AtkinsRéalis

National Maritime Museum Heat Decarbonisation Plan

Royal Museums Greenwich

January 2024
5224343

HEAT DECARBONISATION PLAN

Notice

This document and its contents have been prepared and are intended solely as information for Royal Museums Greenwich and use in relation to National Maritime Museum Heat Decarbonisation Plan

AtkinsRéalis assumes no responsibility to any other party in respect of or arising out of or in connection with this document and/or its contents.

This document has 71 pages including the cover.

Document history

Document title: National Maritime Museum Heat Decarbonisation Plan

Document reference: Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
1.0	First issue for client review & comments	FA/WWS/TM	WWS/FA	JS/SC	HD	21.11.23
2.0	Final issue	WWS/TM	WWS	JS	AT	31.01.24

Client signoff

Client	Royal Museums Greenwich	**Client signature/date**
Project	Heat Decarbonisation plan	
Job number	5224343	

Contents

Tables

Figures

EXECUTIVE SUMMARY

Executive Summary

Purpose of the Heat Decarbonisation Plan

This Decarbonisation Plan outlines the decarbonisation pathways that are available for the National Maritime Museum (NMM), Queens House and Park Row Wing which are treated as one site with a combined floor area of approximately 23,000m^2. The recommended retrofit measures are analysed based on indicative capital cost and the associated savings in terms of energy (kWh p.a), carbon (tCO$_2$e p.a) and financial impact on future operational bills.

This plan aligns with the ‘RMG Plan 2023-27’ sustainability objectives and the UK Government’s legally binding target of Net Zero carbon emission by 2050. RMG has also adopted the Greening Government Commitments, targeting a 33% reduction in direct emissions, and a 58% reduction in total emissions by 2024/25 (compared to 2017-2018 baseline year).

The Queen’s House, National Maritime Museum and Park Row Wing have significant heritage value and are located within one of the most protected landscapes in England. All works have been considered in light of the significance of the site, and a Heritage Impact Assessment (appended) provides further detail. An early engagement meeting between Historic England, RMG’s Sustainability and Estates team and the AtkinsRéalis team was held on 26th October 2023.

The format and methodology of the Heat Decarbonisation Plan follows the scheme criteria of Public Sector Low Carbon Skills Fund (LCSF) phase 4 guidance set out by Salix Finance, and Historic England’s ‘Conservation Principles, Policies and Guidance’ (2008).

The plan has taken ‘A Whole Building Approach’ to decarbonise the site where Energy Efficiency Measures (EEMs) have been identified that reduce both system capacity/duty and annual energy consumption, focussing first on improving the building fabric where possible. These measures have been considered alongside their financial impacts where payback periods have been assessed.

Current Position

Interventions have been assessed against a ‘Do Nothing Scenario’. Delivering no interventions would reduce carbon emissions across the NMM site by 48.2% by 2050. This is mainly due to the decarbonisation of the electricity Grid.

Increasing energy prices and volatility in energy markets are likely to increase future revenue budget pressures if no action is taken to reduce grid electricity and gas consumption. The financial business case for investment in carbon reduction measures would be further strengthened if the UK government imposes additional green levies or carbon taxes.

Recommended Decarbonisation Measures

See Table 2 for a details of associated capital costs and carbon savings for the below recommended measures:

Metering & Monitoring:

There is only one incoming gas supply and two electricity supplies serving the three buildings. Determining energy use across the site requires establishing the basis of actual heating demand and electricity demand for further detailed assessment and design. It is vital that metering and monitoring is carried out. A metering and monitoring programme from the feasibility study stage through to the detailed design stage will go a long way towards optimising larger capacity reductions and facilitating further proactive energy and carbon management following the implementation of the heating decarbonisation scheme.

Optimising Facilities Management:

Reviewing current Facilities Management (FM) approach is recommended to ensure that the team are appropriately trained and supported to optimise the operations of Mechanical and Electrical (M&E) plant.

Training FM staff in Energy Management (ISO 50001), Metering, Monitoring and Targeting (MM&T) and Measurement and Verification(M&V) are likely to lead to more efficient operation and maintenance, and result in reduced carbon emissions and utility bills. Both MM&T and M&V are facilitated by Automatic Meter Reading (AMR) technology and advanced BMS systems.

Establishing a pay-for-performance system with the FM Contractor is recommended to encourage proactive improvement of the operational carbon performance of the buildings. Contractual constraints and MM&T and M&V will more effectively drive the Facility Management team's effective maintenance and management. For example, timely replacement of filters in ventilation systems, cleaning strainers in heating and chilled water systems, ensuring Variable Speed Drives on motors are being controlled correctly, timely replacing of inefficiency motors.

Based on industry experience the savings from behavioural change and effective FM can be up to approximately 5%. For the purpose of this Decarbonisation Plan, any savings resulting from these behavioural change programmes will be subsumed under BMS savings.

Energy Demand Reduction Key Recommendation:

- Thermal Blinds in NMM and Park Row Wing
- Loft Insulation in NMM, and Park Row Wing
- Draught proofing in NMM and Park Row Wing
- BMS upgrades across the whole site.

Heat Decarbonisation:

Decarbonising the existing end-of-life gas-fired boilers with ASHPs.

It is expected that installation of the ASHP will create an additional £124,870 annual operating expense (based on current RMG energy prices). This figure will change with any future variation in electricity rates in the coming years.

On-site Renewable Energy:

The retrofit renewable energy technologies such as PV panels have been evaluated to offset the indirect carbon emissions and energy savings. Two scenarios of PV modelling have been applied in this report, however, due to the poor return on investment, small proportion of generation on the whole site energy consumption, and expected statutory consent challenges, it is not recommended on this site.

Power Purchase Agreement:

PPAs (Power Purchase Agreement) can help businesses to reduce scope 2 emissions (the indirect emissions from power purchased).

There is potential on the Kidbrooke site and off-site to generate excess electricity providing an opportunity to export the excess electricity and supply the NMM site via a PPA. These agreements are usually around guaranteed volumes of energy and are often considered in conjunction with REGOs (Renewable Electricity Guarantee of Origin).

Decarbonisation Scenario

For the purpose of this report and to provide projected carbon savings, it has been assumed that all proposed interventions will be installed by 2027.

The projected cumulative carbon emission savings up to 2035 and 2050 for each recommended measure is shown below in Table 1 and summarised in Figure E-1.

Table 1 - Carbon Emission Savings from Decarbonisation Interventions

Intervention	Type of Fuel Saved	Cumulative CO_2 Saved by 2035 (tCO_2e)	% of Total	Cumulative CO_2 Saved by 2050 (tCO_2e)	% of Total
Fabric	Gas	335	7%	893	7%
ASHP	Gas	4,155	92%	11,081	92%
BMS	Electricity	43	1%	62	1%
Total		**4,533**	**100%**	**12,036**	**100%**

The initial baseline for carbon emissions for NMM have been established at 1,051 tCO_2e/year during 2023. As works are complete in Q1 2027, it is forecast that emissions will fall to 244 tCO_2e by 2030 creating a 76.8% decrease in direct carbon emissions against the 2023 carbon emission baseline. By 2050, with the further decarbonisation of the grid, carbon emissions are expected to decrease by 99.1%, against the 2023 baseline, to 9.41 tCO_2e p.a. Offsetting options for the remaining carbon are explored in this report and are estimated to cost £3,557 annually by 2050.

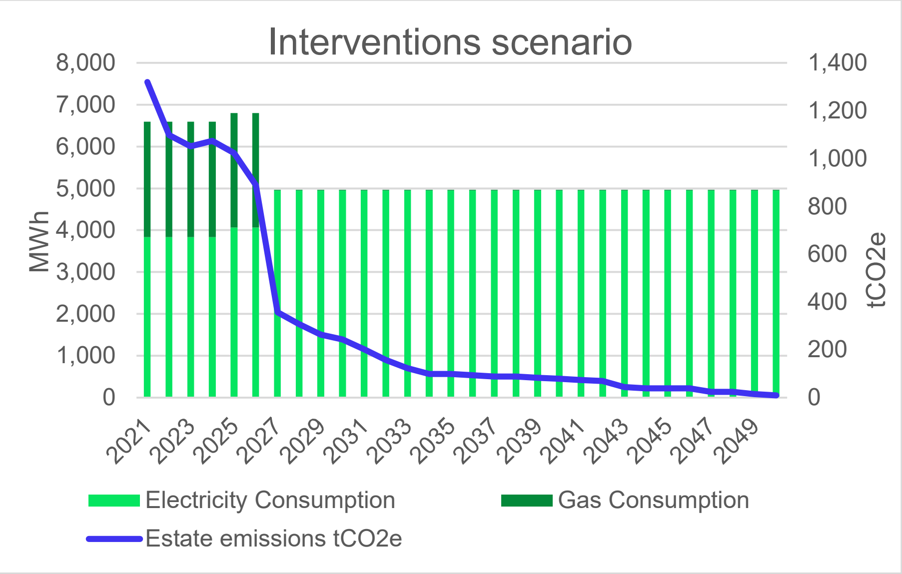


Figure E- 1: 2021 - 2050 Carbon Emissions and Energy Consumption for Decarbonisation Scenario

Financial Implications

The total cost of all interventions is £5.0 million. These costs are based on rates in Q4/2026 (excluding VAT, professional fees and contingency). An additional allowance has been calculated for professional fees & surveys at 15% (£750,000), A contingency of 15% has also been included (£860,000), making the total estimated project cost £6.6 million (excluding VAT). No allowances have allowed for ongoing maintenance, or for the DNO application (where further engagement with the DNO is required to review quote options).

Risk Management

There are various risks and uncertainties associated with the HDP. The sources of uncertainty include the rate at which the UK's electricity grid decarbonises and future climate scenarios (including the potential for milder winters), both of which may change the Net Zero trajectory.

Project and programme risks include technical obsolescence, structural load assessment, industry capacity, supply chain bottlenecks, heritage consent and planning risk. A risk register is provided at Appendix B.

Benefits Realisation

The International Performance Measurement and Verification Protocol (IPMVP) is an internationally recognised standard for M&V. An IPMVP-adherent M&V Plan and M&V Reports would provide important feedback on carbon emissions performance and would allow the trajectory to Net Zero to be monitored.

Next Steps

The following recommendations and next actions are made and presented in suggested chronological order.

1. Early engagement with Local Authority and further engagement with Historic England is required.
2. Delivering a comprehensive meter upgrade programme.
3. Identify and secure funding, both from external bodies (e.g., Salix Finance Limited) and from within RMG. This may include the use of existing budgets to fund the recommended works, e.g., metering upgrades.
4. Confirm governance arrangements and identify resources (in-house and consultants) required to plan, design, and install the measures recommended in this Decarbonisation Plan.
5. Conducting site heating assessment based on installed heat meters
6. Source an experienced PPA consultant to support with early stage of PPA options and start the process for negotiation of an RMG PPA.
7. Commission the design and project management services required for the planning application and other consents and for the procurement and delivery of the works.
8. Continue discussions with the University of Greenwich regarding the location for the ASHP and any required electrical supply interventions.
9. Commission a detailed assessment of electrical infrastructure to determine the capacity to meet the additional load required for heat pump systems based on installed sub-meters. This should include liaison with project teams to finalise the maximum demand from the upcoming retrofit programme at Ocean Court, ATES heat pumps replacement programme and any electrical sub-station upgrades
10. Consider acoustic assessment for the ASHP (particularly if located near student accommodation).
11. Arrange for an IPMVP-adherent M&V Plan to be developed and for proactive energy and carbon management through robust Metering Monitoring and Targeting (MM&T).
12. After implementing the heat decarbonisation plan, RMG Facility Management team is required to add the new system to the site's Asset Register and maintenance schedule for the ASHP plant and new calorifiers in the existing plant rooms annually

Decarbonisation Action Plan Timeline

- 2024: It is recommended that carrying out a metering and monitoring programme should be considered as a priority. Commence HDP development governance permitting. Start the process for negotiation of an RMG PPA.

- 2025: According to the data from energy meters and electricity meters, heating, cooling and electricity demand assessment should be considered. This assessment would optimize the size and output temperature of ASHP further refining future operational costs beyond the current modelling.

- 2026: Building Fabric Retrofit and MEP design

- 2027: Low Carbon Heating system and building fabric installation

Decarbonisation Intervention Summary

Table 2- Decarbonisation Intervention Overview

Intervention	Capital Cost (£)	Type of Energy Saving	Energy Savings (kWh p.a.)	Bills Savings (£ p.a.)	Payback (Years)	First Year Carbon Savings (tCO_2e)	Intervention Recommended
ASHP Option 1[1]	£2,415,000	Gas	2,534,411	-£34,206	-	462	Yes
ASHP Option 2[1]	£2,445,000	Gas	2,534,411	-£34,206	-	462	Yes
ASHP Option 3[1]	£2,500,000	Gas	2,534,411	-£34,206	-	462	Yes
Thermal Blinds	£395,000	Gas	93,987	£2,479	93	17	Yes
Loft Insulation	£233,000	Gas	92,116	£2,429	56	17.16	Yes
Draught Proofing	£140,000	Gas	12,562	£467	175	3.23	Yes
BMS Upgrade	£88,000	Electricity	115,010	£14,071	6	17.14	Yes
Energy Metering & Monitoring	£28,000	-	-	-	-	-	Essential
Total Intervention Base Construction Cost (Option 1)	**£3,300,000**	**-**	**-**	**-**	**-**	**-**	

---

[1] *Please note that the capital cost mentioned above includes the cost of ASHP option 1 plus the additional costs (see cost plan in Appendix E) associated with option 2 and 3. Preliminaries (15%), the Main Contractor's overheads and profits (5%), design risk (3%), design fee, and inflation rate (10.05%) are not included in these costs (in-line with Salix Finance guidance). If all these fees and overheads are included the overall project cost is £5m excluding VAT, 15% professional fees& surveys and 15% contingency. Note, the Cost plan details the equipment cost for the ASHP only within option 1; option 2 and 3 costs for the ASHP detail the additional costs (on top of the Option 1 cost) associated with these alternative locations.*

INTRODUCTION

1. Introduction

Royal Museums Greenwich (RMG) has requested a Heat Decarbonisation Plan (HDP) of one of their owned and operated sites, the Grade I Listed NMM, located in within a UNESCO World Heritage Site. The HDP has been undertaken to support future funding applications to the Public Sector Decarbonisation Scheme (PSDS).

The site consists of 4 buildings:

- Grade I Listed Park Row Wing – The administration wing of the site that's primary use is office space for employees of RMG. This section of the site is not open to the public.
- Grade I Listed National Maritime Museum – The largest building on the site, that's primarily used as a museum. However, parts of the east and west wings are used as office space for staff of RMG, and there is a library and archive located in the Southwest Wing.
- Scheduled Monument & Grade I Listed Queens House – The Queen's House was commissioned by Queen Anne in 1616 but was completed by Queen Henrietta Maria from 1629-38 as a residency and place to display artwork. The Queen's House is of the highest significance on account of it being the first example of a Renaissance building in Britain. Its primary use is as a museum where nautical artwork is displayed to the public. However, the site is also used to host events such as weddings.
- Sammy Ofer Wing – Opened in 2012 the Sammy Ofer wing is the newest extension to the NMM and is used as the main entrance to the museum with space for exhibitions located on the ground and basement floors. The space heating is being serviced by a GSHP which is not fossil fuel and as

such heat decarbonisation is not feasible in this building. The back-up boilers and energy efficiency options for Sammy Ofer Wing are included within the scope of the plan.

A non-intrusive site survey was conducted to acquire the necessary information to compile the high level HDP for the site. Any information that was not obtained during this survey was supplemented through information requests to RMG. Where information was not available/obtainable, assumptions have been made. These assumptions have been outlined in more detail where relevant in the HDP.

The information and assumptions have been used to determine a bespoke set of interventions for decarbonisation of the building that align with both RMG's sustainability targets, and the PSDS requirements.

1.1 Estate Buildings Summary

The NMM site is situated near the River Thames in Greenwich Park, Greenwich, southeast London. The estate buildings information summary of National Maritime Museum Site can be found in Table 3 below. It should be noted that, as detailed later in the report, there have been no suggested improvements to the building fabric of the Queen's House and Sammy Ofer wing. This is because the Queen's House has been refurbished in 2016 and the Sammy Ofer Wing was constructed in 2011 and remains in good condition. As such peak heat losses have not been calculated for both buildings.

Table 3 - In Scope National Maritime Museum Site Building Information

Building Name	Construction Year	Listed Status	Gross Internal Floor Area (m^2)	Building Use	Estimated Peak Heat Loss (kWh)
Queens House	1635	Scheduled Monument, Grade I	3,685	Art Gallery, Events	N/A
National Maritime Museum	Early 1800s	Grade I	16,576	Gallery, Event, Library, Archive	849.6
Park Row	Early 1800s	Grade I	3,207	Office	190.6
Sammy Ofer Wing	2011	None	4,338	Gallery, Workshop, Cafe	N/A

The site is situated within a UNESCO World Heritage site with Grade I Listed Greenwich Park, owned and maintained by Royal Parks, located to the south of the site. Located to the north of the site is the Grade I Listed Royal Naval College, currently leased by the University of Greenwich. An aerial image of the NMM site can be seen in Figure 1-1, marked by a red box.

Figure 1-1: Aerial View of the NMM Site

1.1.1 Queen’s House

Queen’s House is located at the centre of the NMM site and is designated as a Scheduled Monument due to its historical importance, and recognition as Britain’s first classical building. Its status as a Scheduled Monument ensures that any works proposed to be carried out are controlled and need to be authorised through Scheduled Monument Consent. The building was recently refurbished in 2016 after the discovery of asbestos under the floorboards in 2014. The Queen’s House 2016 Project was approved for Scheduled Monument Consent and allowed for the following improvements to be made to the site:

- M&E upgrades for end-of-life (EOL) equipment
- New flooring
- New lighting
- Repairs to the Great Hall ceiling
- Glazing replacement.

Figure 1-2: Aerial View of the Queen's House at the National Maritime Museum

Figure 1-3: Southern Profile of the Queen's House at the National Maritime Museum

Table 4 - Queen's House Operational Details

Daily Use	Typical Opening Hours	Annual Visitors (22/23)	Typical Activities
Everyday	10:00 – 17:00 (Typical) 22:00 – 01:00 (Events)	152,244	Museum, Events (Weddings /Corporate)

1.1.2 National Maritime Museum

The NMM consists of 6 sections:

1. Neptune Court (soon to be Ocean Court) – Atrium at the centre of the building that is used for showcasing larger items and hosting events.
2. East Wing – The ground and first floors are comprised of compartmentalised exhibition rooms with a small section of the second floor used as office space.
3. West Wing – The ground and first floors are comprised of compartmentalised exhibition rooms and a lecture theatre, with a small office space located at the northern end of the first floor.
4. The South Wing - The ground and first floors are comprised of compartmentalised exhibition rooms.
5. The Southwest Wing – The Ground and first floor consists of a library that is open to the public and an Archive operating under strict environmental conditions and with no public access.
6. Sammy Ofer Wing – Opened in 2012 the Sammy Ofer wing is the newest addition to the NMM and is used as the main entrance to the museum from Greenwich Park. There is space for exhibitions located on the ground and basement floors. This wing is the only section of the site that is currently being served by a Ground Source Heat Pump (GSHP).

Figure 1-4: Aerial View of the National Maritime Museum Main Building

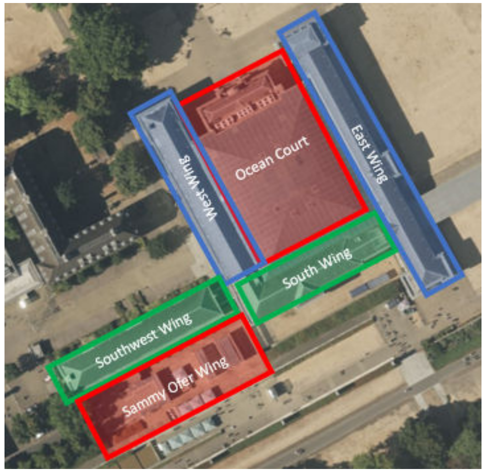


Figure 1-5: Section Breakdown of the National Maritime Museum Main Building

Figure 1-6: Northern facade of the National Maritime Museum Main Building (Stanhope Entrance)

Table 5 – National Maritime Museum Operational Details

Daily Use	Typical Opening Hours	Annual Visitors (22/23)	Typical Activities
Everyday	10:00 – 17:00 (Typical) 18:00 – 01:00 (Events)	1,062,346	Museum, Office

Spikes in summer temperatures in recent years have shown that the roof of Ocean court is not suitably designed for use in the summertime. During periods of high temperatures, the solar gain through the atrium causes the podium to reach temperatures over 40°C, forcing the space to close. There is currently a project, in RIBA Stage 3, to replace the existing glass in Ocean Court with 70% ceramic fritting, upgrade the air supply from the two northern plant rooms, and increase the capacity of the chillers supplying this area.

1.1.3 Park Row Wing

Park Row Wing is the administration section of the site that is not open to the public with its primary use as office space. In 2016 Park Row underwent refurbishment with the following works undertaken:

- Removal of existing tenant fit out partitions, taking it back to an open plan shell with some existing rooms remaining.
- Asbestos Removal
- New electrical and plumbing services such as:
  - Lighting – excluding the southern ground floor
  - New radiators
  - Data
  - Containment
  - Upgrading power
- Replaster Existing Walls
- New ceilings installed.

Figure 1-7: Aerial View of Park Row

Table 6- Park Row Operational Details

Daily Use	Typical Opening Hours	Typical Daily Occupants	Typical Activities
Mon – Friday	08:00 – 18:00	60	Office

Figure 1-8: Photo of Park Row (Right) taken from the South of the Building

1.2 Site specific restrictions or challenges to decarbonisation

The statutory protections relating to, and surrounding, NMM, Queen’s House and Park Row Wing present specific restrictions and challenges to decarbonisation. The Queen’s House and the northeast part of the site (including most of Park Row Wing) are Scheduled Monuments, which are statutorily protected, nationally important archaeological sites. Scheduled Monument Consent from the Secretary of State for Culture, Media and Sport (advised by Historic England) will be required for any proposed works above or below ground. The NMM, Queen’s House and Park Row Wing are also Grade I Listed Buildings, and as such, any proposed works will require Listed Building Consent approval from the Local Authority. The site is located within Greenwich Maritime World Heritage Site, adjacent to a Grade I Listed Park owned by the Royal Parks, Listed Buildings owned by Greenwich University and the Grade I Listed Royal Naval College, and as such, any decarbonisation proposals have to be sensitive to the impact they will have on all stakeholders. This is especially apparent when considering fabric interventions and new MEP installations. As such, we have conducted an initial assessment of whether the public economic, social or environmental benefit of proposed interventions outweighs the harm caused to the significance of the site. A copy of the Heritage Impact Assessment, which reviewed proposed interventions has been provided in Appendix F of the Heat Decarbonisation Plan.

DECARBONISATION GOVERNANCE

2. Decarbonisation Governance

2.1 Summary

A whole solution approach has been taken to developing a cost-effective pathway to operational Net Zero operational carbon emissions.

The approach covers retrofit measures including building control systems optimisation, electrical energy efficiency measures, thermal energy efficiency measures (building fabric improvements), renewable energy generation and decarbonisation of heating systems. The technologies considered are ‘tried and tested.’ New and emerging technologies could be considered in the future for incorporation into RMG’s ‘Delivery Plan.’

This Decarbonisation Plan sets out the recommended retrofit measures, their indicative capital costs, and the associated savings in terms of energy (kWh p.a.), carbon (tCO_2e p.a.) and financial (impact on energy bills, based on current tariffs).

2.2 Programme and procurement

2.2.1 Project Programme

RMG have not specified a timeline for the programme and therefore the project programme has been compiled under the assumption that works will take place in 2026 as agreed with RMG.

The full project programme can be found in Appendix A.

2.3 Resources

2.3.1 Governance

Approval of the plan is the responsibility of RMG’s Head of Estates and FM, who has the required authority to approve works of this value. Final approval of the output decarbonisation plans will also be provided by The Head of Estates and FM, in consultation with the Sustainability Manager and M&E Manager.

The plan will be presented to RMG’s Senior Leadership Team (Heads of Department and Executive Directors) to raise awareness of long-term measures required to reach Net Zero.

Figure 2-1 details RMG’s Sustainability Governance Structure. The Sustainability Manager, with the support of the Sustainability Group, is responsible for the implementation of the Sustainability Management Systems to deliver the aims of RMG’s Sustainability Strategy.

Figure 2-1: Royal Museum Greenwich Sustainability Governance Structure

2.3.2 Management and personnel

The resources required to implement this plan will include the Project Team:

1. Project Sponsor
2. Client Project Manager, who will be responsible for:
    - Internal Stakeholder Management, including Sustainability Group
    - Funding applications (e.g., Public Sector Decarbonisation Scheme)
    - Monitoring and annually updating this Decarbonisation Plan
    - Agreement of annual adjustments to maintain the decarbonisation trajectory.

The below Consultants are also required to implement the plan:

1. Project Manager
2. Designers (e.g., MEP Engineer and Building Surveyor)
3. Heritage Specialist
4. Principal Designer (CDM Regulations 2015)
5. Quantity Surveyor
6. Structural Engineer
7. Planning Consultant
8. Acoustician
9. Archaeologist
10. PPA Specialist
11. Measurement and Verification Specialist

2.4 Summary of supporting information

The following information was provided by RMG for the development of the HDP:

1. Asbestos Register
2. Asset Drawings
3. Energy Data
4. Gas & Electric Invoices
5. Site Plans
6. Schematics
7. Conservation Management Plan

2.5 Challenges and Delivery Risks

The site is located within one of the most protected landscapes within England, and as such engagement with a range of stakeholders is required.

Identification of available locations for installing low carbon equipment whilst considering minimum impact pipework connections.

Proposed fabric interventions to NMM and Park Row Wing will require Listed Building Consent approval, which will require detail on the technical and aesthetic impact of the installation of:

- Draughtproofing strips to windows and external doors.
- Thermal blinds to accessible windows; and
- Loft insulation.

There is one incoming gas supply and two electricity supplies serving the three buildings. Lack of accurate metering for each building within the site limits the accuracy of the modelling we are able to do. This therefore represents a risk to accurate benefits modelling. This can be mitigated through installation of sub-metering at strategic points across the site.

Whilst consideration and analysis of the upcoming retrofit programme Ocean Court has been incorporated into the forecasting of operational energy modelling and electricity infrastructure feasibility study, the ‘as-is’ position may differ from forecasting assumptions. This may have an impact on the modelling of decarbonisation and energy efficiency interventions. This can be mitigated by updating modelling following the completion of works at Ocean Court if discrepancies between design and as-is are identified.

Programme schedule risks include technical obsolescence, industry capacity, supply chain bottlenecks, funding (including the availability of grants from the government) and planning risk. A risk register, covering key financial, organisational and delivery risks, can be seen in Appendix B. Programme risks can generally be mitigated through early engagement with the supply chain and through effective project management support.

CURRENT ENERGY, EMISSIONS, AND SYSTEMS

3. Current energy, emissions, and systems

3.1 Current energy consumption and associated carbon emissions

3.1.1 Data collection

To identify baseload electrical consumption at the RMG NMM site, half-hour electrical consumption data spanning September 2022 to August 2023 was analysed. Alongside the half-hour energy data, electricity invoice statements spanning April 2021 to August 2023 were provided to support financial analysis.

Half-hourly gas consumption data was unavailable upon request and therefore analysis of gas usage has been limited to a monthly basis, provided in the form of gas invoice statements from April 2021 – July 2023.

3.1.2 Energy consumption

Table 7 below provides an overview of the energy consumption at the NMM site over a typical year, using an average of energy data provided for the years 2021-2023. As the NMM site does not have separate meters to provide insight into energy consumption by building, the average consumption figures for gas and electricity have been assessed on a site wide basis.

Table 7- National Maritime Museum Site Energy Consumption Overview

Building Name	Year of Construction	Estimated Gas Consumption (kWh/annum)	Estimated Electric Consumption (kWh/annum)	Gross Internal Floor Area (m^2)
National Maritime Museum	1813 – 1873	2,755,692	3,833,665	16,576
Park Row	1813			3,207
Queens House	1635			3,685

3.1.2.1 Electricity Consumption

Appendix D.1 shows that within a typical year the NMM site consumes more electricity during the summer months from April to October which is most likely due to humidity set points required across the site to reduce the risk of damage to museum inventory.

3.1.2.2 Gas Consumption & Heat Demand

On an average annual basis, the NMM consumes approximately 2,755.7 MWh of gas over the entire site.

Figure 3-1 shows the average monthly gas consumption for NMM over the period April 21 – July 23. Winter heating periods can be seen through the months of November – March where gas consumption peaks in December with an average monthly consumption of 292 MWh. There is a reduction in gas consumption throughout the summer months of April-October with an average monthly consumption low of 176 MWh in May. While there is an aspect of gas consumption driven by the café located in the Sammy Ofer Wing, this usage is relatively negligible when compared to that of the gas fired boilers.

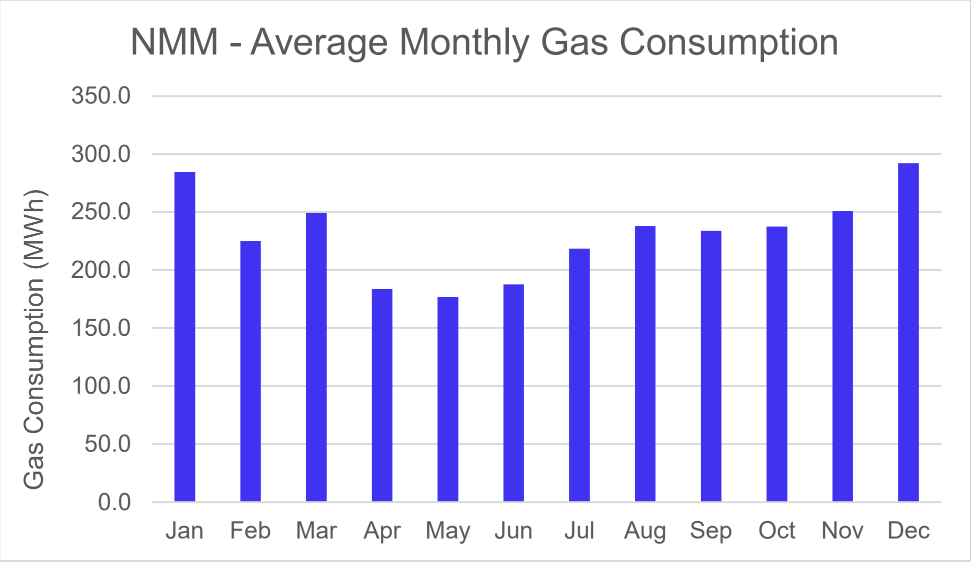


Figure 3-1: Average Monthly Gas Consumption

3.1.3 Carbon emissions

The modelling outputs in the following section are based standard grid-average emissions factor[2].

The NMM is on EDF's 'Blue for Business' tariff meaning that all grid electricity consumed is generated from nuclear sources and, therefore, zero carbon at the point of generation. However, this is not compliant with Renewable Guarantees of Origin (REGO) requirements, and therefore reporting guidelines require the use of grid-average emissions factors.

3.1.3.1 Current emissions

Figure 3-2 shows a reasonably flat trend in carbon emissions throughout a typical year. Where relatively significant carbon emissions are seen during the winter months when there is greater need for space heating. Higher emissions due to greater electricity usage is seen in the summer months where the humidifiers operate more frequently to maintain the set environmental conditions in place around the site. On average, the gas-fired boilers make up 51% (507.0 tCO_2e) of the sites annual carbon emissions, with the remaining 49% (478.6 tCO_2e) from the electrical demand.

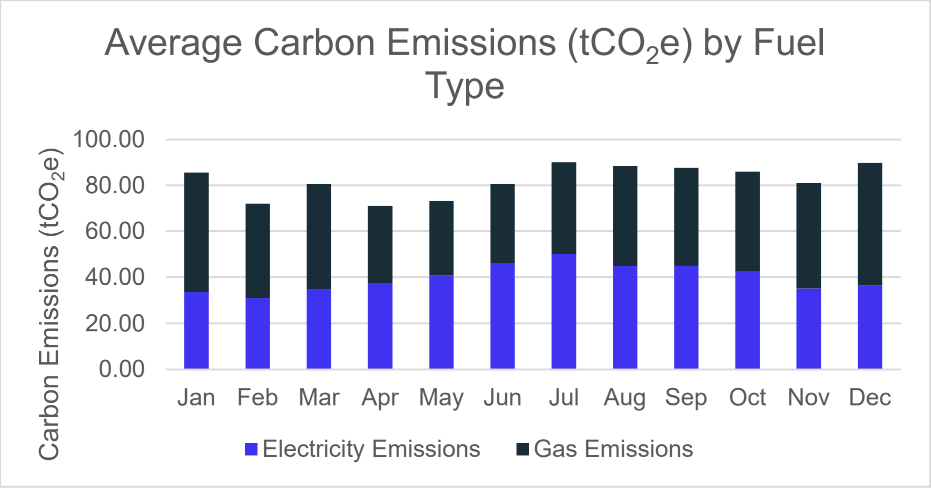


Figure 3-2: Average Monthly Carbon Emissions by Fuel Type

---

[2] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

Table 8 - Average Annual Carbon Emissions from 2021 to 2023

Average Annual Carbon Emissions due to Gas (tCO_2e/annum)	Average Annual Carbon Emissions due to electricity (tCO_2e/annum)	Total Average Annual Carbon Emissions (tCO_2e/annum)
507.00	478.62	985.62

3.1.3.2 Projected emissions

Figure 3-3 demonstrates the 'Do Nothing Scenario', illustrating the carbon emissions from each fuel source, assuming no change to the existing electricity and gas consumption across NMM. A reduction in carbon emissions across the NMM site from a carbon emission baseline in 2023 of 1,051 tCO_2e to 507 tCO_2e in 2050 can be seen. The drop in carbon emissions from 2023 to 2050 represents a 48.2% reduction. This is mainly due to the decarbonisation of the electricity Grid and the forecast reduction in carbon factors from 2023 to 2050. However, gas savings and additional electricity consumption have also been estimated from the on-going works on the Ocean Court roof and contribute a 4.1 tCO_2e drop in gas emissions from 2024 to 2025. The ongoing works for Ocean Court have also been estimated to increase the electricity consumption of the site by 6%, based on increased demand.

It is forecast that the National Grid will reach a minimum carbon emissions factor of 0.005 $kgCO_2e/kWh$ from 2048 onwards. Therefore, carbon emissions due to the usage of electricity will remain up to 2050. The development of new technologies may provide increased energy efficiency and result in decarbonisation of the National Grid occurring ahead of current estimate, further reducing carbon emissions.

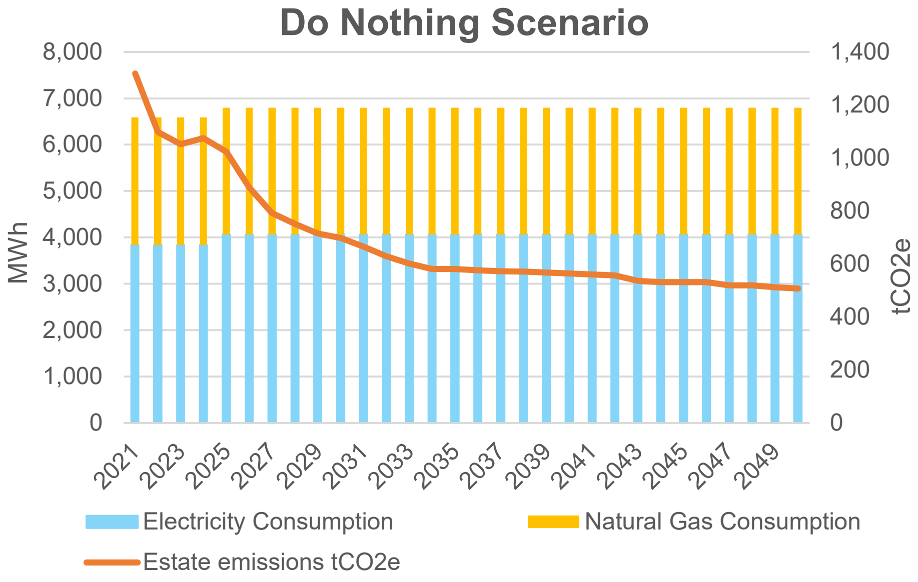


Figure 3-3: Do Nothing Scenario Energy Consumption and Carbon Emissions

3.2 Current Space Heating and Hot Water Systems

3.2.1 Current heating system and Domestic Hot Water generation

The existing gas-fired condensing boilers (Table 9) for all the buildings in NMM site are located in the National Maritime Museum Southwest Wing basement. The boilers were replaced in 2011. According to CIBSE Guide M, the existing boilers have reached end-of-life, however with regular maintenance lifespans can and frequently do exceed this.

Table 9 - Current Space Heating System

Model	Fuel-Type	Year Installed	Output Per Unit (kW)	No. of Units	Output (kW)	Efficiency*
WESSEX ModuMax220	Natural Gas	2011	220	5	1100	85%

**Efficiency has been calculated based on CIBSE Guide A Formula:*

$$E_C = 0.99^{A_b - 1} * E_I$$

Where;

- E_C = *Current efficiency (%)*
- A_b = *Age of Boiler (Years)*
- E_I = *Initial Efficiency (%) = 92%*

Primary and secondary LTHW circuits are distributed from within the boiler plantroom to provide heating to the existing site district heating circuit, domestic hot water, reheat and back-up heating for the Ground Source Heat Pump heating circuit via a plate heat exchanger.

LTHW flow and return pipework is distributed from the plantroom throughout the Sammy Ofer Wing building before entering the service trench and serving the Southwest Wing. The existing site wide distribution pipework runs through the basement service tunnel and distribute the sub-pipe sets to the plantroom of each building.

Figure 3-4: Distribution pipework toward to Queens House Plantroom and Main Pipe work in the tunnel.

The overview of end-use heating system profile for each building has been summarized in Table 10

The radiators and heating pipework in Park Row Wing had been newly replaced during the 2016 refurbishment programme.

At Queens House, where 59 fan coils were installed, the existing flow and return headers were retained, but all pipework, valves and fittings from these headers were replaced throughout the house, and connections to all 59 fan coils were made as part of the internal refurbishment in 2016.

Existing radiators and heating coils are typically sized on water temperatures to 80°C.

Table 10- Current Space Heating System Overview

Building	Leading Heat Resource	End-use heating system
Park Row Wing	Boilers	K2 Radiators with thermostatic radiator valves (TRVs) Boardroom AHU heating coils
Queens House	Boilers	3 Air handling units (AHUs) and 59 4-pipe fan coil units as principal heating system. Underfloor Heating, retaining steel panel radiators for basement.
National Maritime Museum	Boilers	East Wing and West Wing: AHUs and Fan Coil Units Ocean Court: AHUs, underfloor heating, and Fan Coil Units
Sammy Ofer Wing	GSHP	Underfloor heating, Fan Coil Units, AHUs with thermal wheel and Central Control Unit

3.2.2 Domestic Hot water generation

Current Domestic Hot Water (DHW) for the site is shown in Table 11. The hot water storage (Calorifier and Cylinder) has been set at a maximum temperature of 65°C, water distribution is to be no less than 55°C and hot water delivery at outlets, not less than 50°C. Local mixing valves have been installed to reduce the hot water flow to 43°C at wash hand basins.

Table 11 - Current Domestic Hot Water Heater

Location	Type	Size (L)	No. of Units
East Wing	Calorifier	1000	2
West Wing	Calorifier	1000	1
Boiler Plantroom	Calorifier	1200 and 1000	2
Park Row Wing	Local immersion heaters	NA	4
Queens House	Calorifier	1000	1
Sammy Ofer Wing	Dual coil Cylinder	1100	1
Southwest Wing	Electric Water Heaters		

3.3 Current Air Conditioning and Ventilation Systems

Environmental control of the special exhibition galleries in Queens House, Sammy Ofer Wing, and National Maritime Museum. In the majority of AHUs on site, the control of the ventilation system is via temperature and humidity sensors which (through the centralised automatic control system) dictate the operation of the AHUs. A supply air duct temperature sensor acts as a supply air flow limit device to bring on the safety freeze protection (such as preheat coil and preheat battery) if the outside air temperature is below 5°C. A differential pressure switch mounted across the fan, and a contact of the fan starter provides status feedback to the outstation controller. 90% of AHUs have 30% or 0% fresh air mixing with return air. Two AHUs in Sammy Ofer Wing have 100% fresh air and therefore have a higher thermal load to offset the heat loss from outdoor weather; the plantroom where they are located has limited space to retrofit.

Three units of AHUs in Queens House were installed in 1999 and the motors were replaced in 2020.

3.4 Current Lighting

Following the recent 2016 refurbishment programme and extension programme of Sammy Ofer Wing in 2011, the current lighting in Park Row Wing, Queens House and National Maritime Museum are at least 90% LED.

3.5 Current Building Controls

The current Building Management System is in good condition. The remote controlling covers all Heating, Ventilation, Air Conditioning and Lighting system. The screenshot of the whole site BMS could be found in Figure 3-5

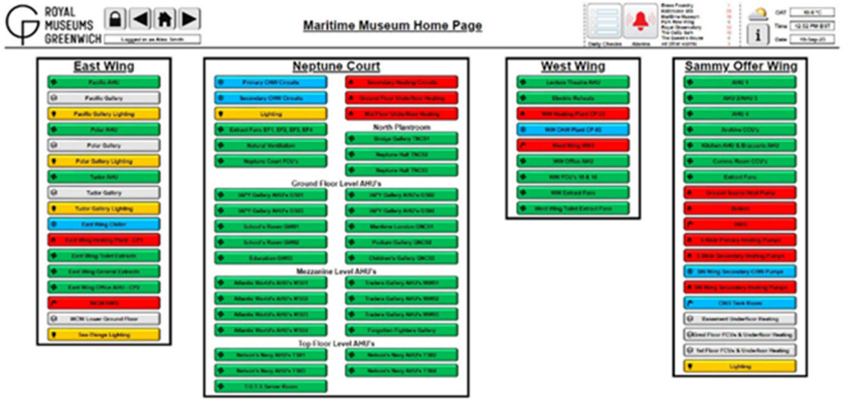


Figure 3-5: Screenshot of the whole site BMS system

3.6 Current Renewables

There are no renewables on site.

3.7 Current fabric and energy efficiency

3.7.1 Building Fabric Overview

The Queen's House was built in three phases between 1617 and 1662 to the designs of Inigo Jones. The windows were changed in 1708 and there were many internal alterations in the 18th and 19th centuries. Major restoration programmes were carried out in the 1930s and 1980s, together with the most recent major refurbishment project in 2015-2016 where the glazing was replaced. The roof is of shallow pitch timber construction covered with lead sheet and is concealed behind parapets. The walls are of solid masonry construction with lime plaster internally and painted lime render externally. The hoppers and downpipes are also of lead. The windows are a combination of timber framed sash and case, and iron casement windows, all with single glazing. The doors are timber, some of which have glazing. The external facing elevations of the Queen's House have very high aesthetic and historical significance, with the roof, former roadway and roadway elevations having high significance.

When the Queen's House was re-assigned as a residential school for the children and orphans of sailors in 1806, increased accommodation was needed. It was at this time that Daniel Alexander designed the East Wing of NMM and Park Row Wings, connected to the Queen's House by two colonnades. The colonnades and the southern parts of the two wings were built first and the wings were then extended to the north. The project was substantially completed at the end of 1811 but the break between the phases is visible where the vermiculated stone plinth of the original building ends and the brick-arched basement storey of the northern extensions begin. The East Wing was refurbished for the NMM in 1932-36 and opened in 1937. Park Row Wing refurbishment began in 1939. During these refurbishments, the windows were replaced, and the chimney and roof ventilators were removed. The roofs are of timber trussed construction with Welsh slate coverings and lead flashings and parapet gutters. The walls are of solid masonry construction with painted render externally. The rainwater goods are painted cast iron. The windows are timber, single glazed sash and case and the doors are timber. The roof and south, west and north elevations of Park Row Wing are considered to have high significance, however, the east elevation has moderate significance. The north, east and south elevations of the East Wing are of high significance, but the west facing elevation in Neptune Court is of moderate significance. The colonnades are constructed from Portland stone columns of the Tuscan order. The floors of the colonnades are paved in stone flags, largely York stone with some Portland and Purbeck stone. The shallow pitched roofs are covered in lead with eaves gutters. Some of the stone columns have internal rainwater pipes. The colonnades are considered to be of very high significance.

The South and West Wings of NMM form an L-shaped extension built in 1861-62 to the designs of the practice of Philip Hardwick and his son Philip Charles Hardwick. The design is similar to the East Wing, but the first-floor windows are larger and there is a slight difference in roof height. The South and West Wings were refurbished in 1935-36 and the inward facing elevations were affected by the Neptune Court (soon to be Ocean Court) project of the late 1990s. The South and West Wing elevations and roofs are considered to be of moderate significance.

The North Wing of NMM is the north façade of the school gymnasium, which was constructed in 1873. Apart from its north façade the gymnasium was demolished in the 1990s to make way for Neptune Court. The space between the North, East, South and West Wings was covered with a double-glazed curved roof structure. The gaps between the North Pavilion and East and West Wings were filled in by glass walling as part of the Neptune Court project. The north elevation is of high significance and was the main public entrance to the Museum, a role it now shares with the Sammy Ofer Wing entrance. The Neptune Court roof is of moderate significance.

The South-West Wing was built in 1876, designed by the Admiralty Office of Works. The development of the Sammy Ofer Wing involved complete internal alterations to the South-West Wing and changes to the north, south and east elevations. Internally there were formerly three floor levels, but the interior was gutted and re-built with four floor levels during the project. The elevations of the South-West Wing are of moderate significance, with the roof being of some significance.

The Sammy Ofer Wing was designed by architects C.F. Moller and the executive architects were Purcell Miller Tritton. It provides a new face towards Greenwich Park, a new main entrance, two galleries, a library, archive storage, a restaurant and a café. It has a deep basement where the café kitchen and plant room are located. The Sammy Ofer Wing elevations are of moderate significance, with the roof being of some significance.

3.7.2 Roofs and Ceilings

The Queen’s House has a very shallow pitched lead roof concealed from view behind a parapet with stone balusters to the north and south elevations, which has external, lead covered access hatches. The maintenance contractor reported that the roof is in fair condition. There is limited space in the roof void and a dendrochronological report carried out in 2015 confirmed that some of the existing timbers date from the 17th Century, and as such, have high significance. The ceilings to the Queen’s House are plaster and are very ornate, particularly on the first floor.

The colonnade roofs are low pitched lead roofs which are in good condition. The colonnades are open sided, so no insulation is required in the loft space.

The roof to Park Row Wing is of pitched timber construction covered in Welsh slates with lead ridge flashings. Park Row Wing has 4 no. Single glazed rooflights which are now redundant and are a source of water ingress. The original chimneys were removed during the 1934 refurbishment works.

The roofs to NMM are of pitched timber construction covered in Welsh slates with lead ridge and hip flashings. To the north of the east wing is a hipped lead covered roof. The roof is accessed through lead covered dormers and there are 2 no. rooflights, one above the main staircase in the South Wing and the other above the Caird Rotunda. There is insulation in some of the roof spaces, however it is of varying condition and inconsistent in material and depth. For example, in the west wing there is rigid foam board insulation and in the east wing there is wool insulation.

The Neptune Court roof is a gently curving structure of fritted double-glazed units manufactured by Eiffel in Toulouse. There are some opening lights, some of which have developed faults. During the increasingly hot summers there has been severe overheating, making the space unusable. To address this, there is currently a project at RIBA Stage 3 to replace the glazing with a higher level of fritted glass to reduce overheating.

The Sammy Ofer Wing has a flat roof with a Portland Stone terrace and gravel with planters and railings to the north part. It is assumed that there is insulation in the roof.

3.7.3 Rainwater Goods and Drainage

The rainwater goods to the Queen’s House consist of deep lead gutters behind the parapet with lead hoppers and downpipes to the elevations. There were no obvious defects visible during our site survey.

The colonnade has eaves gutters, with downpipes concealed within the columns.

Park Row Wing and NMM have lead parapet gutters with cast iron hoppers and downpipes. The addition of the Neptune Court glazed roof increased the amount of rainwater being collected by the Neptune Court facing parapet gutters to the East, South and West Wings and during heavy rain this can overflow into the roof space and Neptune Court causing significant water damage.

The Sammy Ofer Wing has internal downpipes which are not visible.

3.7.4 Glazing

The windows to the Queen’s House were altered in 1708 with sash windows inserted in place of the original mullions and transoms, some windows of the original type can still be seen in the internal roadway (although these date from the 1980s restoration). The number of windowpanes may also have changed over the years as currently the first-floor windows have 15 panes, but some early prints show 12 panes. The windows were re-glazed in 2015-16 and most windows still retain their shutters, which are closed at night for security reasons. Whilst on site it was reported that there is an issue with interstitial condensation between the shutters and the glazing, which suggests that the windows fit tightly in the frame and are providing very little natural ventilation. To rectify this problem, we would suggest altering the shutters where possible to allow for some ventilation and prevent deterioration of decorative finishes and timber.

The windows to the basement of Park Row wing are a combination of 3x6 pane glazed single glazed sash and case windows and arched single glazed casement windows. The ground floor windows are large, 12x12 pane sash and case, single glazed windows. To the first and second floors the windows are smaller 3x3 pane, single glazed sash and case windows. The windows were in operable condition, and some have had draughtproofing installed previously.

The windows to the East Wing ground floor are a combination of 12x12 pane and 6x9 pane single glazed sash and case windows. The windows to the first floor are 3x3 pane single glazed sash and case windows. The South Wing has 9x9 pane sash and case single glazed windows to the first floor, with smaller 6x6 pane sash windows to the ground and second floor. The North Wing has plain 1x1 sash and case, single glazed windows which are smaller at basement and first floor levels and much larger to the ground floor. The West Wing has a combination of 6x6 and 9x9 pane sash and case windows. There are smaller 6x6 sash and case windows to the ground and second floor. Not all windows are accessible due to exhibitions, however, they appeared to be in fair condition. Secondary glazing has been installed to the library and west wing offices. In the West Wing offices some of the units are starting to fail.

There are large, dark glazed walls to the Sammy Ofer Wing which are assumed to be at least double glazed.

3.7.5 Walls

The walls to the Queen’s House are of solid masonry construction, of approximately 1 metre thick. Externally the walls have painted stucco render and internally painted plaster. Many of the decorative external features are in stone.

The walls to Park Row Wing and NMM are of solid masonry construction of approximately 650-800mm thickness. Externally the walls have painted render and internally they are painted plaster. Some of the exhibition spaces have partition walls built in front of windows.

The external walls of the Sammy Ofer Wing are Portland stone clad and to the south elevation there is a large expanse of dark glass. It is assumed that the walls to the Sammy Ofer Wing are insulated.

3.7.6 Doors

The Queen's House has timber external doors, some of which are glazed. The main visitor entrance is now through the door at basement level on the north elevation which is fully accessible. The main entrance on the terrace is no longer used except for special occasions. Whilst on site, staff noted that this door is draughty and gaps between the doors and frame were visible. The central double ground floor doors to the south elevation are currently closed to the public. There are doors opening onto the roadway, however, these are normally closed to the public.

The external doors to Park Row Wing are timber, some of which are glazed. The main glazed entrance doors to the east elevation were installed when the entrance was created in the 1930s and were at first used as the main entrance for visitors coming from Maze Hill station but are now only for access to the RMG offices. The doors to the north elevation are no longer in use, except in the event of a fire. There are single timber doors which provide access to basement level.

The doors to NMM are mostly timber, except from the glazed doors to the main entrances. There are timber glazed doors of a similar style to those in Park Row Wing. The original public entrance was via the colonnade doors, but these are now only used by staff as fire doors. The doors appeared to be in fair condition.

The doors to the Sammy Ofer Wing are glazed and mostly automatic sliding doors.

3.8 Ongoing Development

There is an ongoing development programme in Neptune Court (to be named Ocean Court). Currently this programme is at RIBA Stage 3. The primary objective is to improve the issue of overheating within the Ocean Court area. In Table 12, we itemize the Ocean Court upgrade elements linked with the crucial aspects that impact the heat decarbonisation plan. In the following energy, carbon and operational cost modelling, we will incorporate this continuous development plan. We expect the completion of this development programme by the year of 2025.

Table 12 - Ongoing Development

Building Fabric	Retrofit Description	Key Impact Factor
Roof Lighting	High Performance Double Glazing with 70% Ceramic Fritting	Baseline Peak Heat Loss and Energy Savings
Lighting and Control	A new lighting control system combining 3 control elements: architectural lighting, remote controlled spotlights, the event theatrical lighting, emergency lighting.	Energy Savings
Chillers	The new chillers will be designed with an additional spare capacity	Electric Infrastructure allowance and energy consumption
BMS	BMS: the existing BMS will be upgraded to incorporate all modifications to the M&E system.	Energy Savings
Pipework Insulation	Any missing or damaged insulation on pipework should be replaced.	Energy Savings

OPTIONS APPRAISAL

4. Heat Decarbonisation Options Appraisal

4.1 Fabric interventions

4.1.1 Conservation Repairs

The buildings are generally in good condition, however, there are issues with water ingress, particularly in NMM where the rainwater goods are failing to cope with the increase of water from the Neptune Court Roof. Wet building fabric is significantly less energy efficient, and as such, repairs should be undertaken quickly to ensure the building fabric is waterproof. We understand that the rainwater goods sizing issue associated with Neptune Court is being addressed during the Ocean Court project.

The windows to NMM and Park Row Wing are generally in fair condition, however, the first step towards energy efficiency in traditional buildings is undertaking traditional repairs and maintenance to ensure the building is functioning as intended prior to installing retrofit measures. Repairs works are suggested to be considered in the estate annual maintenance programme rather in this Heat Decarbonisation Plan.

4.1.2 Thermal Upgrades to Windows

The windows to NMM, Queen’s House and Park Row Wing are generally large single glazed timber sash and case windows to the ground floor with smaller windows to the basement and upper floors. The Queen’s House has operational timber shutters which are closed overnight as part of the building management strategy. Due to this, and the negative aesthetic impact that installing secondary glazing would have on the interior of the Queen’s House this option was discounted at an early stage. Whilst on site we were advised that there is an issue with interstitial condensation between the shutters and the windows, which would suggest there is a lack of natural ventilation. We would recommend modifying the shutters in a sympathetic way to allow for ventilation.

Some of the windows to NMM are inaccessible as they are located behind exhibition walls. As such, we would suggest that these windows are upgraded during exhibition change over.

4.1.3 Draughtproofing

Approximately one fifth of a building’s heating is lost through windows and most of those escapes through air gaps. Research conducted by heritage bodies has shown that by adding draught-proofing air infiltration to a sash window in good condition can be reduced by approximately 80%. It also has the advantage of reducing external noise and dust which will assist with caring for the collection.

In both NMM and Park Row Wing some of the windows have had draughtproofing strips fitted but are in varying states of repair. The proposal is to replace all draughtproofing strips where they are in poor condition.

Compression seals made of EDPM rubber are proposed to the sides and top of the external doors and casement windows, and along the top rails and bottom rails of the sash windows. The reason behind this is that compression seals are most effective where the moving part of a window or door meets the frame.

Wiper seals are proposed to the sides and meeting rails of the sash windows as they allow moving parts of windows to slide past each other. Wiper seals are also proposed to the base of doors to reduce draughts.

4.1.4 Secondary Glazing

Secondary glazing has already been fitted in some areas of NMM, notably the library in the Southwest Wing and the first-floor office in the West Wing of NMM. The secondary glazing in the library is black, side-hung, double units. The mullion is central to the window, and as such is visible in the middle of the central glass panes in the sash and case windows. We have not proposed to copy this design. The secondary glazing in the office in the West Wing are large white, 1x1 pane sash sliding secondary. These units are less visually intrusive, however, some of the units are in disrepair due to a lack of maintenance. Secondary glazing has been discounted as an option due to the high cost of installation and long payback period. There are also concerns over ongoing maintenance costs.

4.1.5 Thermal Blinds

Thermal blinds by Duette have been proposed as an option to reduce heat loss through glazing to NMM and Park Row Wing. The blinds are installed as normal blinds are with a rail fitted to the head of the window. The blinds have been proven to reduce heat loss by up to 50% when closed and are translucent so allow natural daylight in. The blinds also reduce solar gain during summer months and allow for natural ventilation from open windows while closed which reduces the mechanical ventilation load.

4.1.6 Loft Insulation

During our site visit we accessed the roof spaces of the East and West Wings of NMM, which have both got loft insulation fitted but in varying states of repair. The East Wing has a rigid foam insulation, and the West Wing has a wool insulation. Where there has been water ingress, or M&E repairs, the insulation has been lifted to provide access and has not been reinstated properly. We could not access the roof spaces to the South Wing, South-West Wing or Park Row Wing. The proposal is to install 240mm thick Steico Flex 036 Woodfibre insulation between the rafters, covered with a vapour permeable breathing paper. Woodfibre insulation is breathable, which reduces the risk of trapped moisture causing decay to the timber or plaster materials. The boards also have a negative Global Warming Potential, unlike other insulations. The building paper will protect the Woodfibre insulation should there be water ingress.

Table 13– Financial Impact for Building Fabric Intervention Options

Intervention Options	Capital Cost (£)	Peak Heat Loss Improvement (%)	Type of Energy Saved	Energy Savings (kWh p.a.)	Energy Savings (£ p.a.)	Direct Carbon Savings (tCO_2e/year)	Electricity Cost Avoidance Payback (Years)	Payback (Years) In Gas	Recommended (yes or no)
Roof lighting	£-	6.6%	Gas/Elec	22,586	596	4.1	NA	NA	Ongoing programme in Ocean Court
Loft Insulation	£233,000	6%	Gas/Elec	92,116	2,429	17	56	131	Yes
Secondary Glazing	£834,000	5%	Gas/Elec	99,209	2,617	18.11	185	436	No
Thermal Blinds	£395,000	4%	Gas/Elec	93,987	2,479	17.16	93	218	Yes
Draughtproofing	£140,000	7%	Gas/Elec	12,562	331	2.29	175	579	Yes

4.1.7 Fabric Intervention Summary

We have assessed the financial impact and return on investment as outlined in Table 13.

We suggest implementing the Thermal Blinds, Loft Insulation and Draughtproofing for Park Row Wing and National Maritime Museum. Considering the heritage status of the buildings, the protective actions required during retrofitting and bespoke size of the materials, the initial capital cost at this stage has left a significant margin. Additionally, the current gas and electricity tariffs are much lower than the average commercial market price. It results that the payback period is relatively long.

According to the Salix calculation methodology, the direct impact of building fabric is on fossil fuel. However, as low carbon heating system is the future option of heat decarbonisation for the whole site, we have included the projected electricity cost avoidance to reflect the corresponding payback period (assuming the heat pump proposals are adopted) for reference.

The current thermal capacity of low carbon heating system is estimated using the maximum daily consumption of natural gas and the actual capacity of boilers, instead of post peak heat loss figures. By installing additional energy meters in the future, we can monitor the actual heat demand of each building more accurately. This would enable (during further detailed design) the size of the ASHPs to be optimised (likely downsized).

4.2 Heat Decarbonisation Options Appraisal

4.2.1 District Heating Network

According to GLA (Greater London Authority) Energy Assessment Guidance 2022 and in line with London Plan, major developments are expected to achieve Net Zero by following the Energy Hierarchy Figure 4-1.

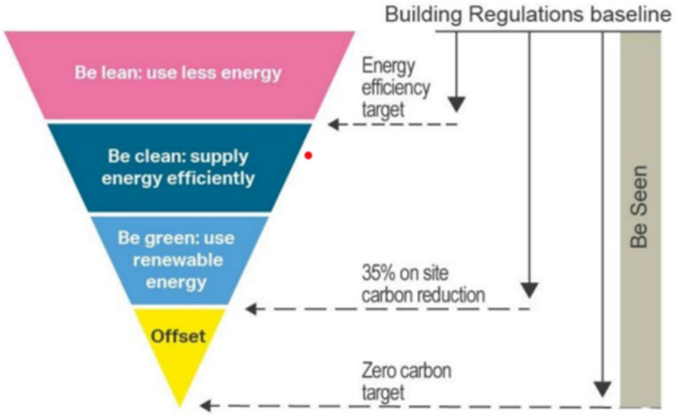


Figure 4-1: Energy Hierarchy

Exploiting local energy resources (such as secondary heat) and cleanly by connecting to District Heating Networks is the first step.

There is no clearly defined development strategy for District Heating Network in Greenwich currently and it would unlikely happen in the next 10 years.

4.2.2 Hydrogen or Biomass

Hydrogen:

Hydrogen is currently considered as the best approach for very large industrial consumers of natural gas with a high-grade heat demand. Currently the potential to use hydrogen as a direct replacement for natural gas is in its infancy and this technology has not been considered in this plan.

Biomass Boilers:

Biomass is a renewable energy source, generated from burning wood, plants and other organic matter, such as manure or household waste. It releases carbon dioxide when burned, but considerably less than fossil fuels. There is growing alarm about the impact on air quality from the process of Biomass heating. Additionally, Biomass boilers require larger spaces than gas or oil equivalents and separate space for storing the fuel – space limitations mean this is not a viable solution for RMG.

4.2.3 Heat Pumps

There are three types of Heat Pump which are Air Source, Water Source and Ground Source.

When applying Water Source Heat Pump, the principle requirements for water source system are adequate water quantity, moderate water temperature, suitable water quality and stable water supply. Specifically, the amount of water in the water source should be sufficient to meet the needs of users for heating load or cooling load. In this case, Water Source Heat Pump technology is not suitable for National Maritime Museum site.

Issues identified with current Ground Source Heat Pump in Sammy Ofer Wing, suggest that a Ground Source Heat Pump would not be a reasonable option for this plan due to the balance between heating and cooling loads.

We have therefore selected an ASHP as the most viable low carbon heating technology for this site.

4.2.4 Salix Feasibility Study for Proposed ASHP Heating System

When assessing the viability of converting the current fossil fuel heating system to ASHP, several key factors have been taken into account as stipulated by the Salix guidance. The following approach has been adopted to review feasibility at the National Maritime Museum site:

1. **Reduce Heat Demand:**

Reducing existing heat demand on central heating leads to minimise the size and cost of installing heat pumps.

- To analyse the actual energy demand (maximum demand) by heat meters or hourly gas consumption.

- To improve existing building fabric, key parameters is pre and post peak heat loss (Salix Peak Heat Loss).

- To incorporate thermal storage to reduce the impact of high heating demand during peak period.

There is only one gas meter for the entire site and solely monthly data is accessible. Based on monthly data Figure 4-2, the maximum consumption month is January 2022. The assumption of running at full capacity per day is made by 24 hours in January 2022 (Table 14). Due to the requirement for constant indoor temperature and humidity, the boiler operates around the clock. However, it is inaccurate to use peak monthly gas consumption as an indicator for determining the proposed heating system. This is because the heating system operates at a constant temperature and the load fluctuates seasonally with the weather. In short, the boiler does not operate at its peak every hour. Referring to the current monthly natural gas data would significantly underestimate the total heat demand. It is highly recommended that a heat meter or hourly gas meter should be installed in each plant room to determine the actual heat load demand at initiate design stage.

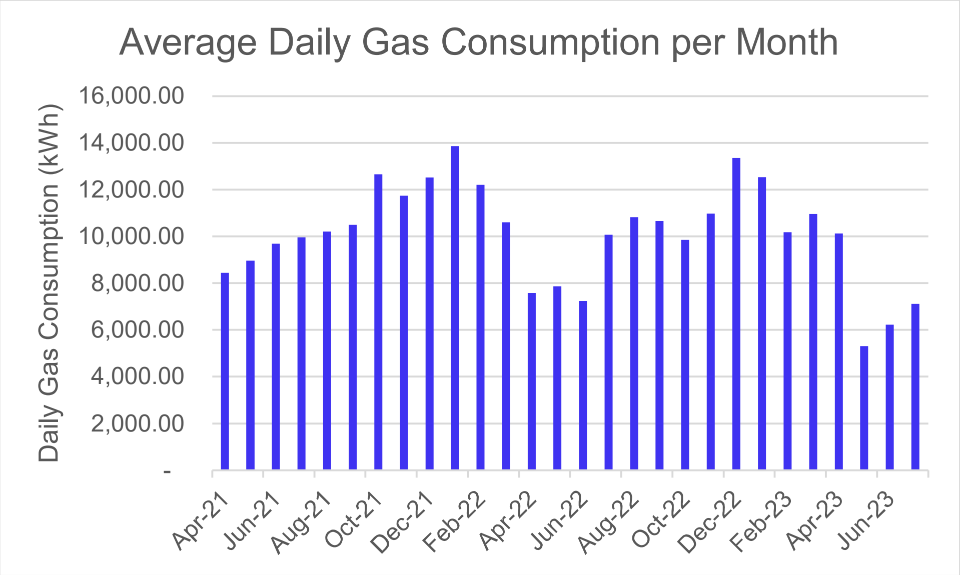


Figure 4-2: Peak Daily Gas Consumption per Month

Table 14 - Peak Gas Consumption Analysis

Month of Peak Consumption (kWh)	Peak Day Gas Consumption (kWh)	Full loaded Operating Hours (hrs)	Peak Boiler Demand (kW)	Peak Demand Thermal Load (kW)
292,403	13,863	24	578	491

In section 4.2 - building fabric improvement options appraisal, the recommendation has been to install draughtproofing, loft Insulation and thermal blinds. There is no building improvement recommendation for Queens House and Sammy Ofer Wing; therefore, peak heat loss calculation is not applied to Queens House and Sammy Ofer Wing. The peak heat loss was estimated via Salix Peak Heat Loss calculation tool. The pre and post peak heat loss improved rate for NMM and Park Row Wing can be found in Table 15. The U-Values which decides the Peak Heat Loss figure are referred from Ocean Court thermal analysis report and MCS ASHP calculator.

Table 15 - Peak Heat Loss Improved Rate with Recommendation

NMM and PRW	Loft Insulation	Thermal Blinds	Draughtproofing	Combined all
Improved Rate	6%	4%	15%	26%

The existing gas-fired boilers are 1100kW with 85% efficiency. The actual capacity is 936kW. The required thermal capacity of ASHP is estimated using the maximum daily consumption of natural gas, the actual capacity of boilers and the reference of peak heat loss improved rate.

2. **Reduce the temperature of LTHW to the lowest feasible level:**

Reducing the temperature of LTHW (Low Temperature Hot Water) is an effective approach to save carbon and energy with ASHP systems, as lower output temperatures lead to higher efficiency. This approach may however require increasing in sizes or numbers of radiators or convectors, enlarging the size of AHU heating coils, or resizing the pipework which can negatively impact the feasibility (particularly in a heritage environment) and capital cost of the project.

In Section 3.2 and Section 3.3, the existing heating, ventilation and air conditioning system is designed with an operational temperature of 82/71°C. There are strict indoor environmental requirements in Queens House and throughout the galleries in NMM - the constant room temperature should be between 18-22°C and humidity between 40%-60%. The heating coils sitting in AHUs are important to temperature and humidity control.

We have conducted an analysis into the impact of using a lower temperature system for the NMM site. If the proposed heating system output temperature is set at 65/55°C (optimal for ASHP systems), the size of heating coils would need to be increased by approximately by 20%. The existing AHUs, located in Queens House and NMM, are bespoke and therefore unlikely to have enough space to accommodate larger heating coils. Furthermore, based on 65/55°C, the radiators size would need to be increased by 25% or additional units would need to be added. It is therefore proposed, at this planning stage, to consider replacing the existing gas-fired boilers with a high temperature ASHP system to avoid significant changes on distribution system and heat emitters.

Decentralised heating (ASHPs) is considered to be one of the viable options as it would reduce heat loss through pipes and associated valves and tees compared to a centralised heating system. However, evaluating this approach requires an accurate calculation of the heat demand of each building which is not possible until the installation of heat meters. The following discussion about ASHPs is therefore focused on a centralised system for the whole site.

During initial design stage, actual energy usage data should be collected by new installed heat meters or hourly gas meters in heating season at least and a detailed IESVE Apache modelling should be conducted to optimize the size of ASHP and output temperature.

At this feasibility study stage, ASHPs and associated Vessel Buffer Tank capacity are estimated based on the existing boilers' capacity accounting for current efficiency. This would reduce the risk related to underestimating the thermals loads and low carbon heating system capital costs at design stage. In addition, a design margin of 12% (taken from a range of 10%-15%) has been taken into account. As a result, the proposed ASHPs in this early stage can conservatively meet all current heat demands. The preferred option is to install heat meters in order to propose a system optimised for greater capacity reduction from the initial design stage to the detailed design stage.

Based on the above analysis, we recommend 5x 201kW ASHPs (model: Enerblue Black Evo HT) with 1x 3500L Vessel Buffer Tanks (Table 16 and 17). Given the heating system's robustness in the event of an ASHP failure, it is proposed to maintain two gas-fired boilers as a backup for the system. After the proposed heat pump system has been commissioned and been in stable operation for a period, the two existing standby boilers can be completely removed. However, the boilers are end-of-life, two boilers replacement costs have been considered in the Appendix E Cost Plan. Please be aware, under the Salix PSDS scheme it is not possible for new fossil fuel boilers to receive grant funding even for back-up purposes. The proposed heating schematic can be found in Appendix C.

Table 16 -High Temperature Air Source Heat Pump Datasheet

Model	Nominal heating capacity(kW)	COP	Noise (dB)	Size per Unit (m)	Flow/Return Temperature (°C)
W55 205	201	2.73	97	5.33x1.2x2.4(H)	80/70

Vessel buffer tanks have two basic functions. Firstly, it minimises the start-up of the heat pump compressor by providing a 'buffer' between the heat pumps and the heat distribution system. Secondly, it saves energy by allowing the heat pump to recharge the tank when demand is low. Finally, it levels out peaks and troughs in demand. Vessel buffers therefore allowing the heat pump to operate more efficiently and extend its lifespan.

The location for the vessel buffer tank[3] may be located in one of two locations which should be clarified during later design stages. Firstly, for locations 1 and 3, as it is bundled with the ASHPs as a centralised energy centre, a 3500L vessel buffer tank could be located externally in the same area as the proposed ASHPs, and the existing hot water storage tanks located in each building plantroom would then be retained (refer to Table 11). Alternatively, there is potential space in the boiler plantroom following the decommissioning and removal of the existing ATES ground source heat pump and boilers which could provide a suitable internal location for

---

[3] 3500L Vessel Buffer Tank (Vertical version) reference size: 2.5m(height) x 1.52m (outer diameter).

the vessel buffer tank. Location of the tank should therefore be confirmed following the review and decommissioning of the ATES system.

Table 17 - Vessel Buffer Tank Technical Parameters

Total Thermal Store Size (L)	Time to heat via ASHP (hr)	Equivalent Thermal Capacity(kW)	With Charging Periods accounted for(kW)	Total System Thermal Capacity includes ASHP (kW)
3500	0.04	40.7	39	1,044

3. ASHP Location Options:

Location 1 (car park, University of Greenwich and NMM shared area)

RMG currently leases a small area of space, just north of the Sammy Ofer Wing, from the University of Greenwich. The space located in University of Greenwich car park and is used by RMG as a bin store. Location 1 shown in Figure 4-3 is the closest location to connect to existing boiler plantroom (located in north basement of Sammy Ofer Wing). Early engagement with University of Greenwich stakeholders has been made. It is planned that further discussion will take place between RMG and University of Greenwich on the detailed size of the ASHP plant. At this stage, the total required ASHP plant size options are approximate, and do not include the ASHP for Sammy Ofer Wing GSHP replacement programme.

The indicative area including Vessel Buffer Tank and ASHPs is 12m (length) by 7m (width) by 2.8m (height) – see figure 4-3.

Figure 4-3: ASHP Location 1 with 12x7m Arrangement (Buffer Vessel included) (Drawing scale 1:200)

Location 2 (between the fence of University car park and NMM)

Connecting the ASHP pipework to the existing boiler room in Location 2 shown in Figure 4-5 would be more complex and require a longer length than Location 1. The area indicated falls in university grounds and as such an agreement would have to be arranged for the leasing of this space, the cost plan includes an additional fee for an Archaeology consultant during excavation process. In this option, the buffer vessel tank can be placed either in boiler plantroom located in Sammy Ofer Wing after replacing the ATES system and removing three boiler units; or within the ASHP compound.

Further acoustic assessment will be required during the design stage. The approximated size requirement is indicatively suggested to be 17.5m (length) by 4m (width) by 2.8m (height) including buffer vessel tank.

Figure 4-4: ASHP Location 2 with 17.5x4m Arrangement (Drawing scale 1:200)

Location 3 (Park Row Wing Bin Storage area)

As location 3, shown in Figure 4-6, is the furthest distance from the existing boiler plantroom, we assumed that the pipe from ASHP would connect directly to the main pipe beneath the tunnel. The current flow direction of the main pipe valves must be adjusted. The ASHP plant including vessel buffer tank is indicatively suggested as 12m (length) by 7m (width) by 2.8m (height). The cost plan includes an additional fee for an Archaeologist consultant during excavation process.

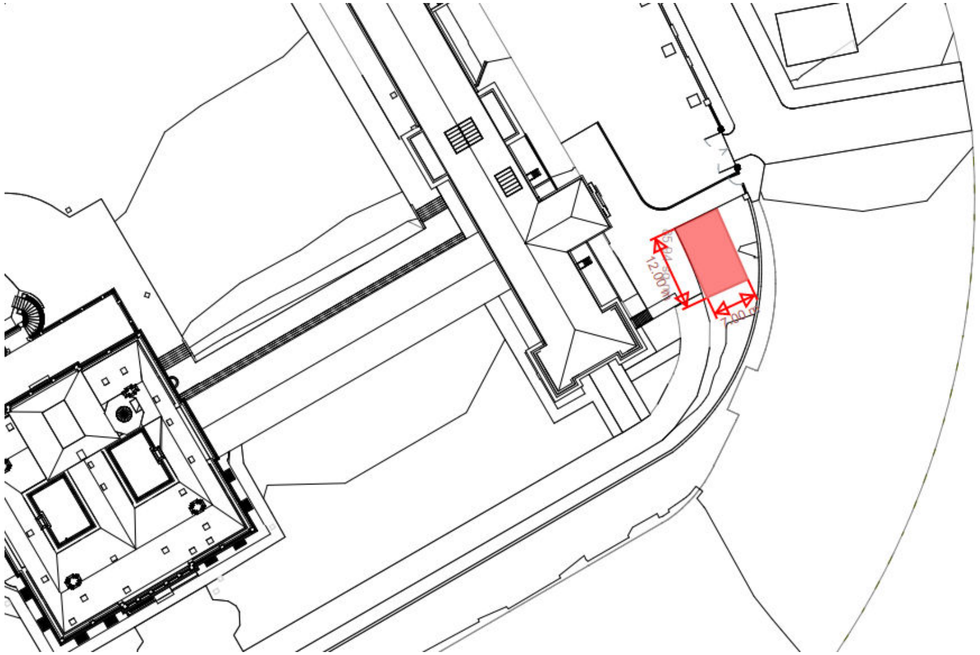


Figure 4-5: ASHP Location 3 with 12x7m Arrangement (Drawing scale 1:500)

Grated underground or basement for ASHPs:

To place ASHPs in grated underground or basement would reduce the visual impact on the site. However, unobstructed airflow is one of the crucial factors for the efficient operation of ASHPs.

None of the vacant space in front of the National Maritime Museum site is being considered due to ecological implications, and feasibility of connecting to existing pipework and tunnel.

We have included acoustic treatment for the ASHP in the cost plan on all three options. It would be designed to minimise aesthetic impact and ensure required noise attenuation is achieved. Further technical details of acoustic treatment should be provided in detailed design stage and an acoustic assessment should be conducted during design stage.

All indicative ASHP compound sizes are high level and indicative only. These will require further detailed design, analysis of HV/LV infrastructure and any sub-station or DNO network upgrade requirements. A summary of three ASHP location appraisal options could be found in Table 18 below. Construction Capital Costs includes all ASHPs enabling work including estimated electrical upgrade costs, structural platforms, acoustic treatment, and pipework connection. Additional costs resulting from preliminaries (15%), main contractor overheads (5%), design risk (3%), design fees, and inflation from 2023-2026 are detailed in the cost plan (appendix E).

Table 18 - ASHP Appraisal Options

ASHP Location	Construction Capital Costs (£)	Additional Costs (£)	Total Projected Electricity Consumption (kWh p.a)	Increase in Energy Bills (£)	Direct Carbon Savings (tCO_{2e} p.a)	Cumulative Direct Carbon Savings by 2050 (tCO_{2e})
Location 1	£2,415,000	£946,000	1,020,627	-£24,971	462	11,081
Location 2	£2,445,000	£957,000				
Location 3	£2,500,000	£977,000				

4.3 Energy Efficiency & Renewable Interventions

4.3.1 LED Lighting Upgrade

Currently, at least 90% of the lighting is LED lighting with controls across the whole site. Replacement of the remaining 10% of T5 and T8 lighting is not recommended as part of this HDP. However, from the first of September 2023, sale of T5 and T8 fluorescent tubes will be phased out altogether under a revision of Restrictions of Hazardous Substances (RoHS) directive. It is therefore recommended that the remaining lighting be upgraded to LED as and when the T5/T8 lighting reaches end-of-life as part of the ongoing life-cycle replacement/maintenance programme.

4.3.2 BMS Upgrade

Currently, the BMS system is functioning well. There is however a requirement for upgrading the BMS to link up to the proposed heating system (Table 19).

Table 19- BMS Upgrade Commercial and Carbon Appraisal

Intervention	Annual Electricity Savings (kWh p.a.)	Annual Electricity Saving (p.a.)	Capital Costs (£)	Payback (years)
BMS reconnected to Meters, ASHP	115,010	£14,071	£88,000	6

4.4 Renewable generation

Proposals to install PV panels on the roof of NMM were discussed with Historic England. Planning consent is unlikely to be given if PV is located in areas visible from public viewpoints, due to the potential impact on the enjoyment of the historic environment. It is possible consent would be given if the PV panels are located on areas of the roof which are not visible from public viewpoints and if the benefit of installing the PV panels can be evidenced to outweigh the harm to the historical and architectural significance of the site. The proposed PV location could be found in Figure 4-7. Two scenarios have been modelled for further discussion. The scenarios energy savings, carbon savings and costs comparison could be found in Tables 20 and 21.

Scenario 1: Location 1 + Location 2 + Location 3

Scenario 2: Location 1 only

Figure 4-6: PV Proposed Location

Due to the challenge of accessing the roof for PV installation and the protection measures for the listed building, we have costed a higher contingency for PV options at this stage. In addition, the current low electricity tariffs result in poor payback for the two PV scenarios. The proportion of generation contributes very small amount of electricity to the overall site energy use profile. Figure 4-8 is showing bellow. It is therefore not recommended to proceed with a PV installation on this site.

Table 20 - PV Proposed Energy and Carbon Savings Comparison

Scenario	Offset % of Increased Electricity by ASHP	Generation from solar panels (kWh p.a.)	Indirect Carbon Offset (tCO2e.p. a)
Scenario 1	3%	31,985	4.77
Scenario 2	1%	12,851	1.91

Table 21 - Solar PV Commercial Appraisal

Scenario	Estimated Capital Cost of PV (£)	Annual Electricity Savings (£ p.a.)	Payback Period (Years)
Scenario 1	285,643	£3,913	73
Scenario 2	201,901	£1,572	128

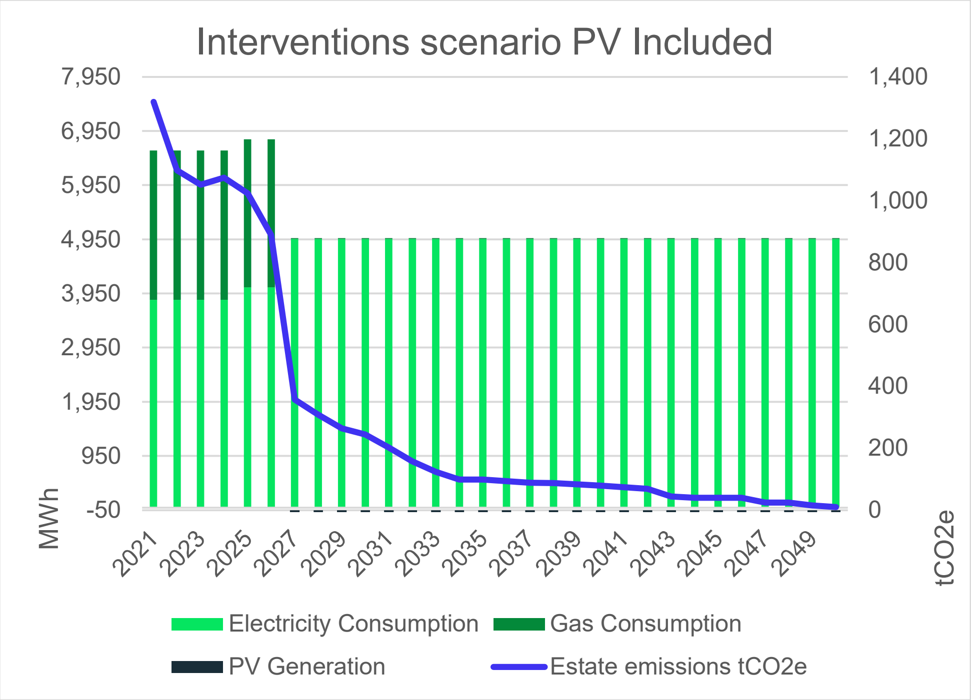


Figure 4-7: Carbon Emissions and Energy Consumption Forecast for Recommended Interventions and Scenario 1 PV Included

4.5 Metering and Monitoring

To identify how energy is used across the site is important to establish the current gas and electricity consumption of each building. For the buildings such as Park Row Wing, Queens House and National Maritime Museum, further sub metering for heating, cooling, humidification, DHW, ventilation, lighting, exhibit power, and lifts is advised. These categories may consist of several individual meters that can be summed virtually to establish the energy consumption associated with each category. Energy meters measuring heating and cooling demand together with fuel input will allow the seasonal efficiency of each system to be calculated.

When consumption of a particular category exceeds the expected consumption, it is possible to drill down to individual meters to identify necessary operational changes. With an intelligent system these processes can be automated, and reporting can highlight specific plant to be investigated allowing responsive building management. This Metering strategy is a key element to provide important feedback on carbon emissions performance and would allow the trajectory to Net Zero to be monitored. Most importantly, it would provide actual energy consumption for each building to support further optimization of ASHP. It is recommended to consider energy meters and electricity meters for each building. The requirement of meters is listed below:

Thermal Energy Meters

Heat meters should include inline flow sensors, a matched pair of temperature sensors and a calculator. Calculators should be provided with outputs to enable remote monitoring via the Building Management System (BMS). They should have the ability to communicate via network (e.g., M-Bus, Modbus, BACnet) and should include at least one pulse output for thermal energy in kWh/MWh. Potential position for the proposed heat meters:

- Boilers main pipework flow output (1x unit)
- East Wing Heating Plant input (1x unit)
- West Wing LTHW circuits input (1x unit)

- SOW: Low grade LTHW pipe flow (1x unit)
- Neptune Court: Secondary LTHW circuit (1x unit)
- Park Row Wing input (1x unit)
- Queens House input (1x unit)

Electricity Meters

Electricity meters should be multi-functional 1ph or 3ph solid state units with the ability to connect to either 3ph 4-wire or 3ph 3-wire delta circuits.

Electricity meters should be provided with outputs to enable remote monitoring via the Building Management System (BMS). They should have the ability to communicate via network RS485 and should include pulse output.

Electricity meters should be MID certified Class B accuracy.

Electricity sub-meters for each building and ASHPs Plant:

- Park Row Wing – 1 x unit,
- Queens House – 1 x unit,
- Sammy Ofer Wing - 1 x unit,
- National Maritime Museum – 1 x unit and
- ASHPs Plant - 1 x unit

These 5 units will identify the consumption and electrical peak demand of the ASHP and each building enabling the heat decarbonisation strategy to be optimised. The museum may wish to consider commissioning a IPMVP compliant metering strategy to review the cost-benefit of asset-level metering to collect the data required to optimise the operational efficiency and FM maintenance of each asset.

4.6 HV/LV Infrastructure

The electric capacity feasibility (Table 22) has been analysed. Analysis includes the additional allowance required for the ongoing project at Ocean Court, existing ATES Ground Source Heat Pump replacement plan, occasionally external events, and the Heat Decarbonisation Plan Air Source Heat Pump system.

Existing electricity maximum demand is based on the electricity meters (1200010173820 and 1200010225470) half hourly data from 2020 August to 2023. Please refer to Appendix D.4. The Maximum kWh is 795.3kWh and in an hour is 1590.6kW appearing in summer due to the high demand of cooling requirement. Power factor is considered as 0.99.

The results show the full load of the whole proposed low carbon heating system would draw 1090kVA. This full load value is referred to Enerblue BLACK HT EVO ASHP technical datasheet with unit size 205 and included consideration of buffer vessel tank and pumps, or units with exclusively pumps. Unit Size 205 full load current is 314A, 400-3-50, where the resulting kilovolt-amps is 218kVA, totalling 1090kVA.

Allowance for external events and ongoing project Ocean court is referred to ‘Ocean Court RIBA Stage 3 MEP report’.

Allowance for the ATES Ground Source Heat Pump replacement plan is referred to in the ‘ATES Heat Pump Replacement Feasibility Report (2022)’. From the feasibility study, replacing the GSHP with an ASHP flow would retain a temperature flow of 45/35, with the potential required electrical allowance at 156kVA (400-3-50). We have assumed that the current ATES GSHP SCoP is 4, in line with industry standards, and has a current thermal capacity of 330kW. The electrical allowance that would be released is around 83kVA. As a result, the total electrical allowance for ATES replacement would require an additional 73kVA.

The current electrical infrastructure will need to be upgraded to meet the additional demand of the proposed heating system and a design redundancy of at least 15% is advised. After the rooflight retrofit and chiller upgrades in the Ocean Court programme and the proposed HDP BMS upgrade (3%), the NMM site is estimated to require ~450-500kVA additional electrical allowance (including 15% redundancy).

As a next step, a further electrical infrastructure study should be carried out for a detailed assessment of the HV/LV infrastructure and DNO capacity upgrade options. The University of Greenwich is planning to upgrade its on-site substation in the Devonport House car park, which is close to ASHP locations 1 and 2. Cooperation on proposed substation upgrades with the University of Greenwich should be continued. It is worth noting that if upgrades have to be made through the National Grid rather than DNO this can lead to significant additional costs. At this stage, an estimated cost of connection from potential substation to NMM Southwest Wing electrical mainboard and then to ASHP Location 1 has been made based on previous similar projects in the cost plan, Appendix E. All design and information will need to be confirmed with the appointed design team. It should also be noted that any substation upgrades have not been included in the cost plan.

Table 22 -NMM Site Electric Allowance Feasibility Check

Site	HDP ASHPs Maximum absorbed Power (Units with buffer tank or with exclusively pumps) kVA	Allowance for External Events(kVA)	New Allowance for Ocean Court(kVA)	New Allowance for SOW ATES Replacement(kVA)	Current Total Allowance(kVA)	Existing Max Demand(kVA)	Cap Required (KVA)	Proposed Efficiency by BMS%	Estimated Additional Electrical Upgrading Allowance(kVA)
NMM	1090	200	120	73	3,000	1,607	3,090	3%	450-500

4.7 Power Purchase Agreement

A PPA defines the conditions of the agreement, such as the amount of electricity to be supplied, negotiated prices, accounting, and penalties for non-compliance. Since it is a bilateral agreement, a PPA can take many forms and is usually tailored to specific requirements. Power can be supplied physically or on a balancing sheet. PPAs can be used to reduce market price risks, which is why they are frequently chosen by large electricity consumers to help reduce investment costs associated with planning or operating renewable energy plants.

PPAs can help businesses to reduce scope 2 emissions (the indirect emissions from power purchased). Renewable certificates such as Guarantees of Origin (GoOs) in the European Union or Renewable Energy Guarantees of Origin (REGOs) in the UK are provided as part of an agreement as proof of power purchased from renewable sources.

There are different types of PPAs due to the wide range of possible contractual arrangements and the location of the buyer and where the energy is generated. PPAs are either on-site or off-site, physical or virtual (or financial), A Summary of all type of PPA could be found in Table 23.

An on-site PPAs is a power supply contract where the renewable asset is located on a customer's site and the developer invests into the asset offering the customer a competitive price for surplus power going back into the grid. An off-site PPA is a power supply contract where a renewable asset is located in the same power market.

On-site renewable energy source should take priority over off-site options. Installing on-site renewables can lead to a reduction in grid demand, increased development values, and a decrease in operational costs and indirect carbon emission. For the reasons outlined above, proposing PV on the NMM site presents a challenge and the resulting electricity generation would only meet a small proportion of the overall energy demand. There is potential at the Kidbrooke site and offsite land nearby to generate electricity and export electricity to the NMM site via a Power Purchase Agreement. These agreements are usually around guaranteed volumes of energy and are often considered in conjunction with REGOs. In this case, Indirect Wire via Grid 'new-to-earth' assets could be an option to consider. A further off-site PV plan should be considered at Kidbrooke.

It is important to understand how REGO-supported' green energy' is included with public sector carbon emission reports. This will have a significant influence on which model and approach to PPA's is most appropriate. PPA Sustainability summary is In Table 23. This summary is the resource from Crown Commercial Service. Depending on the type of organisation different standards apply for the reporting of carbon:

- The Greening Government Commitments (GGC) for central government and the voluntary wider public sector Emissions Reduction Pledge (ERP) use strict interpretations which do not count energy from off-site renewable generation as zero carbon.

- Other voluntary standards, including DEFRA's guidance and the international Greenhouse Gas (GHG) Protocol, allow reporting of 'green' energy and carbon offsets as part of an additional Market-based report, which is intended to encourage organisations to invest in green energy or carbon offsets.

Given the nature of PPA's it is recommended that buyers source an experienced PPA consultant to support with the early stages of the procurement documentation development. The role of the consultant would primarily be to undertake the required market testing, cost/price analysis and development and drafting of the specification and evaluation criteria taking into account the specific requirements of a buyer's organisation. The consultant support should provide a buyer with a bespoke suite of PPA tender documentation to use to maximise good quality procurement outcomes.

Table 23 - Summary of Power Purchase Agreement (PPA)

Type of PPA	Green for GGC/ERP Reporting	Green for DEFRA/GHG Reporting	PPA Model and Description	Advantage	Disadvantage
Indirect Wire via Grid existing assets	No	Yes	Three-Way contract: buys/generator/supplier Contractual and electricity supply link between generator and buyer	Lower prices (as set up and installation costs may Already be covered) and be available for immediate delivery on more flexible/shorter contract terms.	Can be considered that less ‘green’ as they are not adding any “new” green capacity to the network. In-Direct PPAs will need to include shape and balancing costs in addition to the commodity cost of electricity.
Indirect Wire via Grid ‘new-to-earth’ assets	No	Yes	Three-Way contract: buys/generator/supplier Contractual and electricity supply link between generator and buyer with new generation being funded	Be considered as more ‘green’ than existing asset PPA’s	In most cases they will be more expensive and generally require longer contracting as the generator needs to incorporate the new generation facility set-up and installation costs.
Direct Wire PPA (off-site)	Yes	Yes	Two-Way contract: buys/generator, can be three if required. Similar to an Indirect PPA, A contract with the generator would be required for the supply of electricity for a specified price and terms.	Agreements in which generator and the buyer are in different geographical locations. The electricity generated by the power producer is fed into the grid, and the purchaser receives financial benefits or renewable energy credits based on the agreed-upon terms.	Consideration of physical aspects: Installation and maintenance of a physical connection into the site. Generator downtime and in-year performance guarantees. Long-term generation and performance guarantees.
Direct Wire PPA (on-site or physical connection	Yes	Yes	Two-Way contract: buys/generator, can be three if required. Contractual and direct electricity link between generator and buyer with new generation being funded on site. Such as roof-mounted PV	Electricity can be supplied without needing to use the Transmission and Distribution systems. Avoid the variable non-commodity costs for T&D. the overall total costs are cheaper than Indirect wire PPAs.	Limited capacity available due to site constraints. Require on-site space. Requires initial investment.
Virtual PPA	No	Yes	Financial Contract A Virtual PPA is another way to allow access to low-carbon electricity through a financial arrangement only.	Doesn’t involve physical electricity delivery.	This form of PPA is not common within the UK and can be interpreted as a financial instrument, so unlikely to be acceptable for use by public sector.

4.8 Challenges and Barriers to Project Delivery

The site is located within one of the most protected landscapes within England, and as such engagement with a range of stakeholders is required. Scheduled Monument Consent is required from Historic England on behalf of the Secretary of State for Culture, Media and Sport for any above, or below, ground alterations to the Queen's House and Greenwich Palace. Listed Building Consent is required from the Local Planning Authority for any alterations to NMM, Queen's House and Park Row Wing before works proceed on site.

There is one incoming gas supply and two electricity supplies serving the three buildings. Limitations to the granularity of the data limit the accuracy of the analysis and any potential designs.

Feasibility study for installing ASHPs on site should consider the limited space condition, power resource, acoustic risks, and impact of strict indoor environmental condition; whilst considering minimum impact pipework connections and pipe excavation spots associated with consideration of archaeologist.

Consideration and analysis of the upcoming retrofit programme at Ocean Court into the forecasting operational energy modelling and electricity infrastructure feasibility study.

Identification and securing of funding, both from external bodies (e.g., Salix Finance Limited) and from within RMG. This may include the use of existing budgets to fund the recommended works, e.g., metering upgrades.

Consideration of further off-site renewable energy options in Kidbrooke and associated with PPA.

4.9 Assumptions

U-Values:

Table 24 – Site U-Values and Area

Building Fabric	Average U-Value (W/m^{2}K)	Improved U-Values(W/m^{2}K)
Roof lighting	2.25	1.8
External Wall	1.6	1.6
Windows	4.8	2.4 for secondary and 2.8 for thermal blinds
Exposed Floors	1.2	1.2
Roof	0.98	0.18

Ongoing Programme:

Ocean Court: Assumption of the completion date would be 2025 4Q.

Sammy Ofer Wing: Assumption of proposed ASHP SCoP would be the same as existing GSHP.

HDP Programme:

Within the project programme, works have been estimated to begin Q1 2026 and finish Q1 2027.

Electricity Carbon Factor:

- Electricity carbon factors will fall in line with figures projected by BEIS for the decarbonisation of the National Grid.
- PPA has not been considered as part of energy and emissions modelling.

Fuel Rates:

Fuel rates and baseline energy consumption for gas and electricity at the NMM site have been calculated based on average values from data provided by Royal Museums Greenwich over the period April 2021 – July 2023.

DELIVERY PLAN

5. Route to Net-Zero

5.1 Heat Decarbonisation Action Plan

This Heat Decarbonisation Plan provides a framework within which Royal Museums Greenwich can plan the scale and pace of change required to decarbonise the National Maritime Museum. The measures listed in Table 25 are recommended to be taken forward and presented at site-wide level to align to the Salix application process. The carbon and financial case for each individual site is made in detail (aligned to the Salix HDP criteria) in Table 26 and 27 (note Queen's house is not presented separately as the only recommended intervention is the site-wide heat decarbonisation and BMS).

Table 25 - Decarbonisation Intervention Overview (site-wide summary)

Intervention	Capital Cost (£)	Type of Energy Savings	Energy Savings (kWh p.a.)	Bills Savings (£ p.a.)	Payback (Years) Cost Avoidance	Intervention Recommended
ASHP Option 1	£2,415,000	Gas	2,534,411	-£34,206	-	Yes
Thermal Blinds	£395,000	Gas	93,987	£2,479	93	Yes
Loft Insulation	£233,000	Gas	92,116	£2,429	56	Yes
BMS Upgrade	£88,000	Electricity	115,010	£14,071	6	Yes
Draught Proofing	£140,000	Gas	12,562	£331	175	Yes
Energy Metering & Monitoring	£28,000	-	-	-	-	Essential

5.1.1 Energy Demand Reduction

5.1.1.1 Building Fabric Measures

Table 26 - Recommended Fabric Measures for NMM

Intervention	Peak Heat Loss Improvement (%)	Gas Savings (kWh/year)	Financial Savings (£.p.a.)	Cost Avoidance (£ p.a.)	First year Carbon Savings (tCO_2e)	Cumulative Carbon Savings to 2050 (tCO_2e)
Loft Insulation	5.2%	81,979	£2,162	£3,674	14.76	374.1
Draughtproofing	6.8%	14,443	£381	£647	2.64	65.9
Thermal Blinds	3.2%	76,617	£2,021	£3,434	13.99	349.6
Combined	15.2%	173,039	£4,564	£7,755	31.39	789.7

Table 27 - Recommended Fabric Measures for Park Row Wing

Intervention	Peak Heat Loss Improvement (%)	Gas Savings (kWh/year)	Financial Savings (£. p.a.)	Cost Avoidance (£ p.a.)	First year Carbon Savings	Cumulative Carbon Savings (tCO_2e)
Loft Insulation	8.9%	10,137	£267	£454	1.85	46.3
Draughtproofing	16.3%	3,276	£86	£147	0.60	15.0
Thermal Blinds	9.2%	17,370	£458	£778	3.17	79.3
Combined	34.8%	30,738	£812	£1,380	5.62	140.5

Table 26 and 27 outline the recommended fabric interventions for installation at the National Maritime Museum and Park Row respectively. As mentioned in Section 4.2 many of the recommended fabric interventions have high payback periods and would not typically be recommended based on those values. However, this is primarily due to the average gas rate for the NMM site which is £0.03/kWh. When combined with the installation of the LCHS, these fabric interventions are key for decreasing the required electrical demand of the ASHP and provide significant cost avoidance savings. Therefore, these interventions are recommended based on their carbon savings and the cost avoidance they provide when running the ASHP.

5.1.2 Heat Decarbonisation

The transition to low carbon heating is a key to achieving RMG NMM Site's Net Zero target. The recommendations are based on carbon savings, operational energy savings, engineering feasibility and financial implications. The summary of appropriate heat decarbonisation recommendations is shown in Table 28. Three potential locations for the ASHP have been identified, and while location 1 has been identified to be the most suitable from an economic and heritage aspect, as the locations is situated on University of Greenwich land, a full recommendation cannot be made until an agreement on the use of the land has been reached. ASHP location will only impact the capital cost of installation, it will have no bearing on carbon savings.

Table 28- Heat Decarbonisation Recommendations for NMM

LCHS	Required thermal loads(kW)	Seasonal Coefficient of Performance (SCoP)	Total projected electricity consumption (kWh p.a.)	Total gas energy bill savings (£ p.a.)	Cumulative Carbon Savings by 2050 tCO_2e
ASHP	1,005	2.73	1,020,627	£124,870	11,081

All proposed external works that will affect the external appearance relating to the proposed heat decarbonisation will require planning approval from the Local Planning Authority, and Historic England. All works will need to be undertaken in accordance with the Building Regulations and relevant industry standards.

5.2 Decarbonisation Scenario

The modelling outputs in the following section are based standard grid-average emissions factor[4].

The NMM is on EDF's 'Blue for Business' tariff meaning that all grid electricity consumed is generated from nuclear sources and, therefore, zero carbon at the point of generation. However, this is not compliant with Renewable Guarantees of Origin (REGO) requirements, and therefore reporting guidelines require the use of grid-average emissions factor.

Figure 5-1 shows the forecast annual carbon emissions and annual consumption per fuel type for the NMM with the suggested intervention measures in place. As RMG have no set timeline for the implementation of decarbonisation measures, it

---

[4] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

has been assumed that works will be completed during Q1 2027 to fall in line with the proposed programme.

The initial baseline for carbon emissions for NMM have been established at 1,051 tCO_2e/year during 2023. As works are complete in Q1 2027, it is forecast that emissions will fall to 244 tCO_2e by 2030 creating a 76.8% decrease in direct carbon emissions against the 2023 carbon emission baseline. By 2050, with the further decarbonisation of the grid, carbon emissions are expected to decrease by 99.1%, against the 2023 baseline, to 9.41tCO_2e p.a. There are many offsetting schemes available to accommodate the remaining carbon emissions and achieve net-zero by 2050. Using the BEIS Green Using the BEIS Green Book guidance[5], it is estimated that offsetting the remaining amount of carbon emissions for the year of 2030 will be £68,320 (Central series at £280/tCO_2e), and for the year of 2050 will cost £3,557 (Central series at £378/ tCO_2e). Alternatively, 'green electricity' could be procured through a renewable electricity tariff.

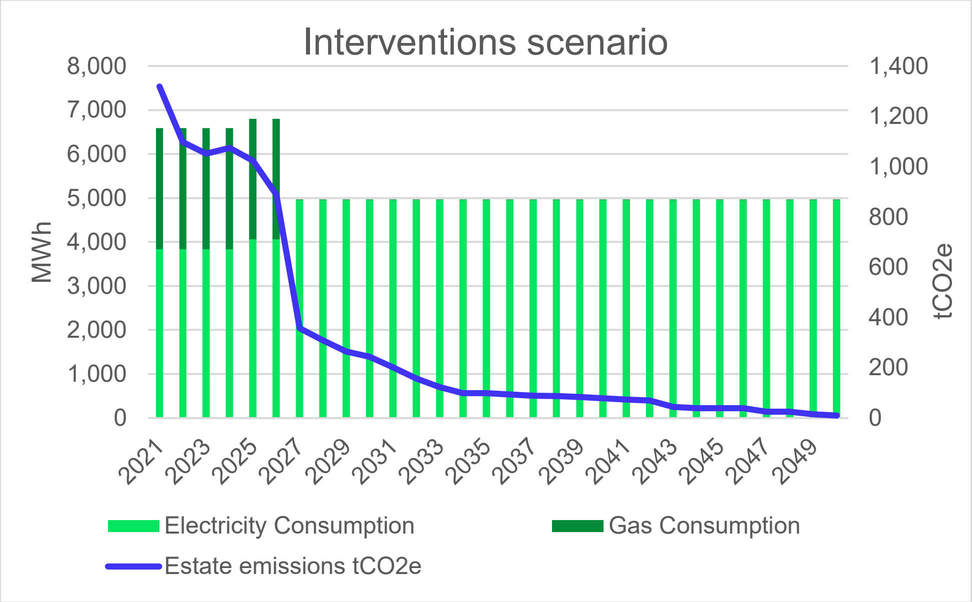


Figure 5-1: 2021 - 2050 Carbon Emissions and Energy Consumption for Decarbonisation Scenario

---

[5] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal - GOV.UK (www.gov.uk)

Table 29- Carbon Emission Savings from Decarbonisation Interventions

Intervention	Type of Fuel Saved	Cumulative CO_2 Saved by 2035 (tCO_2e)	% of Total	Cumulative CO_2 Saved by 2050 (tCO_2e)	% of Total
Fabric	Gas	335	7%	893	7%
ASHP	Gas	4,155	92%	11,081	92%
BMS	Electricity	43	1%	62	1%
Total		**4,533**	**100%**	**12,036**	**100%**

5.3 Cost impact summary

5.3.1 Estimated Capital Costs

The estimated capital costs of the decarbonisation interventions across the RMG National Maritime Museum site are shown in Table 25 and Appendix E. The total cost of all interventions is £5.0 million. These costs are based on rates in Q4/2026 (excluding VAT, professional fees and contingency). An additional allowance has been calculated for professional fees & surveys at 15% (£750,000), A contingency of 15% has also been included (£860,000), making the total estimated project cost £6.6 million (excluding VAT). No allowances have allowed for ongoing maintenance, or for the DNO application (where further engagement with the DNO is required to review quote options).

A construction start date of 1Q 26 and a completion date of 1Q 27 (on the basis of Salix SPDS 3c timescales) has been assumed for the capital cost plan.

5.3.2 Projected Energy Bills

Estimated Energy Bill savings and increases are based on an average of the current energy unit prices from recent invoices provided by RMG National Maritime Museum. The average unit price for electricity is 12.2 p/kWh, and the unit price gas is 2.6 p/kWh.

The expenditure profile for RMG National Maritime Museum is shown below in Figure 5-2. This profile is based on the average energy prices as used in the rest of the report, calculated from an average of rates from 2021 – 2023 for the NMM site. It should be noted that future savings in energy bills will be dependent on the trajectory of energy prices and are likely to change from this forecast.

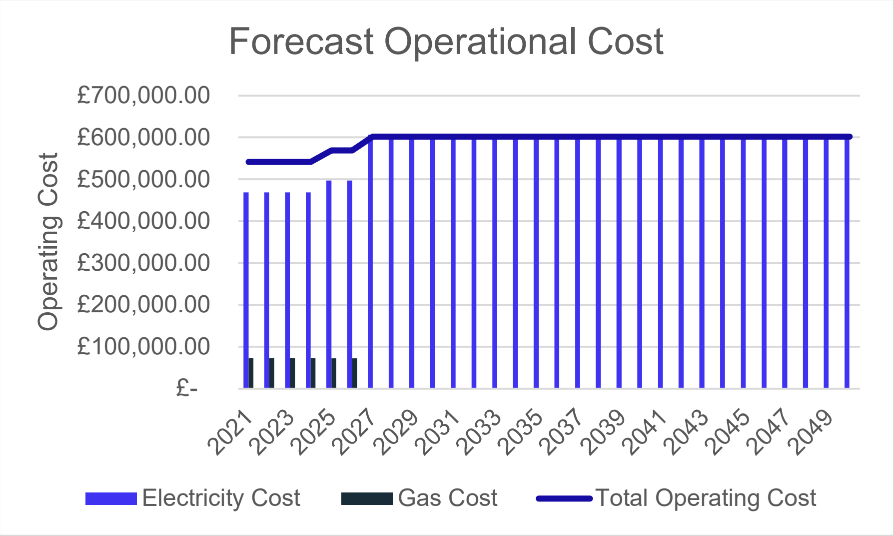


Figure 5-2: Projected Operational Costs 2021 – 2050

Projected gas and electricity consumption for 2023 provides an annual operating expenditure of £541,715. This figure is expected to rise as the ongoing works on Ocean Court are completed in 2025 creating an additional demand for electricity. As the proposed interventions are installed in Q1 2027, savings from the removal of gas boilers and installation of fabric measures are not expected to mitigate the additional electrical demand from the ASHP from a cost perspective. Therefore, the forecast annual expenditure on energy is estimated to rise to be around £602,592 per annum.

APPENDICES

Appendix A. Project Programme

Please see Appendix A – RMG NMM Project Programme.

Appendix B. Risks Register

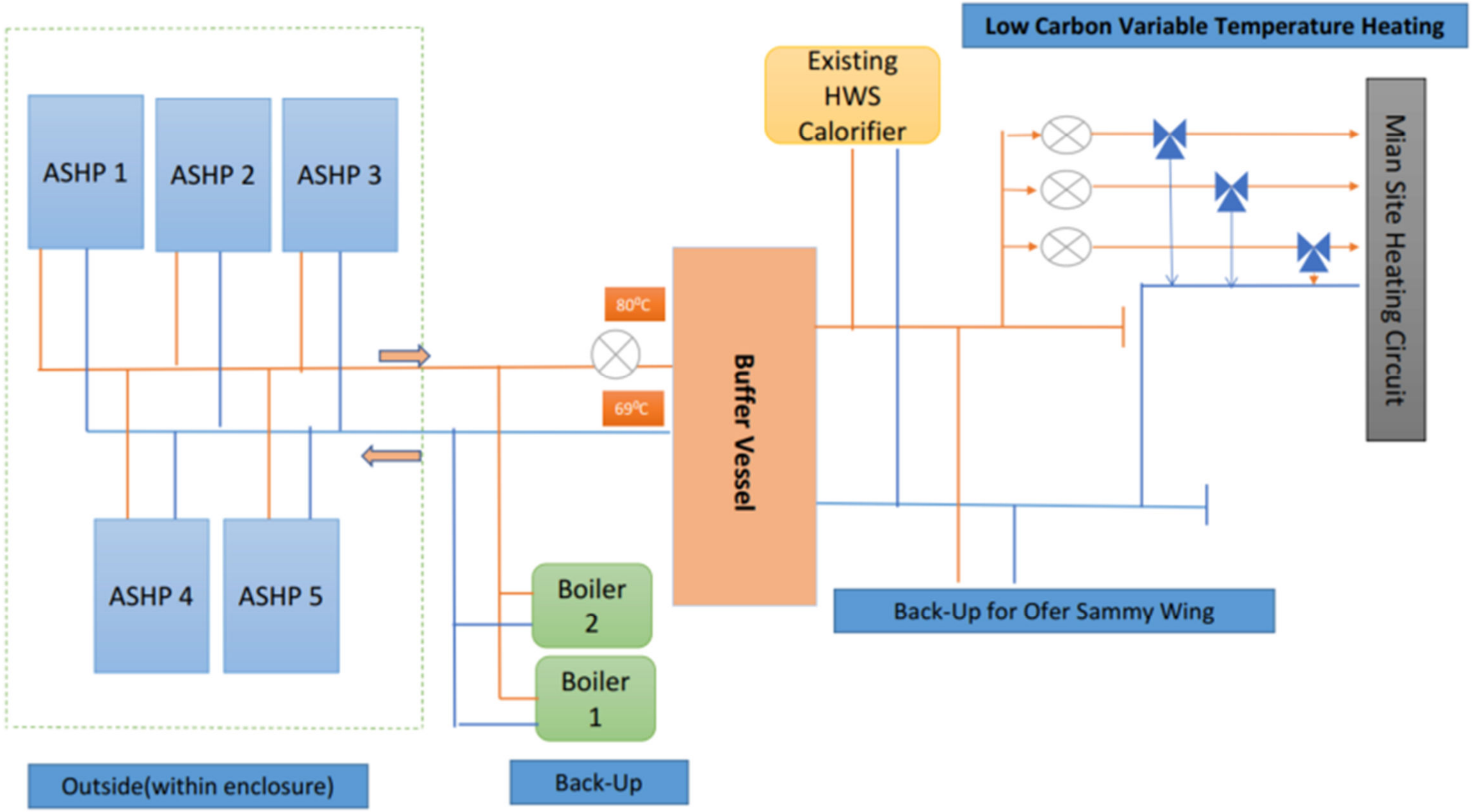
Risk Number	Risk Classification	Risk Title	Risk Description	Probability of Occurrence	Level of Consequence	Current Risk Status	Mitigation Plan
1	Financial	Availability of Funding	The availability of funding and budgets to undertake feasibility studies, bid for funding, the capital cost elements of work (including design fees).	2	4	8	Determining that funding will be available throughout the Decarbonisation Plan. Diversity of funding streams (Salix Finance, RMG Capital).
2	Financial	Price security	Price security, risk of overspending, unforeseen costs (particularly when working in existing buildings), introducing new technologies.	4	4	16	Costs in this report should be regularly reviewed and increased in-line with inflation and up-to-date energy costs. Secure cost with suppliers by placing order ASAP and seek extensions of quotation validity.
3	Financial	Expenditure	Expenditure outside of project for consultancy, securing additional internal resources to deliver the projects.	2	3	6	Secure resource and fees with professional consultants.
4	Financial	Raw Material Cost	Increase in raw material costs between date of obtaining quote and date of delivery of works.	4	4	16	Secure costs with suppliers by placing orders as early as possible and seeking extension of quotation validity.
5	Financial	Brexit	New Trade Tariffs cause an increase in costs for imported equipment	2	2	4	Additional provisions to Brexit related delays in procurement.
6	Organisational	Resource Availability	Availability of resource to deliver, manage and monitor the performance of the Decarbonisation Plan.	1	5	5	Early engagement with the Estates team and wider RMG stakeholders to establish a resourcing plan.

Risk Number	Risk Classification	Risk Title	Risk Description	Probability of Occurrence	Level of Consequence	Current Risk Status	Mitigation Plan
7	Organisational	Decision making	Complex decision chains and routes to sign off proposals and timings to respond/bid for external funding opportunities.	1	5	5	Engagement with governance structure to maintain communications and proactive approach to resolving issues.
8	Organisational	Implementation of behavioural change	Resistance to change when implementing behavioural change policies (top management support required).	1	5	5	Early engagement with the Estates team and wider RMG stakeholders to establish a communication plan and on-going reporting of all site work from both sides.
9	Organisational	Training	Lack of internal capability for implementation of works	1	2	2	Training requirements to be identified and supported (time/funding).
10	Delivery	Planning permission	Time to obtain required planning permission for heat decarbonisation works will need to be secured (e.g., the location of external air source heat pumps, windows replacement).	5	4	20	Engagement with planning department, England Historic and local authority to maintain communications and proactive approach to resolving issues and identify alternative solutions if permission is denied.
11	Delivery	Long lead in time	Possible delivery issues for proposed technologies (lack of available equipment due to COVID-19/Brexit/emerging industry/conflict).	4	4	16	Prompt completion of design & specification to raise POs as early as possible.
12	Delivery	Contractor Experience	Lack of contractor knowledge in delivering low carbon heating projects (emerging technology).	3	5	15	Ensure established contractor is appointed with previous experience in low carbon heating projects and appropriate case studies.
13	Delivery	Monitoring and Metering	Lack of time/funding to facilitate monitoring and metering to provide ongoing feedback to secure the	2	2	4	Adequate Monitoring and Verification Plan (M&V) Plan must be in place, with robust reporting schedules.

Risk Number	Risk Classification	Risk Title	Risk Description	Probability of Occurrence	Level of Consequence	Current Risk Status	Mitigation Plan
			successful implementation of the Decarbonisation Plan. Feedback is vital to develop successful building solutions.			🟨	
14	Delivery	Electrical Infrastructure	Lack of capacity within the electrical infrastructure to facilitate ASHP.	4	4	16	Early engagement with DNO to determine the availability within the electrical infrastructure network.
15	Delivery	Electrical Infrastructure	DNO delays lead to longer than accounted for delays in the project programme.	4	4	16	Early engagement with DNO to provide more contingency in the project programme.

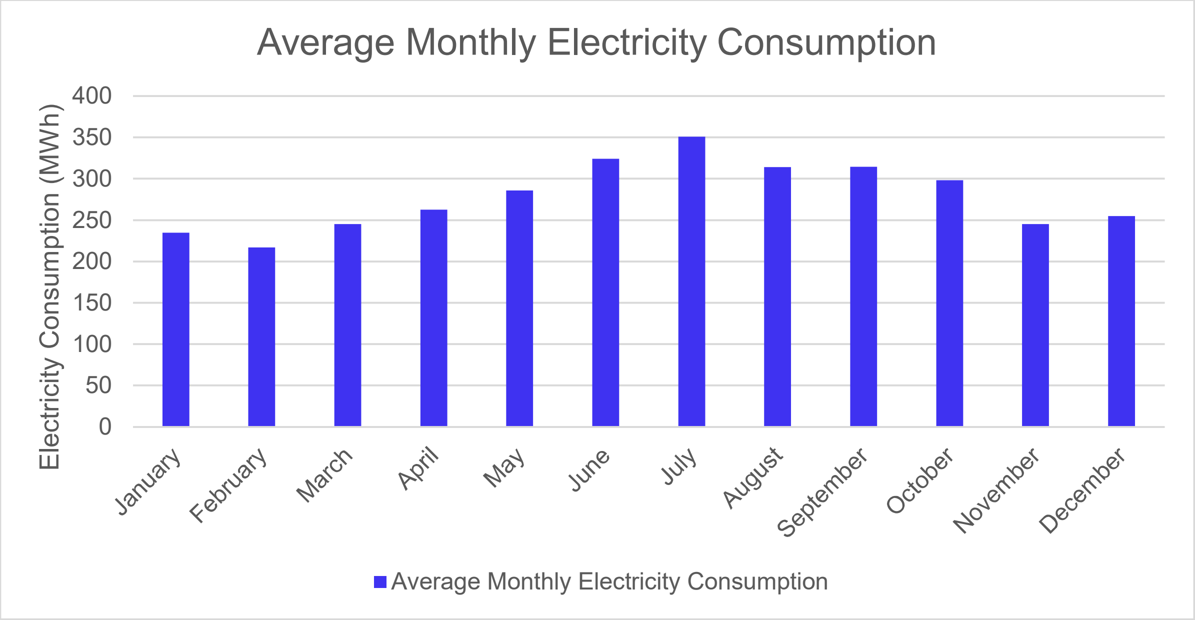
Appendix C. Proposed Heating Schematic

RMG NMM Proposed Heating Schematic

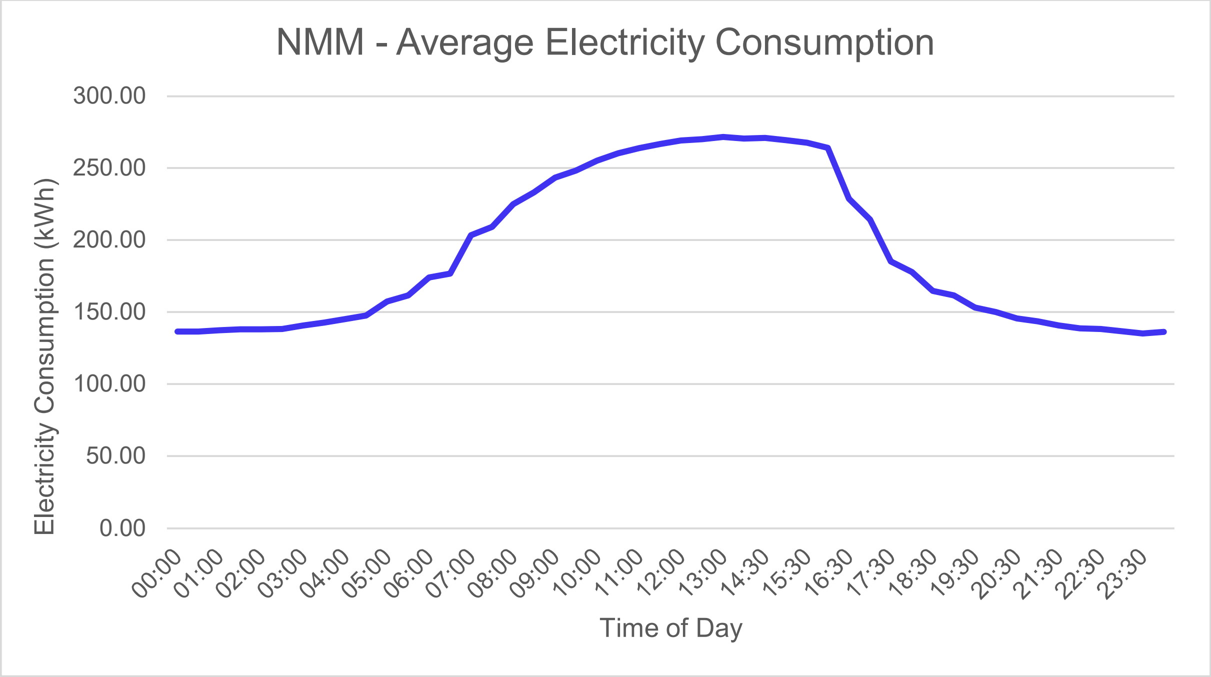


Appendix D. Electricity Consumption Graphs

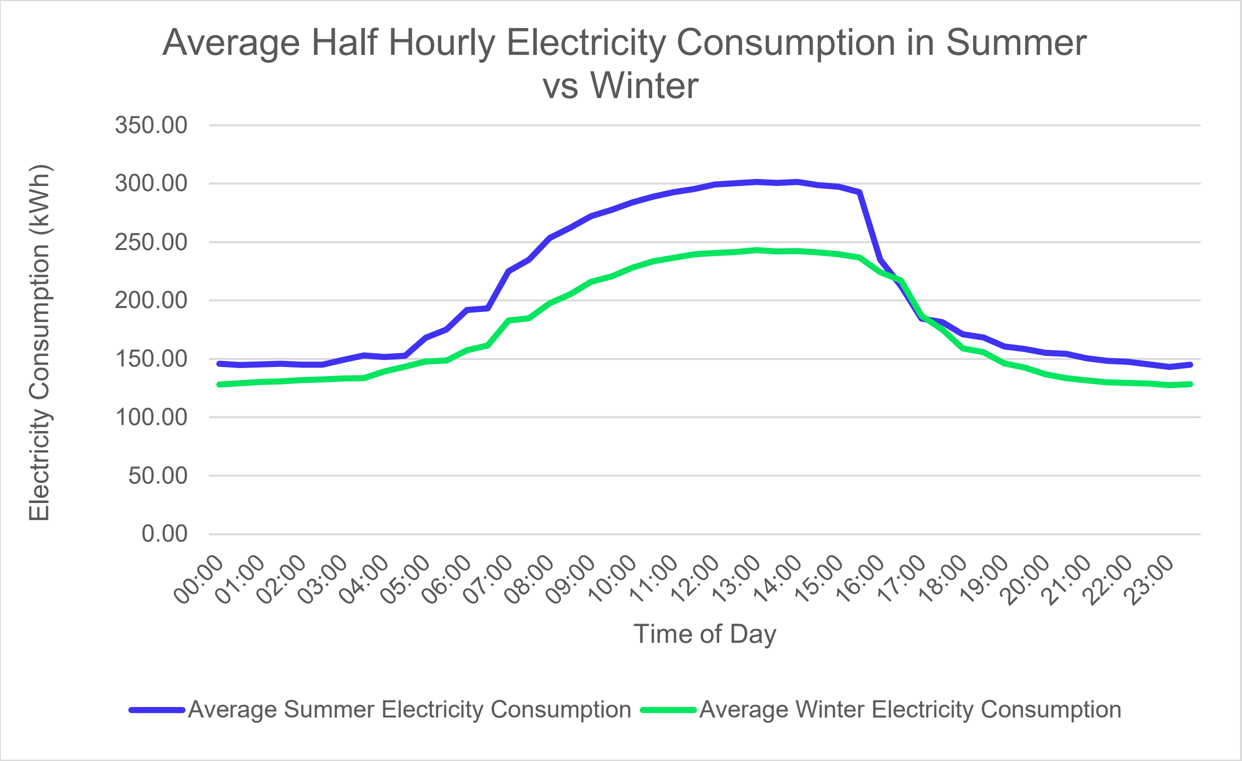
D.1 Average Monthly Electricity Consumption



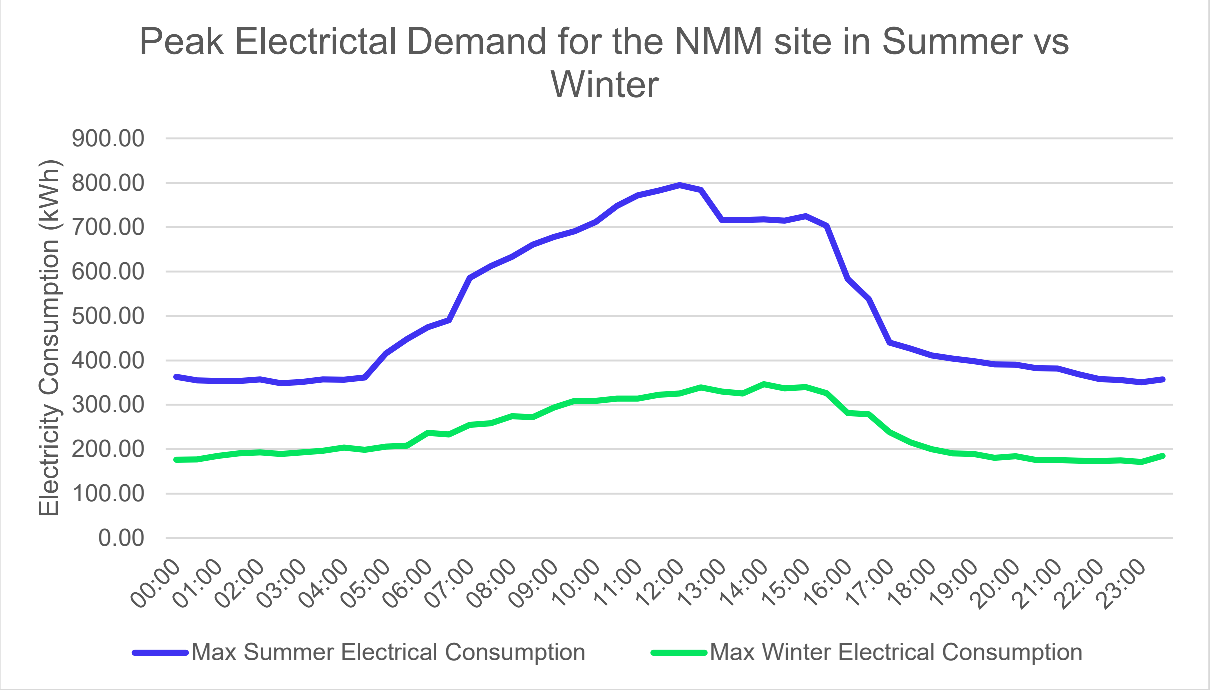
D.2 Year-Round Average Daily Electricity Consumption



D.3 Summer vs Winter Average Daily Electricity Consumption



D.4 Maximum Electrical Demand – Summer vs Winter



Appendix E. Cost plan

Please see Appendix E –Cost Plan

Appendix F. Heritage Impact Assessment

Please see Appendix F – RMG NMM Heritage Impact Assessment Report

AtkinsRéalis

Jack Saunders
AtkinsRéalis
11 Bressenden Place,
London,
SW1E 5BY

jack.saunders@atkinsrealis.com
+442071212872