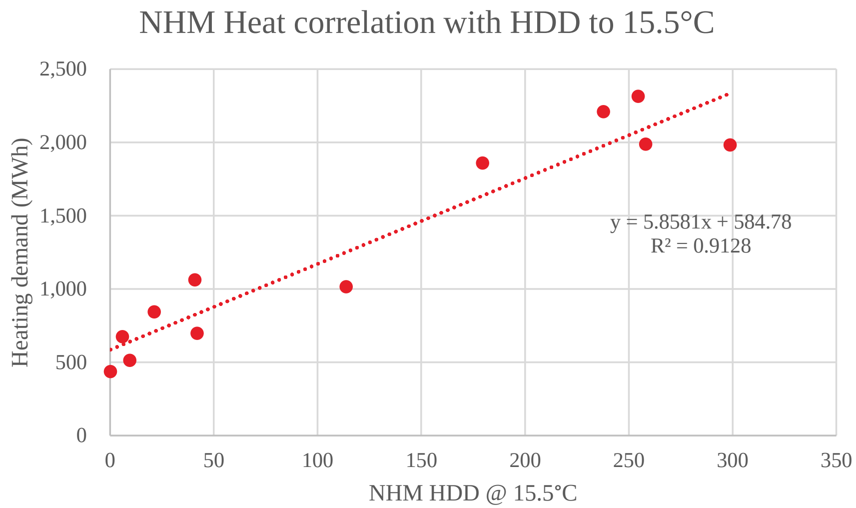

Figure 9. NHM regression analysis of heat consumption and HDD

Example outputs from the regression analysis include:

- $R^2 > 0.85$, which shows that there is a strong correlation between the heating degree days and the NHM's monthly heating data.
- The monthly Domestic Hot Water (DHW) load equals 585 MWh (the x-axis intercept).

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4. Energy modelling

a. Methodology

The regression formula presented in the previous slide was used for the heat demand correction as shown below.

After calculating the Heating Degree Days (HDD) as shown in Figure 10, the hourly profile was then applied to the monthly corrected space heating data to produce an hourly profile resolution of the space heating data as well, Figure 11.

The corresponding figures for the V&A and the ScM are presented in Appendix C.

Table 2. NHM monthly heating data (original and corrected)

Timestamp	NHM Heat, MWh	NHM heat demand correction, MWh	NHM space heating, MWh	NHM DHW, MWh
Aug-17	674	620	35	585
Sep-17	843	710	125	585
Oct-17	1,062	825	240	585
Nov-17	1,858	1,637	1,052	585
Dec-17	2,314	2,076	1,491	585
Jan-18	2,209	1,978	1,394	585
Feb-18	1,982	2,336	1,751	585
Mar-18	1,987	2,097	1,512	585
Apr-18	1,015	1,252	667	585
May-18	697	831	246	585
Jun-18	512	641	56	585
Jul-18	436	586	1	585

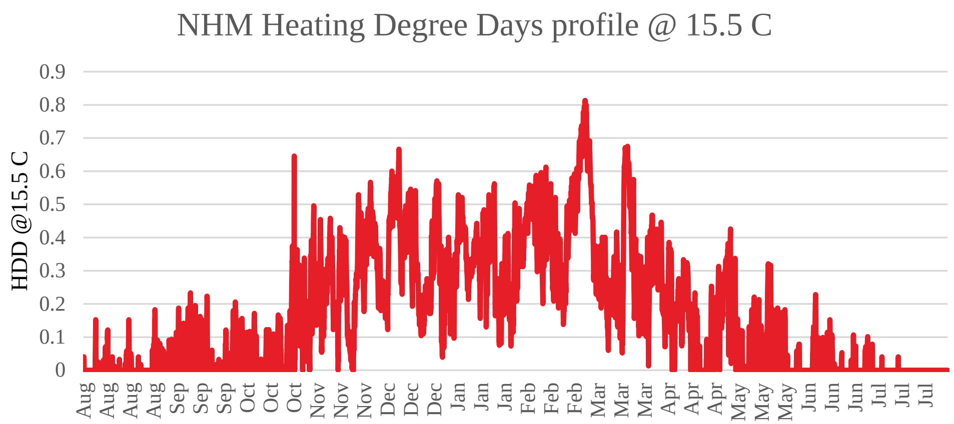

Figure 10. NHM HDD profile

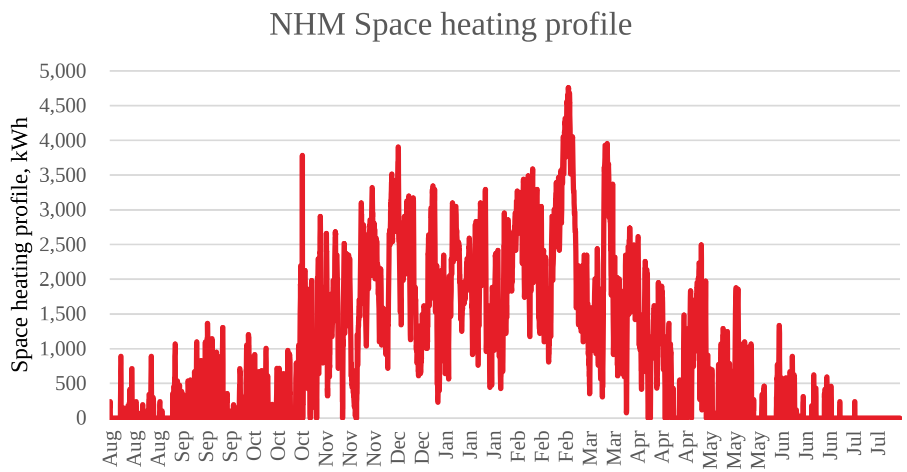

Figure 11. NHM space heating profile

4. Energy modelling

b. Baseline annual heat consumption

Figure 12 presents the total heat demand for all institutions from August 2017 – July 2018. The figures were calculated based on the provided data.

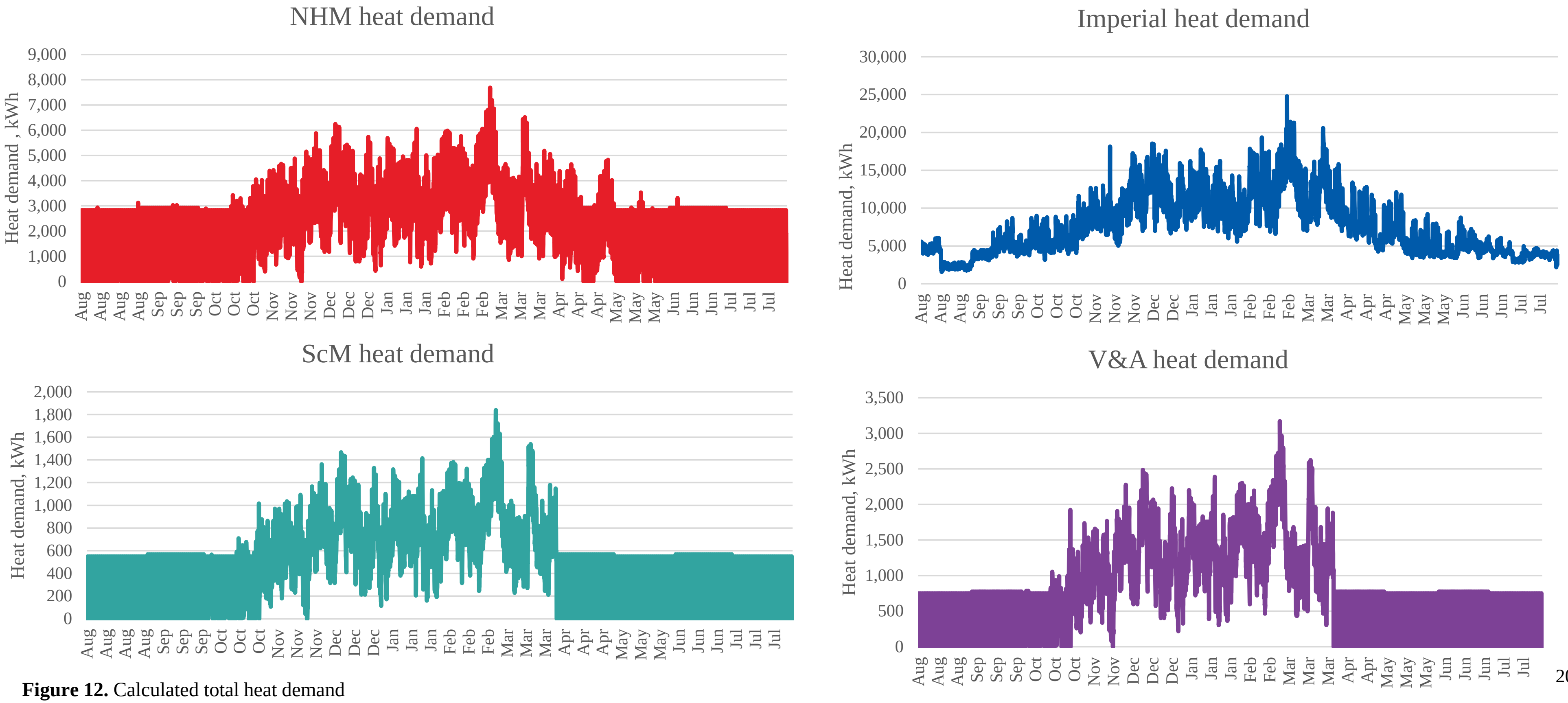

Figure 12. Calculated total heat demand

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4. Energy modelling

c. Heat load duration curve

The duration of the heat loads for each institution is shown in Figure 13. The heat load duration curves will be critical at sizing low carbon heating systems such as heat pumps or electrical boilers. The heat load duration curve also indicates the time for which a load occurs, preventing oversizing of equipment.

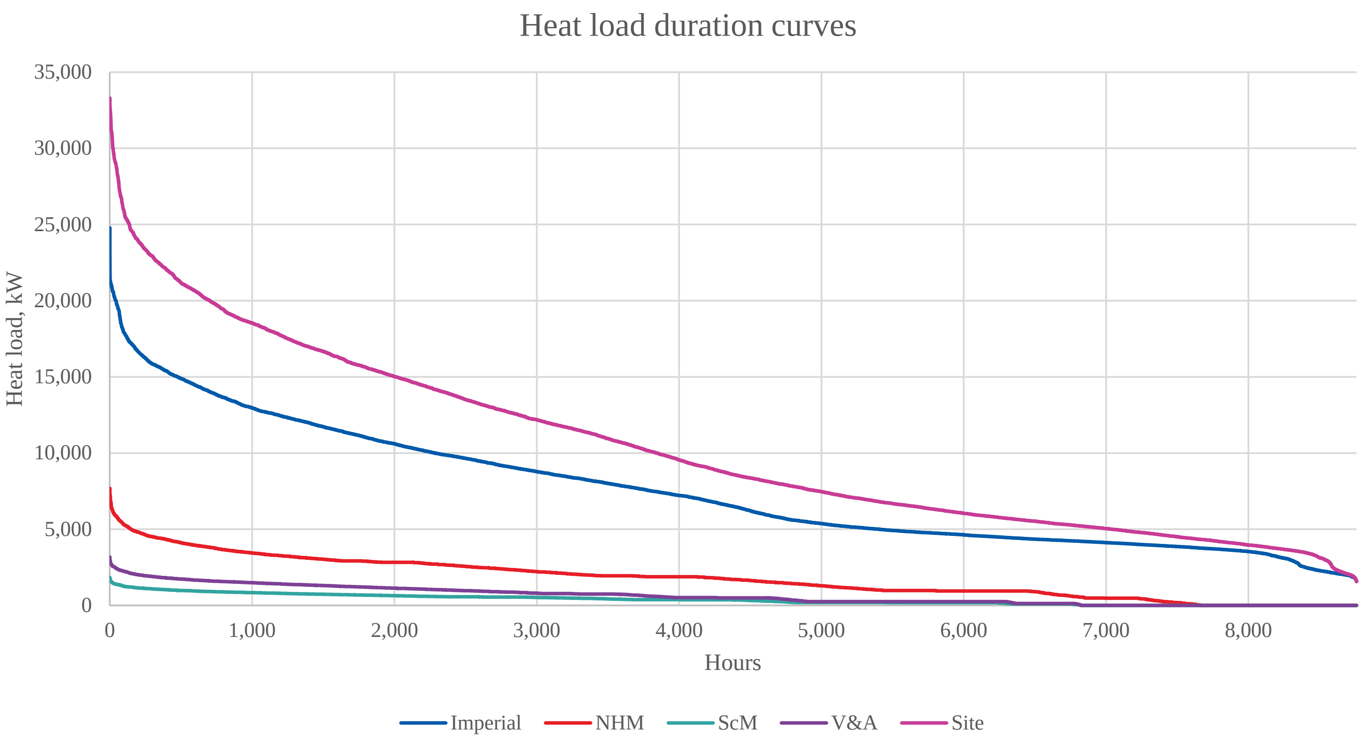

Figure 13. Heat load duration curves

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4. Energy modelling

d. Baseline scenario – summary 2018

The table below summarizes the heat data for the baseline scenario. A breakdown of heat consumption of each institution is also provided. As shown in the Table 3, the total site heat consumption of the site is approximately 87 GWh. The graphs in Figure 14 illustrate the amount of heat provided by boilers and/or CHP to each institution.

All the NHM (including V&A) data presented in the table below is for the period January 2018 – December 2018.
All Imperial data presented in the table below is from the Vital Energi end of year 2018 operational report.

Table 3. Baseline heat summary

Baseline Heat Data	Annual heating, kWh	Heating, kWh/m²
Total heat provided from gas boiler plant	32,548,609	170
• Imperial heat provided by gas boilers	24,183,134	72
• ScM heat provided by gas boilers	3,268,435	52
• NHM heat provided by gas boilers	5,097,040	46
Total heat provided from CHP plant	54,524,395	266
• Imperial heat provided by CHP plant	40,883,435	122
• ScM heat provided by CHP plant	N/A	N/A
• NHM heat provided by CHP plant	13,640,960	122
NHM absorption chiller heat consumption	2,345,400	21
Total site heat consumption	87,073,004	368
• Imperial site-wide heat consumption	65,066,569	195
• ScM site-wide heat consumption	3,268,435	52
• NHM site-wide heat consumption	13,571,000	122
• V&A site-wide heat consumption	5,167,000	N/A

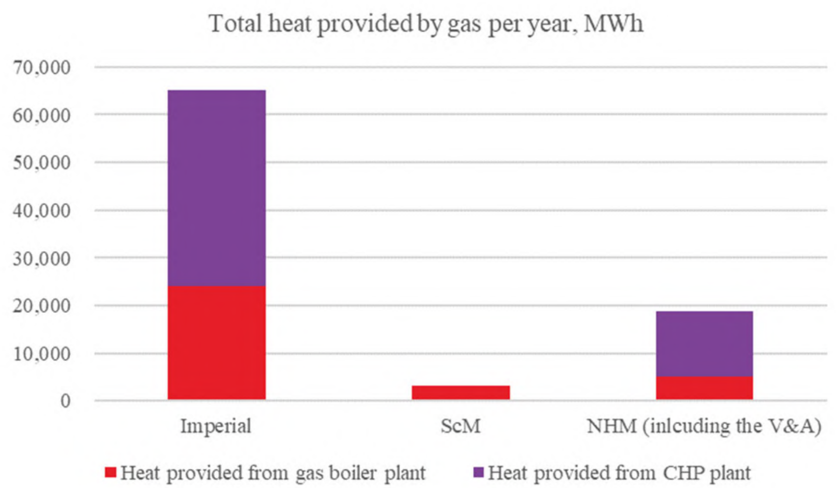

Figure 14. Total heat provided (MWh)

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4. Energy modelling

d. Baseline scenario – summary 2018

The table below summarizes the gas data for the baseline scenario. A breakdown of gas consumption for each institution is also provided. As shown in the Table 4, the total site gas consumption of the site is approximately 244 GWh.

All the NHM (including V&A) data presented in the table below is for the period January 2018 – December 2018.
All Imperial data presented in the table below is from the Vital Energi end of year 2018 operational report.

Table 4. Baseline gas summary

Baseline Gas data	Gas usage, kWh	Gas usage, kWh/m²
Total site gas boiler gas consumption	**43,624,533**	**258**
• Imperial consumption	26,690,339	80
• ScM consumption	3,845,218	61
• NHM consumption	13,088,976	117
Total site CHP gas consumption	**200,104,833**	**825**
• Imperial consumption	162,195,943	485
• ScM consumption	N/A	N/A
• NHM consumption	37,908,890	340
Total site boiler and CHP plant gas	**243,729,366**	**1,083**
• Imperial consumption	188,886,282	565
• ScM consumption	3,845,218	61
• NHM consumption	50,997,866	458

4. Energy modelling

ARUP

d. Baseline scenario – summary 2018

The table below summarizes the electricity data for the baseline scenario. A breakdown of electricity consumption for each institution is also provided. As shown in the Table 5, the total site electricity consumption is approximately 111 GWh.

All the NHM (including V&A) data presented in the table below is for the period January 2018 – December 2018.
All Imperial data presented in the table below is from the Vital Energi end of year 2018 operational report.

Table 5. Baseline electricity summary

Baseline electricity data	Electricity usage, kWh	Electricity usage, kWh/m²
Total imported electricity	**32,605,216**	**179**
• NHM imported electricity	13,678,216	123
• Imperial imported electricity	18,927,000	57
Total exported electricity	**405,000**	**1**
• NHM exported electricity	0	0
• Imperial exported electricity	405,000	1
Total CHP generated electricity	**78,159,985**	**322**
• NHM CHP generated electricity	14,683,500	132
• Imperial CHP generated electricity	63,476,485	190
Total site electricity consumption	**111,012,188**	**472**
• Imperial electricity consumption	82,403,485	246
• NHM electricity consumption	14,171,015	127
• Export electricity to ScM	6,204,926	98
• Export electricity to V&A	8,232,762	N/A

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4. Energy modelling

d. Baseline scenario – summary 2018

Table 6 summarizes the total carbon emissions of the site for the period January 2018 – December 2018, detailing emissions from gas and electricity. These results are also shown in Figure 15. Their corresponding greenhouse gas conversion factors are outlined in Table 7.

Table 6. Baseline scenario summary

Baseline carbon dioxide emissions	Units	Values
Total emissions	tCO_2e	67,968
Emissions from gas	tCO_2e	44,490
Emissions from electricity	tCO_2e	23,478

Table 7. Greenhouse gas conversion actors (BEIS)

Greenhouse gas conversion factor, 2022	Units	Values
UK electricity (including transmission and distribution)	$kgCO_2e\ kWh^{-1}$	0.21107
Natural Gas (Based on Gross Calorific Value)	$kgCO_2e\ kWh^{-1}$	0.18

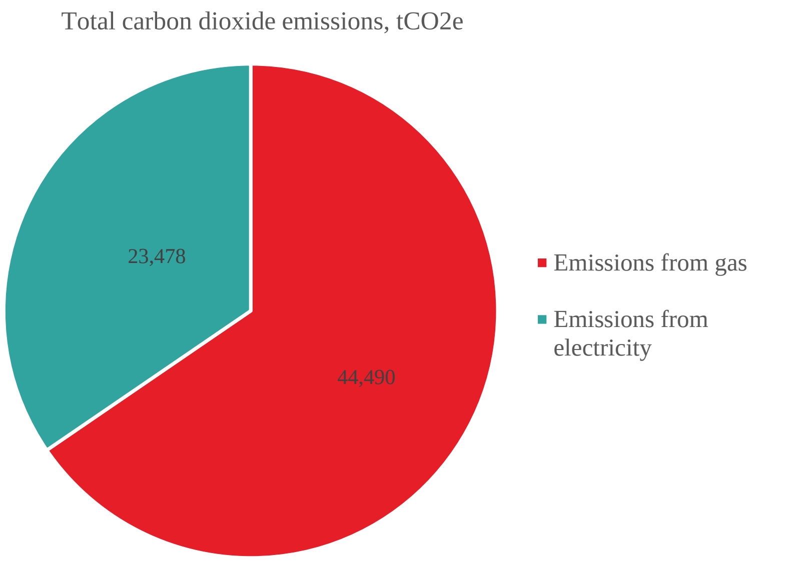

Figure 15. Baseline CO_2 emissions

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4. Energy modelling

e. Results of the energy modelling (load benchmarking)

After receiving electricity and heat data from the institutions, the data was assessed, and a baseline energy model was produced to allow the benchmarking of the existing energy load at each of the four institutions and at the site level. The key outputs from this baseline energy modelling are:

- Total heat demand of the site
- Total electricity demand of the site
- Total gas consumption of the site
- Total carbon emissions.

A consolidated energy infrastructure record plan was also produced; please refer to Appendix A. The ongoing and planned possible retrofit changes to the site have also been considered in the preparation of this baseline energy infrastructure record plan. From this baseline, a full carbon trajectory can be created when considering the interventions in the next phase where the decarbonisation measures will be compared to the baseline figures summarized in Tables 3, 4, 5 and 6.

5. Interfaces with external partners

Stakeholder Engagement

Within the scope of this feasibility study on heat network decarbonisation, there are opportunities to investigate the potential for heat recovery from various sources, including the region's sewers, adjacent underground systems, and buildings in close proximity. Arup have also engaged with the potential stakeholders at this stage of the project.

Thames Water

An initial meeting with Thames Water was held on the 18 April 2023, where Arup provided background on this project to the Thames Water team. Thames Water seemed eager to help with providing the data needed for the waste heat recovery modelling upon receipt of an NDA, which Arup has since submitted.

Key conclusions from the Arup/Thames Water meeting:

- Thames Water are developing a pricing mechanism for selling heat recovered from the sewers.
- Thames Water can provide a sewer map for the South Kensington area, however this is a lengthy process.
- Sewer water temperature is typically between 15 – 25ºC.

Transport for London (TfL)

Arup had a meeting with Transport for London on the 9 May 2023 to discuss the SK ZEN project and potential heat recovery from nearby underground stations, particularly the South Kensington (SK) Station. TfL are keen to support and they mentioned the availability of a constant underground pumped water source in the station. They also explained that the station ventilation fans are not operational all the time, therefore the warm air in the tube is not useful as a potential reliable heat source. TfL provided their pumped water source report, as it was written by Arup, which is used as a basis for the feasibility study, but which cannot be shared as it was supplied on a confidential basis.

Westminster City Council (WC)

Arup met with Westminster City Council Energy Team on 19 April 2023. The goal was to identify any nearby heat networks, heating and cooling sources. Buro Happold are developing heat maps for the area, which are going to be shared with Arup within the framework of this project.

Royal Borough of Kensington and Chelsea (RBKC)

Arup met with the Royal Borough of Kensington and Chelsea on the 4 May 2023 for the same reasons as for Westminster City Council. We are also exploring the potential to benefit from the existing or future heat networks developed within these boroughs. There will be a follow up meeting at the end of the May 2023 to learn further about the recent developments.

5. Interfaces with external partners

Stakeholder Engagement

UKPN

- The UKPN supply locations were identified.
- These were discussed with the UKPN representative and confirmation was received of these locations.

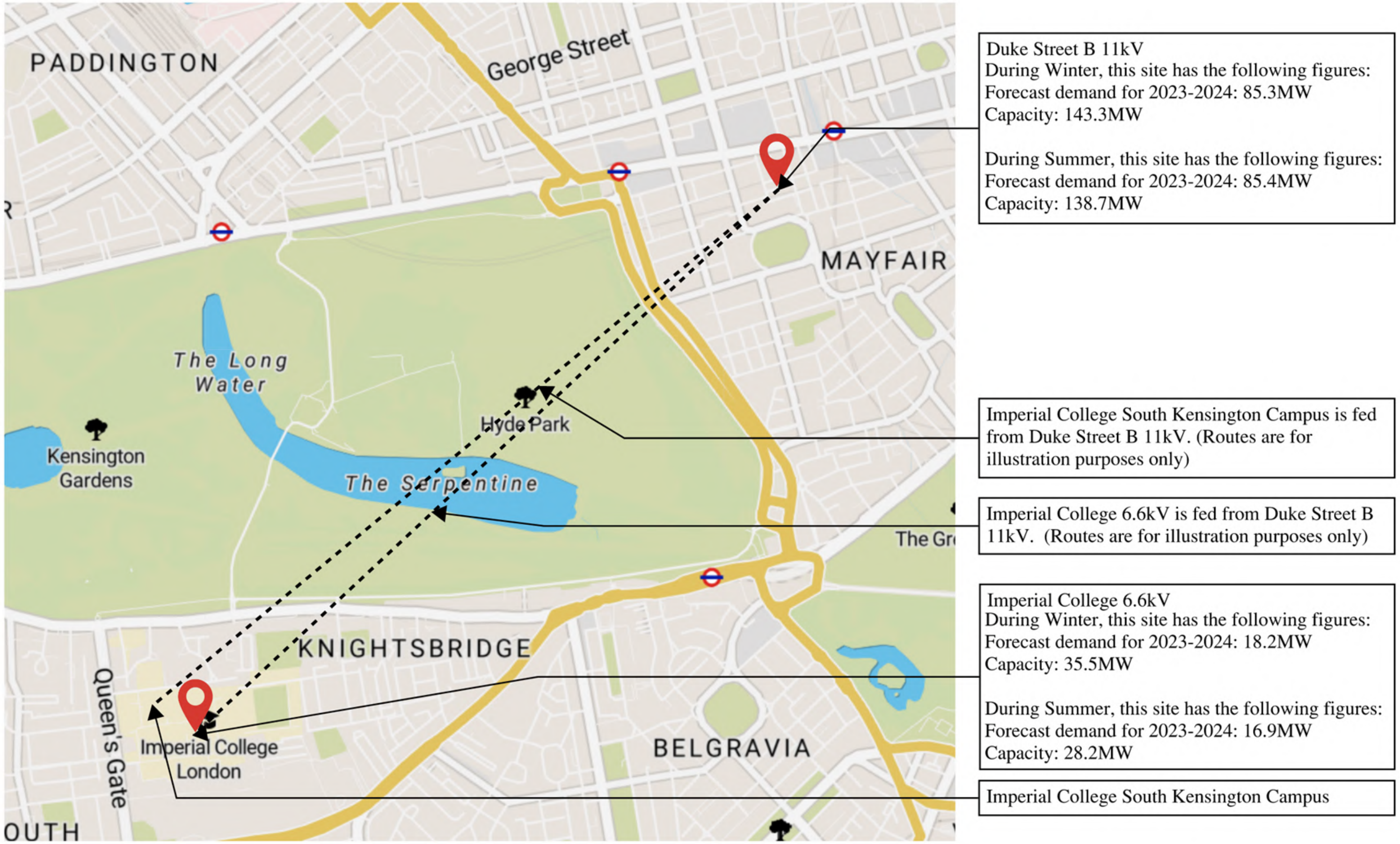


Figure 16. Electrical supply connection from Duke Street to Imperial College

5. Interfaces with external partners

Stakeholder Engagement

UKPN

- Imperial College South Kensington Campus is supplied from the Duke Street 11kV Site.
- Imperial 6kV Site then supplies to the NHM.
- The NHM Site then distributes to the SCM and the V&A.
- The electrical supply diagrams are provided in Appendix D.

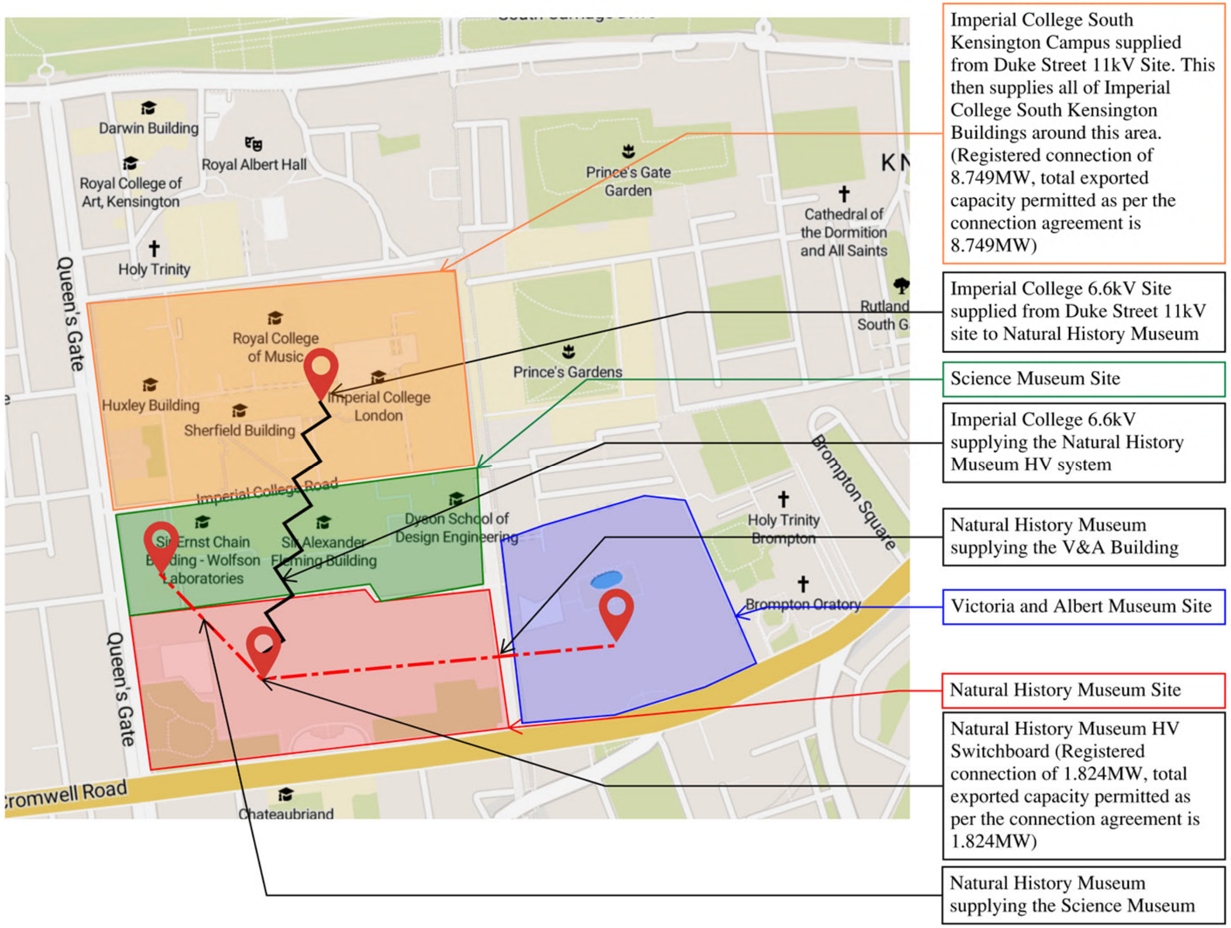


Figure 17. Electrical supply network between the institutions

Appendix A

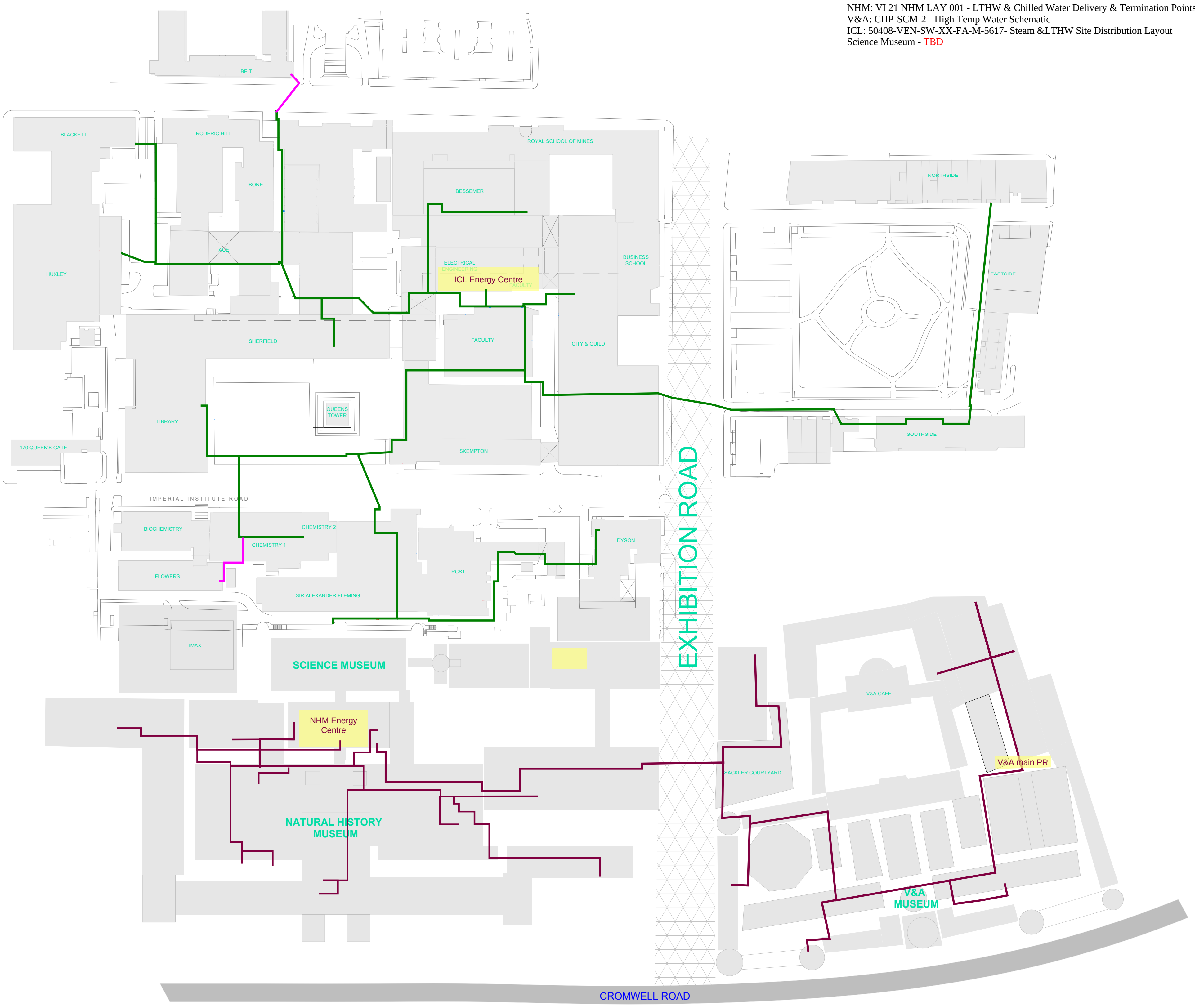
Current energy infrastructure diagram

Current LTHW works in progress

Existing LTHW heat network (verified on-site)

Existing LTHW Heat network (from record information)

NHM: VI 21 NHM LAY 001 - LTHW & Chilled Water Delivery & Termination Points
V&A: CHP-SCM-2 - High Temp Water Schematic
ICL: 50408-VEN-SW-XX-FA-M-5617- Steam &LTHW Site Distribution Layout
Science Museum - TBD



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Job Title SK ZEN			Job No. 294740-00
Sketch Title Simplified existing LTHW heat network			Sketch No. SK-00-0001
Purpose of Issue For Information			Scale NTS
By AdT	Checked DW	Revision 01	Date 18/05/23

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Appendix B

Modelling assumptions

Number	Assumption	Reference
1.	Imperial heat data – baseline period from August 2017 to July 2018.	Arup previous project
2.	Imperial electricity hourly data.	Arup previous project
3.	ScM - Monthly heating data for August 2017 to July 2018.	ScM
4.	HDD baseline temperature assumed to be 15.5C to achieve a temperature inside the Museums and offices between 17 – 19C	
5.	NHM monthly heat data for August 2017 – July 2018.	NHM
6.	NHM half hourly electrical data	NHM
7.	V&A heat data missing for couple months between August 2017 – July 2018. Average values have been calculated from the received data.	V&A
8.	Outdoor dry bulb temperature	Imperial weather station
9.	Imperial Heat network losses 11%	DECC
10.	Gas and electricity carbon factors: - Electricity kgCO2/kWh 0.21149 - Gas kgCO2/kWh 0.18254	BEIS Carbon factors 2022

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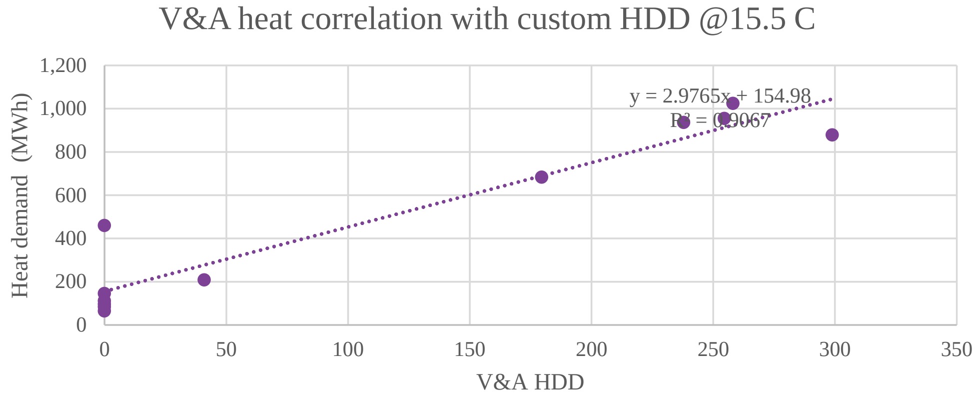
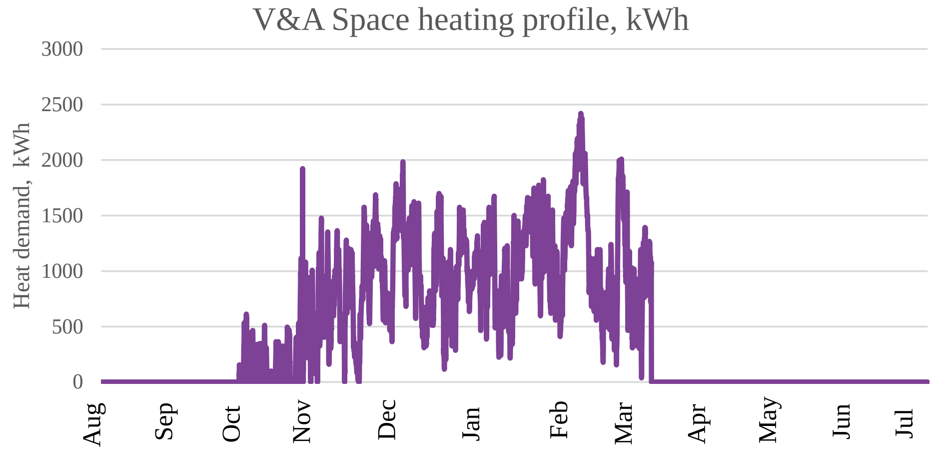
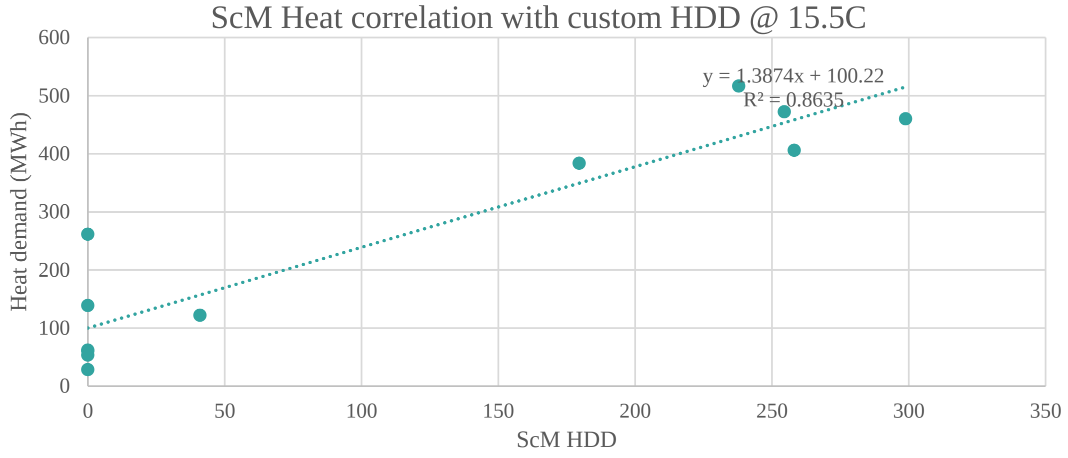
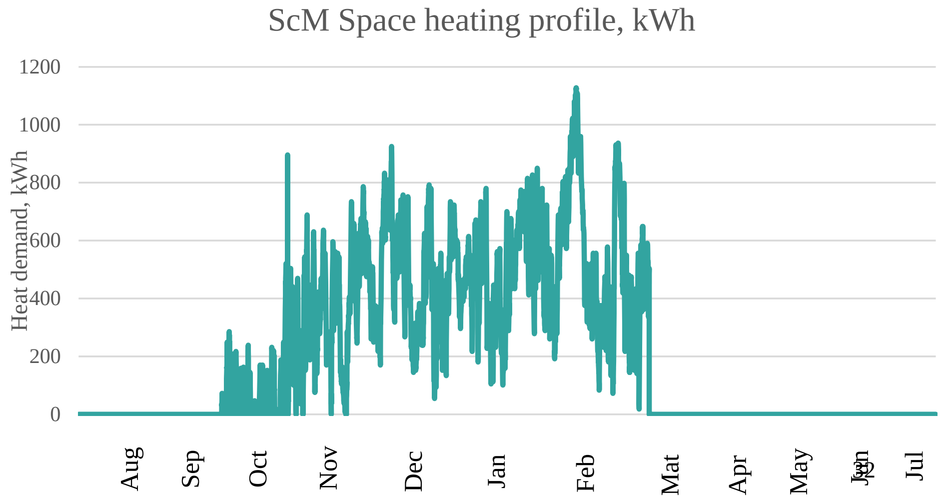
Appendix C

Methodology continued – V&A and ScM energy breakdowns



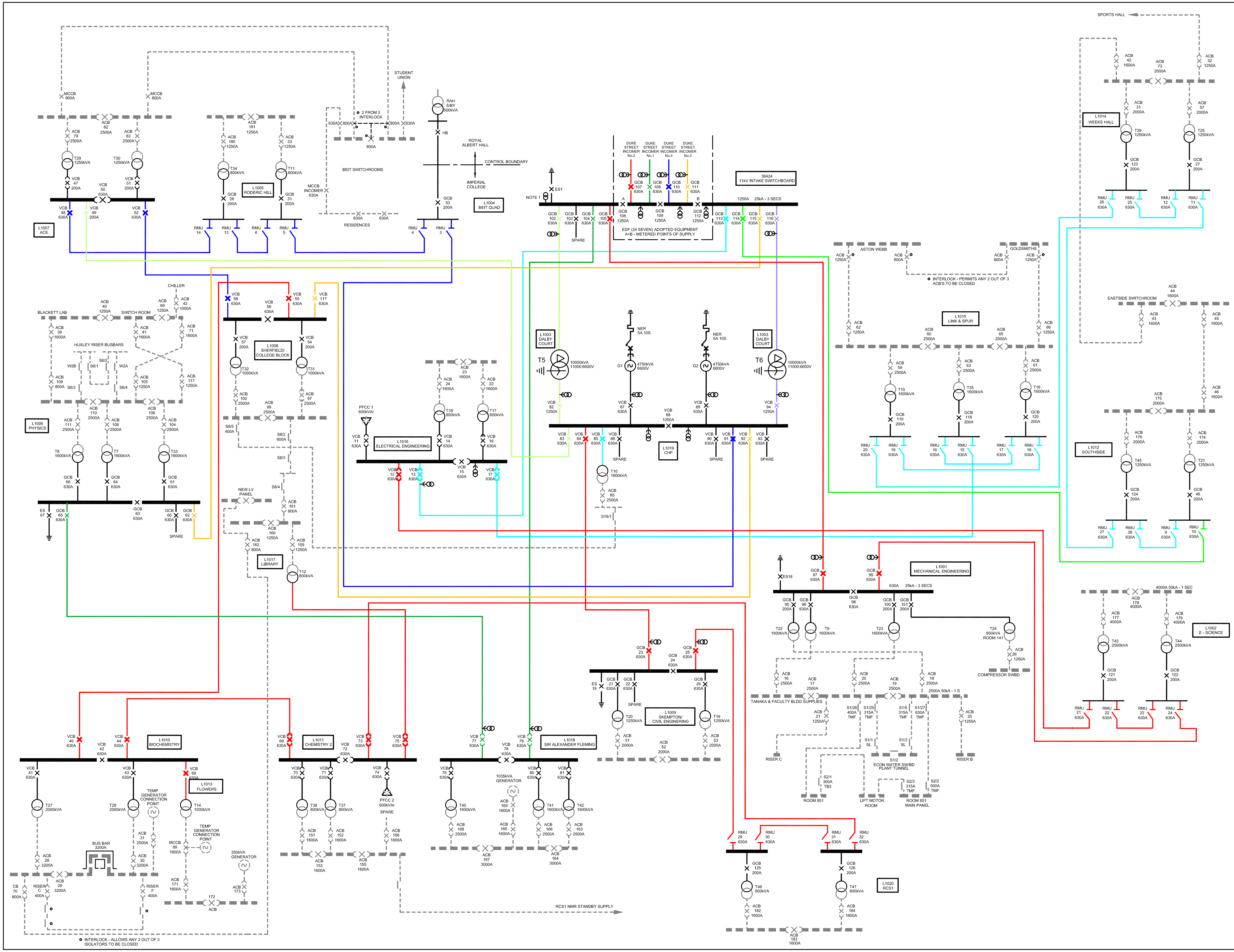






Appendix D

Electrical supply diagrams



LEGEND

- POWER TRANSFORMER
- DISTRIBUTION TRANSFORMER
- VOLTAGE TRANSFORMER
- ISOLATING CONTACTS (ACB)
- H.V CONTACTOR (NER)
- L.V DICONNECTOR/FUSE SWITCH - FUSE TYPE SHOWN FOR FUSE SWITCHES

ACB - AIR CIRCUIT BREAKER (LV)
OCB - OIL CIRCUIT BREAKER (HV)
VCB - VACUUM CIRCUIT BREAKER (HV)
GCB - GAS CIRCUIT BREAKER - SF6 (HV)
RMU - RING MAIN UNIT
NER - NEUTRAL EARTHING RESISTOR

- H.V DISTRIBUTION - 11kV
- H.V DISTRIBUTION - 6.6kV
- L.V DISTRIBUTION

NOTE

1. ISOLATION OF VT, LV ONLY

Revision	Description	Date
G	ACB31 & MCCB89 ADDED	16.07.13

Imperial College London

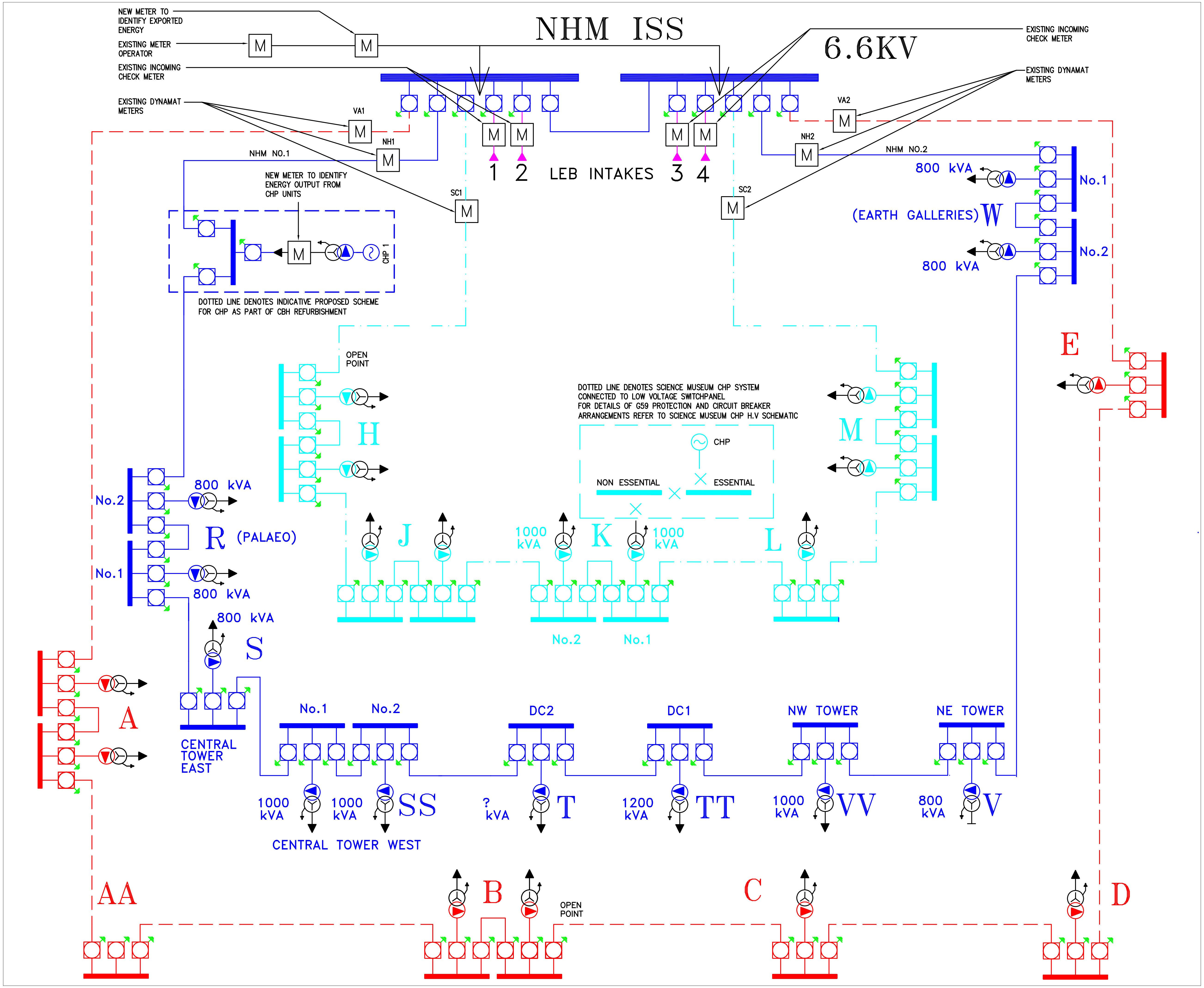
Estates
Project Office
South Kensington Campus London SW7 2AZ
Tel: 020 7594 8926 Fax: 020 7594 8925

Project: SOUTH KENSINGTON CAMPUS

Title: PRIMARY ELECTRICAL DISTRIBUTION SINGLE LINE DIAGRAM

Drawn by	Checked	File
FEP	LJ	SCHE0005G

Drawing Number	Revision	Scale / Date
CAMP/SCH/E/0005	H	N.T.S. / DEC 2015



NOTE

1.UNLESS OTHERWISE DENOTED ALL TRANSFORMERS ARE 800 kVA RATED

KEY

- NHM SYSTEM
- ScM SYSTEM
- V&A SYSTEM
- LEB SYSTEM

REV	DATE	MODIFICATION

ESTATE MANAGEMENT

NATURAL HISTORY MUSEUM

The Natural History Museum
Cromwell Road
London
SW7 5BD

PROJECT EXISTING H.V NETWORK

TITLE

H.V SCHEMATIC SHOWING C.B.H PROPOSALS

DRAWN BY: GPB	SCALE: 1 : 100
DATE: Sept 2006	N.H.M. CHECKED BY
N.H.M. ESTATES AUTOCAD DRAWING REFERENCE NUMBER	
N.H.M. ESTATES DRAWING NUMBER: xx/xx/xxxxx	
REVISION	

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Appendix B – Calculation assumptions

Sewer Source

Primary assumptions
1. Heat recovery is based on 10% of the dry water flow flowrate for LL2 (low level 2) sewer confirmed by Thames Water.
2. Typical range of flow removed from sewer for heat is in the range of 10-50%.
3. The upper limit has been used for this assessment to represent a maximum value - 50%.

Imperial Aquifer

Primary assumptions
1. Refer to "Imperial College London Test Borehole As Built Information Report" issued on early 2015 by IFTECH, the maximum constant rate pumping test and step test flow rates were 50m^3/hr and 60m^3/hr (14 l/s and 17 l/s) respectively. For the subsequent open loop assessment, Arup Geotechnical engineers have assumed a sustainable flow rate of 30 l/s is possible and has been used in this report. This should be validated by a flow test at the next stage.
2. The separation between injection and abstraction borehole is more than 100 metres.[16]
3. No existing ground source system is installed nearby which may affect the Aquifer's thermal properties. It will be followed up in the next stage.

The Serpentine

Primary assumptions
1. The physical dimension of Serpentine varies due to several factors, such as weather conditions and the inflow and outflow of water from the existing borehole. For the purpose of this report, an average surface area of 145,000m^2 and an average depth of 4.5m are assumed, with the heat exchanger installation positioned at a depth of 4.5m.
2. Maximum allowable temperature change of Serpentine due to the system is equal or less than 1°C.
3. The lake water is well mixed, and the water temperature is uniformly distributed in the lake.

TfL Rejected Water

Primary assumptions
1. UK ground water is typically between 8-12°C. Temperature measured during December at SK is 16°C.
2 Heat output estimated using the current pump operating schedule.
3. Average monthly water flow available for extraction is 28 l/s. This value in reality is likely to be more sporadic.

Whole life carbon

Primary assumptions
1. In the absence of manufacturer data of the specific product specified, the following simplified calculation approaches have been assumed:

[16] CIBSE CP3 Open-loop groundwater source heat pumps: Code of Practice for the UK (2019)

- Pumps: The weight of the 22, 28, 29, 30 and 40 l/s pumps have been calculated based on the kg per l/s of a 20 l/s GRUNDFOS pump. This weight has been used to scale the embodied carbon of a circulatory pump with available embodied carbon data. - Water source heat pumps: The weight of the selected plant item has been used to scale the embodied carbon of a similar sized centrifugal chiller. - Pressure regulator: The weight of the unit has been used to scale the embodied carbon of a pressure regulator with available embodied carbon data. - Expansion vessel: The weight of the unit has been used to scale the embodied carbon of an expansion vessel with available embodied carbon data - Buffer vessel: The weight of the unit has been used to scale the embodied carbon of a pressure regulator with available embodied carbon data - Plate heat exchanger (PHE): The weight of each PHE has been calculated based on the kg/kW of a 1MW Alfa Laval TL15-BFM unit. The total weight of the unit has been applied to Alfa Laval Steel with available embodied carbon data. - Titanium PHE: The weight of each titanium PHE has been calculated based on the kg/kW of a 670KW Alfa Laval TL15-BFM titanium unit. The total weight of the unit has been applied to Alfa Laval Steel with available embodied carbon data. - Lake source heat exchanger: The total weight of the unit specified has been applied to Alfa Laval steel with available embodied carbon data. - Sewer extract screw lift motor: 300kg of steel and a motor with available embodied carbon data and similar weight to a 11kW AC motor has been used.
2. For all DN150, DN250 and DN350 pipework a 30% contingency has been applied to the length of the pipework to account for brackets, ancillaries and valves in line with the capital cost calculations.
3. For all DN450 pipework a 40% contingency has been applied to the length of the pipework to account for brackets, ancillaries and valves in line with the capital cost calculations
4. To account for bends in pipework, the cost of the bends compared to the cost of the pipework has been used to calculate a cost adjustment factor to scale up the quantity of pipework.
5. The total weight of R717 refrigerant charge has been taken from the relevant WSHP data sheet, an annual leakage rate of 2% and an end-of-life leakage rate of 1% has been used as recommended by the Arup engineering team.
6. The refill of trenches for pipework has been assumed to consist of only aggregate, concrete to refill pavements has not been included.
7. Future substitution of existing equipment such as ventilation for plant rooms has not been included in the assessment as this equipment will need to be replaced even if none of the options are in place, so the calculation would not impact the results.

Whole life carbon – equipment replacement cycles

Plant Item	Service life (years)
1. Pipework + insulation	35
2. Water source heat pump	20
3. Pumps	20
4. Plate heat exchangers	25
5. Lake source heat exchanger	25
6. Buffer tank and expansion vessel	10
7. Motor	20

Appendix C – Financial assumptions

Operational energy - Exclusions and assumptions

1. The heat demand data was taken for the year from 01/08/17 to 31/07/18.

2. Energy costs (gas and electricity) used were taken from the DESNZ Quarterly Energy Prices: June 2023 (https://www.gov.uk/government/statistics/quarterly-energy-prices-june-2023)

3. Payments to heat providers (TfL, Thames Water, Royal Parks) to be added in the next project stage.

4. Gas fired boiler house parasitic use was estimated from Vital Energi Imperial College London Operational Report (January 2023).

5. Gas fired boiler efficiency was assumed as 82% to determine gas consumption.

Capital cost - Exclusions and assumptions

a. Where historical cost information has been used, the backdated inflation rate published by the Bank of England has been applied to reflect the equivalent present-day value. 2020-2023 equates to 16%.

b. Costs associated with new pipework, insulation, flanges, brackets, valves within plantrooms/energy centre are assumed to equal 25% of the mechanical equipment cost.

c. Brackets, valves and ancillaries have been included as an allowance of 15% of the heat network cost.

d. A client risk allowance of 15% has been included to allow for design development, unforeseen works during construction, client change during design and construction, and any other client risks, to a reasonable extent.

e. An allowance for project/design team professional fees is included at 6%.

f. An allowance of 10% of the estimate for mechanical and electrical services has been included for testing and commissioning.

g. Contractor preliminaries have been included at 15% of the cost of construction works.

h. Contractor’s Overheads and Profit is estimated at 10% of the construction.

i. Rates have been determined using one of the following sources: SPONS 2020, SPONS 2023, manufacturer selections, web-based resources, previous Arup projects and Arup Rules of Thumb.

j. Excavation costs and utility diversions associated with network pipes have not been included.

k. Protection to works areas, plant and equipment being retained, will be required.

l. The estimate does not include committed costs associated with the production of the design information.

m. Does not include for physical restrictions or limitations in accessing site.

n. Fluctuations in labour, materials, equipment and plant costs; and inflation (i.e., differential inflation due to market factors and/or timing) are excluded.

o. All client on-costs and directly procured items associated with the works are excluded.

p. Works to areas not described or shown on the design information provided are excluded.

q. Reconfiguration of internal and external layouts, unless otherwise stated, are excluded.

r. Allowance for Other Development / Project Costs, decant and relocation and the like are excluded.

s. Network trench costs excludes traffic and pedestrian redirection as well as hoarding and permits.

t. Network trench costs excludes penetrations into existing tunnels.

u. All BMS connections and requirements have been excluded.

v. No controls or metering have been included in the costing.

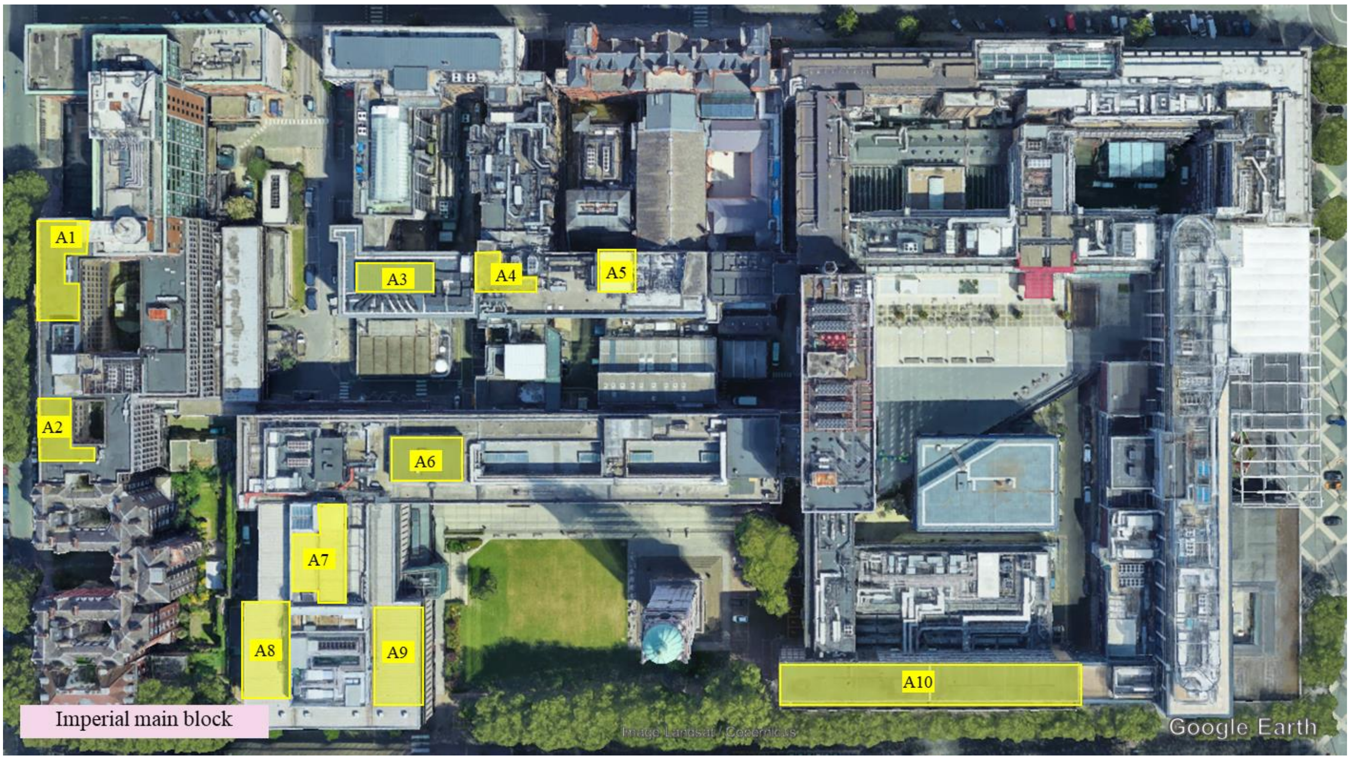
Appendix D – Rooftop PV

The opportunity for the development of solar photovoltaic (PV) provision within the specified area has been assessed. This document is focused on the initial study phase and comprises an initial review the relevant institutions. A list of considerations is shown below.

Considerations

1. Listed buildings
   - Rooftops of listed buildings were excluded where identified.
   - Areas that are on the perimeter of a site with a Grade 1 listed building adjacent, across the road or where rooftop PV would be visible from has been disregarded.
   - Due to proximity to the Royal Albert Hall, the Beit Quad was excluded.
2. Access space
   - Access space to rooftop plant rooms and equipment (e.g., chillers) was considered.
3. Topography
   - The overshadowing from surrounding building heights was considered.
   - The orientation and slant of the rooftop was considered.
4. Maintenance
   - Access to safely maintain and clean the PV panels was considered and the available areas reduced sufficiently.
   - Based on Rules of Thumb, typical inter-row spacing values for inclination angles of 15° and 25° are 0.64 metres and 1.20 metres, respectively.
5. Structural integrity
   - High-level assessment of structural integrity (a full stress and loading analysis is required at a later stage).

Only viable spaces were further investigated. The images on the following pages show the areas identified.




A12
Eastside, Southside, Northside
Google Earth


C1
C2
Natural History Museum
Google Earth


B1
B2
B3
Science Museum
Google Earth

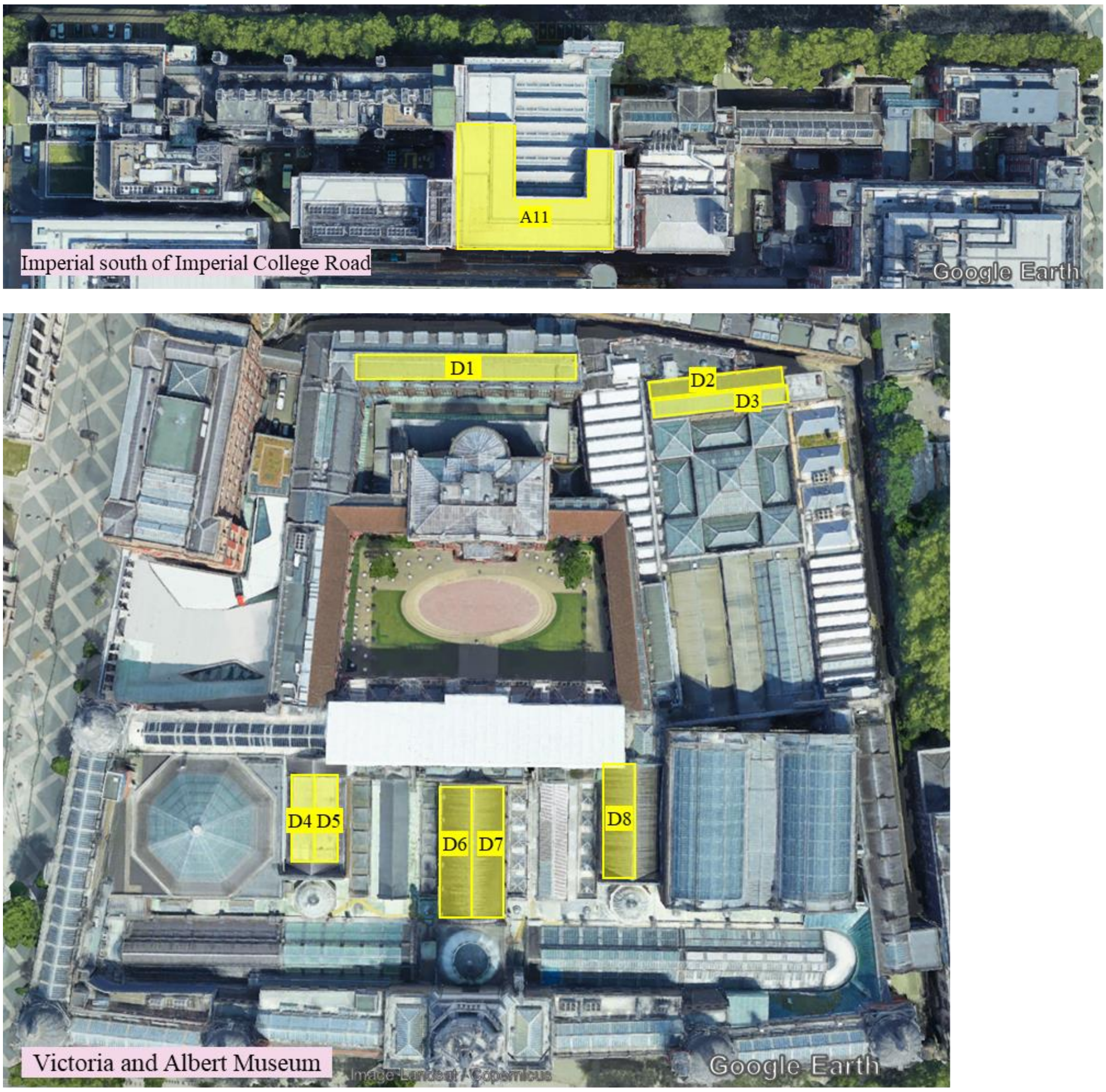


Figure 32: Areas identified for solar PV rooftop

The areas are summarised below.

Table 23: Summary of rooftop space for PV installation

Imperial College London	
A1	267 m^2
A2	135 m^2
A3	157 m^2
A4	89 m^2
A5	89 m^2
A6	225 m^2
A7	290 m^2
A8	252 m^2
A9	293 m^2
A10	821 m^2
A11	947 m^2
A12	317 m^2
Science Museum	
B1	883 m^2
B2	765 m^2
B3	1,046 m^2

Natural History Museum	
C1	240 m^2
C2	296 m^2
Victoria and Albert Museum	
D1	164 m^2
D2	110 m^2
D3	131 m^2
D4	105 m^2
D5	106 m^2
D6	219 m^2
D7	238 m^2
D8	98 m^2

Panel specifications

The PV panels were modelled with the specifications of a standard notional panel (Panasonic PV module HIT® N245).

Table 24: Notional PV panel specifications

Specification	Units	Value
Length	m	1.58
Width	m	0.798
Panel area	m^2	1.26
Peak capacity installed per panel	kWp	0.245
Panel module efficiency	%	19.4
Frame	%	7.72
Net panel area	m^2	1.16

Costing the opportunity

A variety of manufacturers were contacted to establish an order to cost. The quotes provided have been used to determine the cost estimates for solar PV provision at the site. As such, the estimates reflect the cost of a stand-alone project procured through a specialised installer. The following cost breakdown benchmarks have been adapted from the prices outlined by the installers:

- The normalised price range for the array varies between £461 and £467 per panel.
- The price includes purchase and installation of the PV panels only. This does not include the concrete base or structural upgrades.
- The price excludes any surveys, enabling works, design or project management associated with the solar PV installation.

PV performance

The performance that can be achieved by the PV installation is summarised in the table below.

Table 25: PV performance outputs

PV Performance	Units	Existing site area
Active PV area	m^2	3,586
Base area that is active PV	%	50
Total nominal capacity of solar PV	kWp	697
Number of panels	-	2,846
Nominal panel efficiency	%	19.4
Annual electricity generation	MWh	667
Annual CO_2 emissions reduction	tCO_{2e}	141
Cost of PV purchase and installation	£	£1.33M

Appendix E – Risk Register

Key risks		Consequence (Low, Medium, High)	Likelihood	Impact	Ownership	Mitigations
1	Not all institutions want to connect to the common heat network.	This could disrupt or cancel the scheme, however depending on the institutions not connecting, there will be other mitigations so the others can proceed.	1	2	Institutions connected to the heat network	Honest and open discussions amongst the four institutions about their likely intentions.
2	Rejection of the planning applications: This can be a problem which requires construction activities in public areas e.g. The Serpentine.	This can disrupt or even can cancel the whole scheme	1	3	Institutions connected to the heat network	Timely application, engaging early with the involved parties. Following the regulations.
3	Interfacing problems: The interfacing with the stakeholders is essential. Since the heat sources are under these stakeholder's control.	Interfacing problems can cause severe delays in the project.	2	3	Institutions connected to the heat network	Internal procedures of each party should be progressed and fulfilled as necessary.
4	Disruption to the public realm: Disruption to the public spaces is a major problem for the SK area.	The works can interrupt the SK experience for the public.	2	2	Institutions connected to the heat network	The construction works can be done in phases to reduce the disruption.
5	Coordination of multiple stakeholders The locations of the heat sources are within the boundaries of different bodies. This requires a high-level coordination.	This can disrupt the programme.	1	2	Institutions connected to the heat network	Coordination of the works and flow information should be done holistically.
6	Construction problems Construction progress can cause disruptions in day-to-day operation of the institutions.	The ongoing operations in the institutions should be adjusted accordingly.	1	3	Institutions connected to the heat network	The potential problems can be mitigated via strict interfacing in each institution.
7	Procurement risks Problems during the procurement stage.	Potential to cause delays.	1	2	Institutions connected to the heat network	Strict control to the procurement process, moving forward with alternatives.
8	Risks associated with ownership of assets The ownership of the new assets, and the older assets, needs to be agreed.	This may cause conflicts and potential delays.	1	2	Institutions connected to the heat network	The ownership of the new plants and spaces should be agreed prior to installation. Also, the maintenance activities, access rights, and billing should be resolved as early as possible.

9	Electricity and utility costs associated with the heat sources The cost associated by the power and other sources used by the SK ZEN network.	When they continually change prior to financial close, this could cause business case disruption.	2	3		Consideration of the business case, with a range of electricity and gas prices, and environmental case should assist in mitigating issues.
10	Peak demand future changes Heat demand future changes can cause issues.	Sudden increase or decreases in demand can cause problems.	1	2		System flexibility to be considered during the detailed design phase.