Queen Mary, University of London

Heat Decarbonisation Plan

March 2022

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1.0	Sustainability Committee (Consultation)	24 January 2022
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This report has been written from the point of view of Queen Mary, University of London (Queen Mary). The report has been reviewed by Dr. Philip Tamuno (Head of Sustainability) and Liudmyla Pasichnichenko (Sustainability and Energy Manager) from Queen Mary, who have contributed to the text that is presented. All references to pronouns “our“, and “we” refer to Queen Mary, University of London exclusively and there is no relation to Silver EMS Ltd or Hysopt.

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Executive Summary

This plan details Queen Mary, University of London (Queen Mary) Heat Decarbonisation Plan (HDP). This HDP was commissioned from the £124,399.20 grant, which Queen Mary received as part of the Low Carbon Skills Fund (LCSF) in August 2021. This grant enabled Queen Mary to access the required technical expertise in the new and emerging area of heat decarbonisation and low carbon building technology to support the delivery of its commitment to immediately reduce its carbon footprint and energy wastage across its estate as well as attain net-zero ambition.

This Heat Decarbonisation Plan (HDP) will be fundamental to developing evidence-based options to support the delivering of our immediate and long-term responses to the challenges associated with climate change, deliver our environmental sustainability objectives and our corporate responsibility of contributing to the reduction of greenhouse gas (GHG) emissions. The plan also provide an overview of the pattern and intensity of fossil fuel usage of 56 buildings across Queen Mary's estate. The total energy used across these 56 building during the 2019/20 academic year were 30,610,159 kWh (electricity: £4,491,462), 25,762,996 kWh (gas: £734,572) and 100,416 kWh (heating oil: £5,885).

These 56 buildings represent 90% of our current building stock. In addition, the average age of these buildings is 53 years and 23 of these Building had Display Energy Certificate (DEC) rating of between E and G. This implies that there are significant energy efficiency and decarbonisation opportunities across our Estates. Implementing appropriate decarbonised heating and ventilation systems and fabric improvement could contribute to the delivery of our six-year 30% carbon reduction target and our long-term net zero aspiration.

This HDP is aligned with our current Environmental Sustainability Action Plan (ESAP) and our Environmental Policy (2021). Thirty-one low carbon, heat decarbonisation and associated projects have been prioritised and quantified in line with the LCSF's heat decarbonisation guidance. The total capital cost of implementing these initiatives is approximately £9.3 million with associated annual savings of £199,400 per annum[1] (from 2,247,099 kWh natural gas, 355,060 kWh electricity and 82,549 kWh heating oil). The financial savings from implementing these initiatives would be higher than current projections because of the current rising trend in energy prices.

The implementation of the recommendations within our HDP will be prioritised based on building carbon intensity, technical feasibility, ease of implementation, current and future building use and return on investment (ROI).

[1] Based on the current unit rates we pay for electricity 16.78 p/kWh and gas 4.25 p/kWh (during the 2021/22 academic year)

These 56 buildings were surveyed between 4 November and 16 December 2021, subsequent low carbon and heat decarbonisation options quantification were carried out in line the LCSF's and based on current technical standards and specifications.

Methodology

The energy used across these 56 buildings during the 2019/20 academic year were analysed and presented in terms of relative consumption and associated carbon emission (tCO_2e). The breakdown of the Scope 1 (heating) and Scope 2 (electricity) emissions form these buildings are shown in Figure 1.

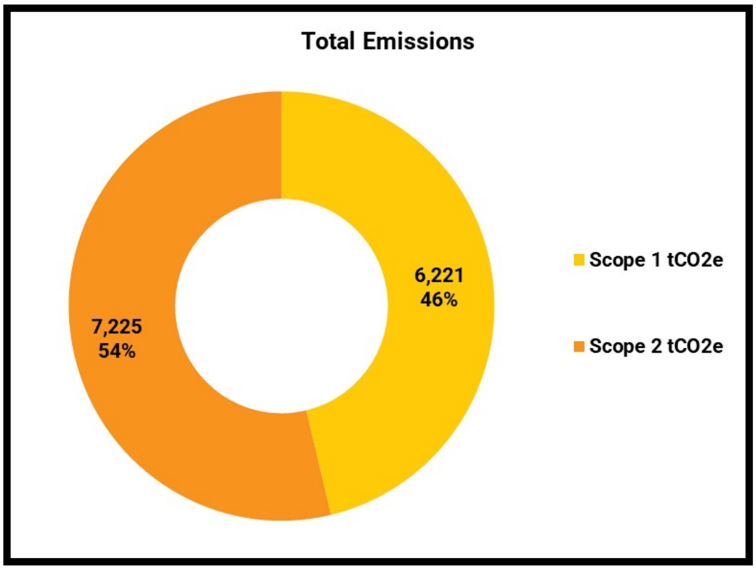

Figure 1: Total Scope 1 & 2 emissions of the building portfolio

The energy survey conducted was used to assess the performances and statuses of the current heating, cooling and ventilation systems and building fabric as well as to explore appropriate renewable energy opportunities and heat decarbonisation measures. These surveys were the basis on which these buildings were prioritised for the purpose of identifying appropriate energy efficiency measures and carbon reduction potential. In addition, these surveys have been used to quantify identify building-level, cluster-level and campus-level heat decarbonisation prospects.

The decarbonisation and energy impacts of immediate, short, medium and long-term estates and capital development strategic, concepts priorities and plans were reviewed with relevant stakeholders.

The capital, installation and commissioning costs of implementing the quantified heat decarbonisation initiatives were based on industry standards, previous quotes and previous experience. The inputs and feedbacks from stakeholders during engagement meetings and workshops were used to refine these costs to refine these initial costs to arrive at the indicative costs of implementing these 31 projects.

Outcomes

Building level opportunities were based predominantly on fabric upgrades including window improvement and roof insulation as well as installation of standalone air source heat pumps and installation of photovoltaic (PV) panels. These building level initiatives are focused on energy reduction and decarbonisation of heating of the prioritised buildings with high absolute and relative fossil fuel consumption.

Campus level opportunities were developed on the premise of the integration of heat pump technology into existing or proposed district heat networks that connects clusters of buildings. This approach is focused on delivering operationally efficient heat pump systems with complementary energy efficiency measures that support lower operating temperatures (flow and return). The costs of these campus-level of cluster initiatives are high level that took into account all key plant components of the proposed interventions.

The carbon reduction and energy savings associated with the building and campus levels energy efficiency measures such as district heating, solar PV-T and fabric improvements were used in projecting the trend of Queen Mary's energy consumption and carbon emission. However, a business as usual (BAU) energy consumption scenario, which assume that our energy consumption will increase by approximately 2% per annum to accommodate for energy demand associated with the projected target population increase of 50% by 2030 compared to our 2019 levels has been applied to these trends.

Figure 2 show the energy consumption of these 56 buildings (2019/20 and 2020/21) as well as projected consumption between 2021/22 and 2049/50 academic years (assuming that this plan will be implemented between 2023 and 2027). This figure includes projected increase in energy demand associated with anticipated annual progressive rise in student population and the impact of the proposed 31 decarbonisation initiatives. The projected trend in carbon emissions is shown in Figure 3. The trend in carbon reduction is based on projected energy usage, decarbonisation of grid electricity in line with the UK's greenhouse gas (GHG) reporting (conversion factors 2021 published by UK government). As seen in Figures 2 and 3, the journey to net zero and complete heat decarbonisation will require continuous investment in energy efficiency and low carbon projects.

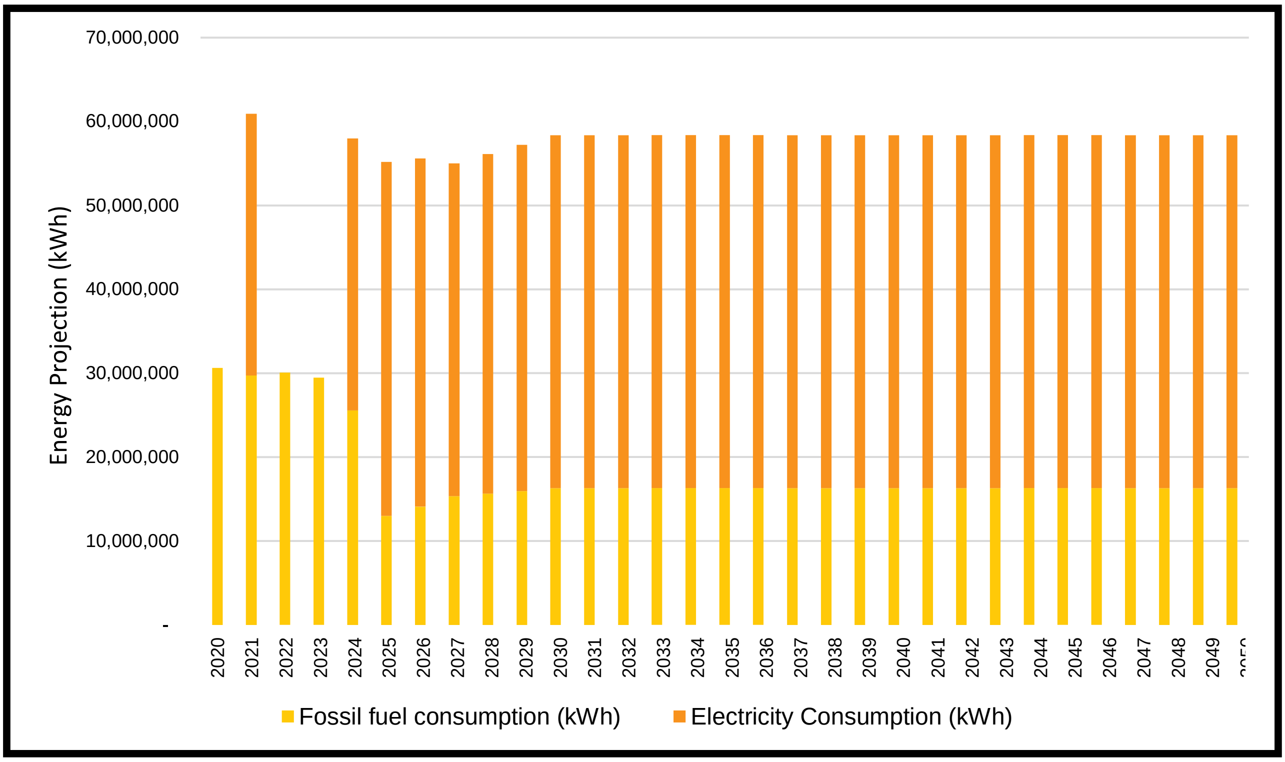

Figure 2: Projected energy consumption of the building portfolio

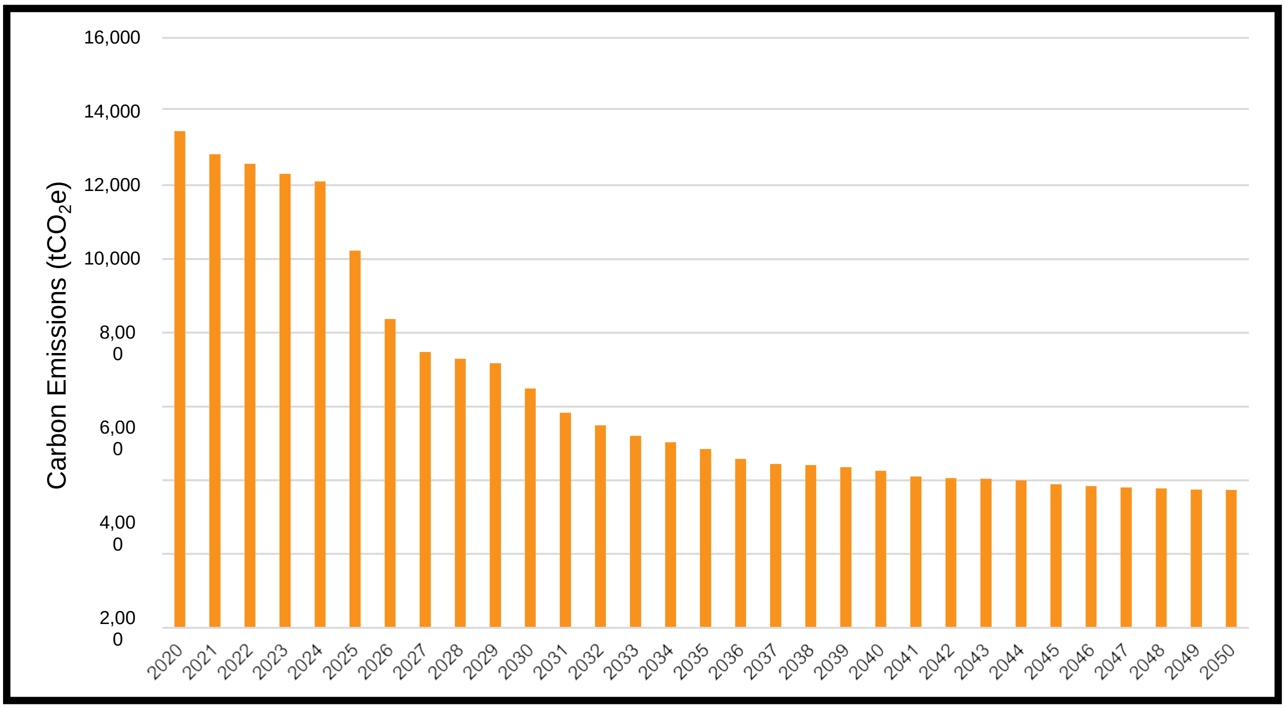

Figure 3: Projected Scopes 1 and 2 Carbon Emissions

Summary of Proposed Measures

Table 1 summarises the indicative capital costs, costs savings, carbon (CO2e) savings and simple paybacks of building level heat decarbonisation measures proposed for the priority buildings.

Table 1 Indicative Costs of Proposed Measures for Priority Buildings

Building	Indicative Capital Cost (£)	Cost Saving (£)	Carbon Saving (tCO_2e/Year)	Life-time Carbon Abated (tCO_2e)	Simple Payback (Years)	MAC [£/tCO_2e]
Queens' Building	£759,000	£12,884	43.7	1,093.8	58.9	£693.94
Albert Stern	£150,000	£4,579	22.0	368.9	32.8	£406.67
G. O. Jones (Physics Building)	£1,385,000	£14,409	74.7	2,055.3	96.1	£673.86
Ifor Evans Place	£96,000	£3,459	4.8	108.1	27.8	£888.39
Francis Bancroft	£459,000	£18,075	32.0	720.3	25.4	£637.23
Peter Landin	£1,260,000	£12,104	58.0	1,624.7	104.1	£775.53
Informatics Teaching Lab	£251,000	(£411)	8.0	180.8	-	£1,388.29
Dawson Hall	£972,000	£21,930	105.1	2,943.6	44.3	£330.20
Wolfson Building	£3,000	-	-	-	-	-
Blizard Building	£317,000	£11,954	16.6	464.8	26.5	£682.03
The Wingate Institute	£80,000	£1,254	6.0	135.2	63.8	£591.57
Innovation Centre	£238,000	£8,966	12.4	348.6	26.6	£682.75
Garrod Building	£538,000	£16,891	68.5	1,762.5	31.9	£305.25
Floyer House	£517,000	£13,413	49.8	1,329.9	38.5	£388.77
Total	£7,025,000	£139,507	501.6	13,137	50.4[2]	

Mile End Campus

Below are the ongoing and planned energy reduction and decarbonisation projects across the Mile End Campus:

- a 200 kW heat pump is planned to be installed which will serve the SRIFF Room IT load, which would be increasing to 600kW within the next 5 years. This project would eliminate the need to replace the current chillers at Joseph Priestley's Building. The heat is expected to be generated via the pump within the SRIFF Room
- the extension of the district heating network to Residential Buildings which would be fed by SRIFF Room and or combine heat and power (CHP) and or the Queens' Building
- the extended district heating network would serve France House and the proposed Business School / Hatton House
- it is anticipated that the Queens' Building Boilers would be connected to the district heating network by the end of March 2022, which would eventually lead to the removal of the current temporary boilers that serves the Peoples Palace
- it is anticipated that the existing electrical infrastructure across the Mile End Campus would be upgraded to improving capacity and resilience. A 11kVA ring main would be installed under Phase 1 (Hatton House) redevelopment with incoming supply from the proposed Business School

[2] Average payback

In addition, to the above planed initiatives two further campus level decarbonisation projects have been proposed. Pre-project technical and techno-economic feasibility studies must be completed prior to the implementations of these initiatives.

- Air source heat pump (ASHP) be installed on the roof of the Informatics Teaching Laboratories to serve this building and the adjacent interconnected buildings (6, 7, 8, 9, 10 and 13), and possibly be extended to Westfield Nursery (11) and Occupational Health and Safety Directorate (12)
- Replacing or supplementing the existing CHP with an air source heat pump (ASHP) as well as upgrading the distribution pipework and ancillary equipment to serve the connected buildings. This intervention would also repurpose and potentially supplement the existing thermal storage for the additional benefits of operational flexibility.

Charterhouse Square Campus

Below are the ongoing and planned energy reduction and decarbonisation projects across the Charterhouse Square Campus:

- The planed replacement of the John Vane Science Centre's chiller (which supports BSU) with an absorption chiller, this will add thermal load to the CHP via the connection of the CIAT Chillers to a CHW loop served by the absorption chiller
- The anticipation that the CHP would eventually be used to store energy and setup a uninterrupted power supply (UPS) central network
- The planned campus-wide upgrade of the ventilation systems
- The anticipated further consolidation of existing VRF systems to be connected with the centralised cooling system.

In addition, to the above planed initiatives three further campus level decarbonisation projects have been proposed. Pre-project technical and techno-economic feasibility studies must be completed prior to the implementations of these initiatives.

- Heat pump installed on the roof of the Wolfson Institute Building (2), electrically fed from the John Vane Centre via the recently upgraded 1.5 MVA electrical supply via the existing heat network
- Connection to an existing off-site district energy network via heat exchanger substation
- Connection to a nearby data centre to capture low grade waste heat from existing chiller systems, with on-site waste heat recovery heat pump system

Whitechapel Campus

The two campus level decarbonisation projects have been proposed. Pre-project technical and techno-economic feasibility studies must be completed prior to the implementations of these initiatives.

- Connection to existing and planned campus buildings to any future off-site or on-site district energy network
- Integration of existing campus buildings with Queen Mary's development masterplan, with optional development of energy centre at Plot C and exporting of energy to neighbouring developments / sites

Phased Development Plan

The timeline for the implementation of building level projects set out in this report will be determined by when funding becomes available and a range of specific factors such as:

- coordinating the implementation of these initiatives with ongoing operational campus functions
- sequencing of the implementation of these projects via a single or multiple framework contract and in line with Queen Mary's internal approvals and procurements processes
- dependent on when planning applications or exemptions are approved

It is recommended that building levels decarbonisation measures should be implemented between 2022 and 2026 or as soon as opportunity or funds become available. Indicative timelines for typical building-level energy efficiency retrofit projects of the scale proposed within this plan are expected to be completed between 9 and 12 months per building. Typical building level measures can be implemented via single works contract. Projects grouped in this way and secured under existing frameworks or through competitive tender process will reduce the risk of delay in project completion and commissioning, optimise budget and technical expertise.

The factors below should underpin the delivery of building level decarbonisation projects proposed within this HDP:

- coordination of the Works with strategic masterplan proposals
- sequencing of the works under a single or multiple framework contracts
- internal approvals and procurements processes
- timescales for receipt of planning permission
- timescales for receipt of external approvals
- timescales for negotiation of commercial agreements

It is recommended that campus level decarbonisation measures should be implemented at the earliest opportunity and preferential between 2023 and 2025. This proposed timeline is aligned with Queen Mary's current six-year 30% carbon reduction target. Campus level implementation time scales are expected to vary significantly according to the project type, for example whether air, ground or waste heat recovery sources are being implemented.

As a priority, it is recommended that wherever feasible that building level initiatives precedes campus-level decarbonisation measures. Therefore, it is imperative that these building level measures are integrated into long term maintenance (LTM) or capital project programmes for the purpose of budget and cost savings optimisation. Generally, building level measures are aimed at reducing energy wastage or consumption and includes improvements to heating and cooling systems to enable operation at lower and higher temperatures respectively, which contributes to improving the operational efficiency of heat pumps.

In the case of the Whitechapel Campus, there may be an opportunity to integrate the strategic proposals within the redevelopment of Plot C under the existing campus masterplan, which would contribute to decarbonising this development. The existing energy strategy for the campus will need to be reassessed/realigned in the context of the current proposals. There may be a case for serving the existing campus from an energy centre located within Plot C, subject to Plot C project development proposals and time scales. It is anticipated that Plot C development will be completed by Quarter 4 of 2026.

Key Challenges

The key challenges associated with implementing the building level decarbonisation proposals include:

- sequencing of the Works across the various campuses within the required implementation timescales and under a limited number of framework contracts.
- coordination of the Works with current campus operational activities
- various timescale, cost uncertainty delivery and implementation risks including:
    - project management and contract administration of Construction Contract(s), given the extent of the project opportunities identified
    - where relevant, dependent on issuance of planning permission
    - CDM health and Safety
    - contractor's supply chain affecting delivery programme
    - grants and funding criteria

The key challenges associated with implementing the campus-level decarbonisation proposals include:

- risks identified as per building level projects
- aligning and coordinating proposals to strategic longer term campus development masterplans
- limited space to integrate on-site heat pump-based projects
- obtaining planning permission for energy system proposals where relevant
- obtaining permits and approvals for heat recovery under selected options
- negotiating commercial agreements with potential project partners under selected options
- financing and obtaining internal business case approval for project opportunities, particularly those which may deliver strategic value over the longer term, but which present additional risks in the shorter term is likely to require significant up-front investment and coordinated internal resourcing

- identifying project partners capable of delivering measures with the required sufficient technical capability and capacity to deliver these proposed measures
- implementing building heating and cooling system retrofit measures within required timescales
- for Whitechapel Campus, integrating proposals into planning permission for current site redevelopment, including opportunity to integrate an energy centre to the Plot C redevelopment

Possible Funding Sources

A number of potential funding sources could be explored to support the delivery of the proposals within this HDP. Below are some of these opportunities:

- Salix Finance's Public Sector Decarbonisation Scheme (PSDS)
- Salix Finance's Recycling Fund. This scheme currently supports heat decarbonisation projects, and it will close on 31 March 2025
- Department for Business, Energy, and Industrial Strategy (BEIS) Green Heat Network Fund (GHNF)
- Greater London Authority (GLA) Local Energy Accelerator (LEA)
- BEIS' Heat Network Efficiency Scheme (HNES)
- GLA's The Mayor of London's Energy Efficiency Fund (MEEF)

Limitations

The surveys of these 56 buildings were conducted between 4 November and 16 December 2021. The information and data gathered through internal stakeholder workshops and email correspondences with relevant interested parties across Queen Mary. External stakeholder engagement and collaboration was very limited prior to developing this HDP. It is recommended that further engagement and active collaboration is required to ensure the optimisation of the proposed district network and energy systems. Timely and successful external stakeholder engagement will clearly be fundamental to the successful implementation of this HDP.

Plant capacity selections for campus level project opportunities and proposals identified within this report are based on modelling carried out using Hysopt software. The proposed projects within this HDP are provisional and further optioneering and optimisation is required at subsequent stages of design and project development.

Similarly, costs presented within this HDP are indicative project costs. These indicative costs are based on a combination of desktop benchmarking and quotations received from similar projects. Prior to applying for external grant funding, it is recommended that these estimates are updated after detailed options appraisals with associated budgetary quotes and delivery timelines for each of these proposed projects.

Partnership and Collaboration

We[3] will continue to explore our current partnerships with organisations, stakeholders and interested parties to optimise heat decarbonisation initiatives, heat networks and energy centres as part of our journey to decarbonise the heating of all our buildings in line with our commitment to attain net zero.

[3] This report has been written from the point of view of Queen Mary University to be Queen Mary's internal document. The report has been reviewed by Dr. Philip Tamuno (Head of Sustainability) and Liudmyla Pasichnichenko (Sustainability and Energy Manager) from QMU, who have contributed to the text that is presented. All references to pronouns "our", and "we" refer to Queen Mary University exclusively and there is no relation to Silver EMS Ltd or Hysopt.

1. Purpose

The purpose of this Heat Decarbonisation Plan (HDP) is to provide an overview of how Queen Mary, University of London (Queen Mary) intends to replace fossil fuel reliant systems with appropriate low carbon alternatives in line with the guidelines of the Low carbon Skills Funds (LCSF). This HDP outlines heat decarbonisation opportunities that support the delivery of Queen Mary's six-year 30% carbon reduction target against its 2018/19 baseline (26,371 tCO_2e) and its 2050 net zero aspiration.

The HDP evaluates current energy consumption and associated carbon emissions of the selected 56 buildings, recently completed energy reduction measures that have been implemented, ongoing initiatives and planned projects. The proposed quantified heat decarbonising opportunities within this HDP were developed based on the LCSF's guidance. The fundamental aspects of this plan are:

- review of current energy consumption, energy intensity, building fabric, building use, hot water, heating and ventilation systems
- collation of recently completed and ongoing energy reduction measures
- review of the estates and capital development strategies to ensure that all recommended heat decarbonisation projects are aligned with these strategies and plans
- recommended building level and campus level heat decarbonisation and associated projects

The scope of this HDP is restricted to the selected 56 buildings across our six UK campuses. One of the conditions associated with the LCSF's grant is that the completed and approved plan will be submitted to Salix by 31 March 2022.

Currently 100% of the electricity procured and used across our UK campuses are on green electricity tariff. This HDP was commissioned from the £124,399.20 grant, which we received as part of the Low Carbon Skills Fund (LCSF) in August 2021.

2. Introduction

2.1 Context

Queen Mary is a Russell Group University and one of the UK's leading research focused higher education institutions that provides higher education to more than 31,000 students and close to 4,500 staff. We are aware that the current environmental and climate change risks are the greatest challenges that society faces, and we are committed to play our part in reducing our environmental impact as well as continue to improve our environmental performances. This HDP is consistent with our Environmental Policy 2021 and Environmental Sustainability Action Plan (ESAP 2020-23).

The scope of this HDP are 56 buildings, which have been selected based on current energy consumption, age of building, boilers and hot water and heating, ventilation and air conditioning systems. These 56 buildings are located in urban areas across the Grater London Area. Below is the breakdown of these 56 buildings:

- Mile End (36 buildings)
- Whitechapel (10 buildings)
- Charterhouse Square (7 building)
- West Smithfield (1 building)
- Lincoln's Inn Fields (1 building)
- Chislehurst Sports Ground (1 building)

These campuses range in size from single building sites at Lincoln's Inn Fields, Chislehurst Sports Ground and West Smithfield to Mile End campus with 36 buildings. Figure 4 show the locations of the 6 campuses.

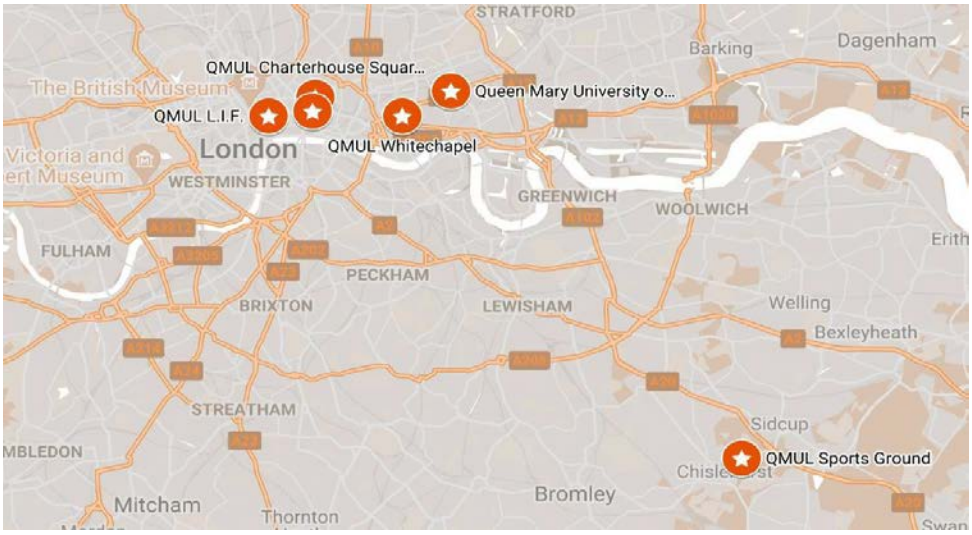

Figure 4: Location of Queen Mary's Campuses

Queen Mary University of London

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Specifically, the medium and long-term redevelopment plan for the Mile End Campus and Plot C as well as current strategic property and redevelopment plans of individual buildings, major capital projects and campus level infrastructure plans have been into consideration during the process of developing this HDP. The implementation of these plans, strategies and projects are dependent on planning application (where applicable), operational and strategic priorities and available funding.

Our ESAP (2020-23) is the framework on which it intends to respond to the current and emerging environmental risks and challenges. This ESAP is also aligned with the UK's 2050 net zero carbon target and de-carbonisation priority. We are also currently working towards embedding the fundamentals of United Nations Sustainable Development Goals (UN SDGs) into our teaching, research, partnerships, and all aspects of our operations. Over the next 12 months, we will be engaging with staff, students and all relevant stakeholders in developing our long-term environmental sustainability strategy and net zero plan.

Our carbon footprint (CO_2e) is represented by the emissions associated with the energy and water used across our UK campuses, fuel used by our vehicles and business travel[4]. A brief overview of our carbon footprint is detailed below:

Scope 1 (Directly controlled emissions)

- The GHG (greenhouse gas) emissions from the fossil fuel used to heat the buildings across our campuses.
- The GHG emissions associated with the fuel (petrol and diesel) used by our own vehicles.

Scope 2 (Emissions from grid electricity)

- The GHG emissions associated with grid electricity we buy and use across our estates.

Scope 3 (Indirect emissions)

- The GHG emissions associated with our business travel.
- The GHG emissions associated with the water used across our campuses.

This HDP primarily addresses fossil fuel used to heat its building, which is a component of our Scope 1 GHG emissions. A review of our 2018/19 carbon footprint, show that energy and water used across its campuses represent 61.8% of its carbon footprint. In addition, only 33% of its 55 Display Energy Certificate (DEC) qualifying buildings currently achieved DEC scores of C and above, which implies that there are opportunities to improve the energy performance of its building.

[4] Distances our Staff and Researchers travel to carry out academic and operational responsibilities (excluding those via Oyster Cards)

It is apparent that our six-year 30% carbon reduction target against Queen Mary's 2018/2019 carbon footprint of 26,371 tCO_2e cannot be solely reliant on heat decarbonisation. An integrated approach, which encompasses, building energy efficiency and management, fleet fuel reduction, water efficiency, water and greywater harvesting and reuse and proactively managing and reducing our business travel.

Based on our 2030 strategy, we anticipate that our student population would increase by 10,000 students compared to our 2019 levels. We have therefore applied a business as usual (BAU) annual energy consumption increase of 2% per annum up to 2030 to our projected energy use and associated carbon emissions.

2.2 Heat Decarbonisation Strategy

The decarbonisation (switching from fossil fuel combustion) of heating systems is fundamental to addressing the risks associated with climate change, reducing Scope 1 carbon emissions, and attaining net zero. Government's investment on greening / decarbonising grid electricity contributed to reducing electricity GHG conversion factor by 55% between the 2005/06 and 2020/21 fiscal years (from 0.47337 to 0.21233). However, the GHG conversion factor for natural gas reduced by 6% during the same period (from 0.21604 to 0.20297). It is therefore, imperative that significant investment on building, site-level and decentralised heat decarbonisation will be required if the UK is to attain its net zero target by 2050.

The proposed projects within this HDP have been based on the energy hierarchy shown in Figure 5.

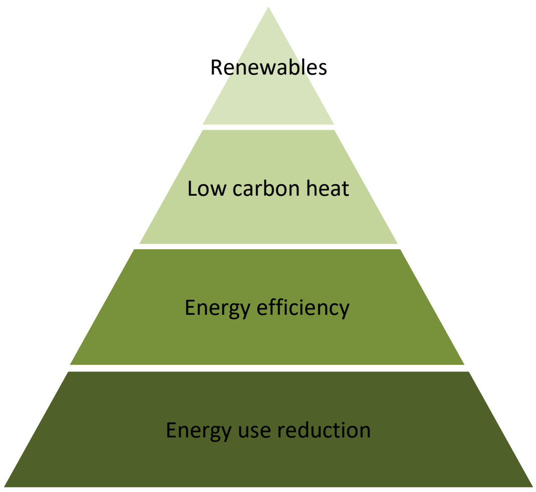


Figure 5: Energy Hierarchy

Overview of these energy hierarchies are summarised below:

- Energy use reduction measures targets energy wastage and inefficient practices via simple steps such as resetting of time clocks and temperatures, upgrading systems controls and good energy housekeeping by staff, students, visitors, and contractor.

- Energy efficiency step includes improvements to building services equipment, such as fitting variable speed pumps or "two port" control of mechanical services, as well as building fabric improvements.
- Low carbon heat option includes the use of heat pumps, district heating systems and other technologies that switches fossil fuel heating to electricity.
- Installation of local renewable energy generation. This should be implemented in conjunction with low carbon heating, understanding the potential increase of overall electrical demand due to electrification of heat. Adequate implementation of renewable energy generation projects can help reduce the impact on local and national electrical infrastructure and reduces the need for high-cost electrical infrastructure upgrades.

This HDP has been developed based on the review of the energy consumption and carbon footprint of 56 buildings across six campuses as well as energy surveys. 55 of the 56 buildings have been physically surveyed by Silver EMS to provide an independent view of the condition of the building fabric, existing heating systems and existing domestic hot water systems.

Heat decarbonisation would require a range of technical options and implementation strategies. Queen Mary's current approach to heat decarbonisation focusses on:

1. Energy awareness campaigns, which encourages good energy housekeeping practices
2. Reducing energy use by installing and upgrading building management system (BMS), building fabric improvement, as well as lighting upgrades, and controls
3. Installation of combine heat and power (CHP) systems, connection to district heating or electrification of heating, either full conversion or through hybrid systems

3. Buildings

The HDP covers 56 buildings within Queen Mary's operational building stock, which Queen Mary is responsible for procuring and paying the energy bills. The metered fossil fuel usage for 2019/20 are shown in Table 2 with calculated carbon emissions in Table 3.

Table 2: Energy Consumption Data 2019/20

Building Name	Campus	GIFA (m^2)	Natural Gas (kWh)	Heating Oil (kWh)	Electricity (kWh)
Informatics Teaching Labs	Mile End	1,443	52,001	0	277,327
Geography Building	Mile End	2,812	411,167	0	142,486
Law Building	Mile End	3,025	336,143	0	245,035
Student Hub	Mile End	3,146	310,563	0	788,582
Computer Science Building	Mile End	3,382	147,594	0	213,709
Mathematical Science Building	Mile End	4,003	227,343	0	238,396
Arts Two Building	Mile End	3,503	122,263	0	243,853
Student Union Building	Mile End	3,906	170,462	0	198,796
People's Palace	Mile End	4,562	1,173,423	0	404,309
G. E. Fogg Building	Mile End	5,454	1,099,060	0	620,996
Arts One Building	Mile End	5,492	323,520	0	251,569
G. O. Jones Building	Mile End	5,580	678,793	0	868,971
Joseph Priestley Building	Mile End	5,942	2,767,151	0	2,989,240
Library	Mile End	9,203	491,128	0	764,400
Queens' Building	Mile End	13,400	2,370,612	0	1,022,304
Francis Bancroft Building	Mile End	14,371	261,884	0	2,201,057
Engineering Building	Mile End	16,015	2,234,394	0	1,269,324
Graduate Centre	Mile End	6,859	456,721	0	523,233
Arts Research Annexe	Mile End	421	42,192	0	26,269
Lock Keepers Cottage	Mile End	236	26,020	0	6,288
The Nursery	Mile End	423	31,293	0	28,601
Ifor Evans Place	Mile End	2,099	271,393	0	83,635
Lindop House	Mile End	1,406	69,917	0	106,644
Hatton House	Mile End	3,570[5]	257,138	0	54,993
Maynard House	Mile End	2,067	225,218	0	312,222
Varey House	Mile End	2,067	140,388	0	277,367
Stocks Court	Mile End	3,142	178,374	0	193,019
Creed Court	Mile End	2,851	102,750	0	168,632
Maurice Court	Mile End	3,835	164,455	0	268,949
Beaumont Court	Mile End	3,887	162,722	0	335,172
France House	Mile End	4,623	375,900	0	342,166
Richard Feilden House	Mile End	4,857	369,867	0	522,862

[5] Includes Lodge, Chapman, Selincourt and Chesney Houses GIAs.

Building Name	Campus	GIFA (m^2)	Natural Gas (kWh)	Heating Oil (kWh)	Electricity (kWh)
Pooley House	Mile End	8,333	331,595	0	434,204
Albert Stern House	Mile End	1,035	438,313	0	57,156
Lynden House	Mile End	526	0	0	6,952
404 Bancroft Road	Mile End	142	24,821	0	6,389
Old Anatomy Building (Rees)	Charterhouse Square	1,011	37,697	0	309,424
Joseph Rotblat Building	Charterhouse Square	1,496	25,874	0	457,861
Wolfson Building	Charterhouse Square	2,042	571,383	0	624,968
William Harvey Heart Centre	Charterhouse Square	3,061	416,681	0	1,067,639
John Vane Science Centre	Charterhouse Square	11,614	2,258,434	0	1,087,184
Lodge House	Charterhouse Square	131	24,050	0	4,875
Dawson Hall	Charterhouse Square	8,177	3,003,761	0	2,502,775
Innovation Centre	Whitechapel	6,811	1,252,765	0	2,104,705
Library	Whitechapel	1,468	199,866	0	132,023
The Wingate Institute	Whitechapel	1,516	968,796	0	430,423
Yvonne Carter Building	Whitechapel	1,209	168	0	118,975
Whitechapel Students Union	Whitechapel	1,715	76,875	0	486,923
Abernethy Building	Whitechapel	3,068	706,238	0	737,604
Garrod Building	Whitechapel	5,457	495,340	0	424,520
Blizard Building	Whitechapel	8,038	2,104,358	0	3,131,674
Floyer House	Whitechapel	4,692	1,085,668	0	241,016
64 Turner Street	Whitechapel	124	13,706	0	2,093
Athletics Ground (Chislehurst Sports Ground - Pavilion)	Chislehurst	1,539	0	100,416	36,287
Lincoln's Inn Fields (Centre for Commercial Law)	Lincoln's Inn Fields	2,797	0	0	228,730
Robin Brook Centre	West Smithfield	4,681	446,314	0	364,152
Total	All	228,265	30,534,552	100,416	30,988,958

The energy data in Table 2 were derived from the data used by Queen Mary's Display Energy Certificate (DEC) Assessor to generate its 2020 DECs. However, the apportionment of the gas usage from the major gas supply meter that serves Dawson Hall, Wolfson Institute, John Vane Science Centre, and William Harvey Buildings used to generate the DEC of these buildings did not reflect the expected heating profiles of these buildings. Therefore, the total gas recorded at meter point reference number (MPRN) 8816979808 have been re-apportioned based on the estimated heat load (kW), which has been calculated based on heat losses through building fabric, thermal bridges, and air infiltration. Going forward, this approach will be used to apportion the gas consumption by these buildings until the installation of sub-meters.

Table 3: 2019/20 carbon emissions

Building Name	Campus	Scope 1 (tCO_2e)	Scope 2 (tCO_2e)	Total (tCO_2e)
Informatics Teaching Labs	Mile End	11	65	75
Geography Building	Mile End	84	33	117
Law Building	Mile End	68	57	126
Student Hub	Mile End	63	184	247
Computer Science Building	Mile End	30	50	80
Mathematical Science Building	Mile End	46	56	102
Arts Two Building	Mile End	25	57	82
Student Union Building	Mile End	35	46	81
People's Palace	Mile End	239	94	333
G. E. Fogg Building	Mile End	224	145	369
Arts One Building	Mile End	66	59	125
G. O. Jones Building	Mile End	138	203	341
Joseph Priestley Building	Mile End	564	697	1,261
Library (Mile End)	Mile End	100	178	278
Queens' Building	Mile End	483	238	721
Francis Bancroft Building	Mile End	53	513	567
Engineering Building	Mile End	455	296	751
Graduate Centre	Mile End	93	122	215
Arts Research Annexe	Mile End	9	6	15
Lock Keepers Cottage	Mile End	5	1	7
The Nursery	Mile End	6	7	13
Ifor Evans Place	Mile End	55	19	75
Lindop House	Mile End	14	25	39
Hatton House	Mile End	52	13	65
Maynard House	Mile End	46	73	119
Varey House	Mile End	29	65	93
Stocks Court	Mile End	36	45	81
Creed Court	Mile End	21	39	60
Maurice Court	Mile End	34	63	96
Beaumont Court	Mile End	33	78	111
France House	Mile End	77	80	156
Richard Feilden House	Mile End	75	122	197
Pooley House	Mile End	68	101	169
Albert Stern House	Mile End	89	13	103
Lynden House	Mile End	0	2	2
404 Bancroft Road	Mile End	5	1	7
Old Anatomy Building (Rees)	Charterhouse Square	8	72	80
Joseph Rotblat Building	Charterhouse Square	5	107	112
Wolfson Building	Charterhouse Square	116	146	262
William Harvey Heart Centre	Charterhouse Square	85	249	334

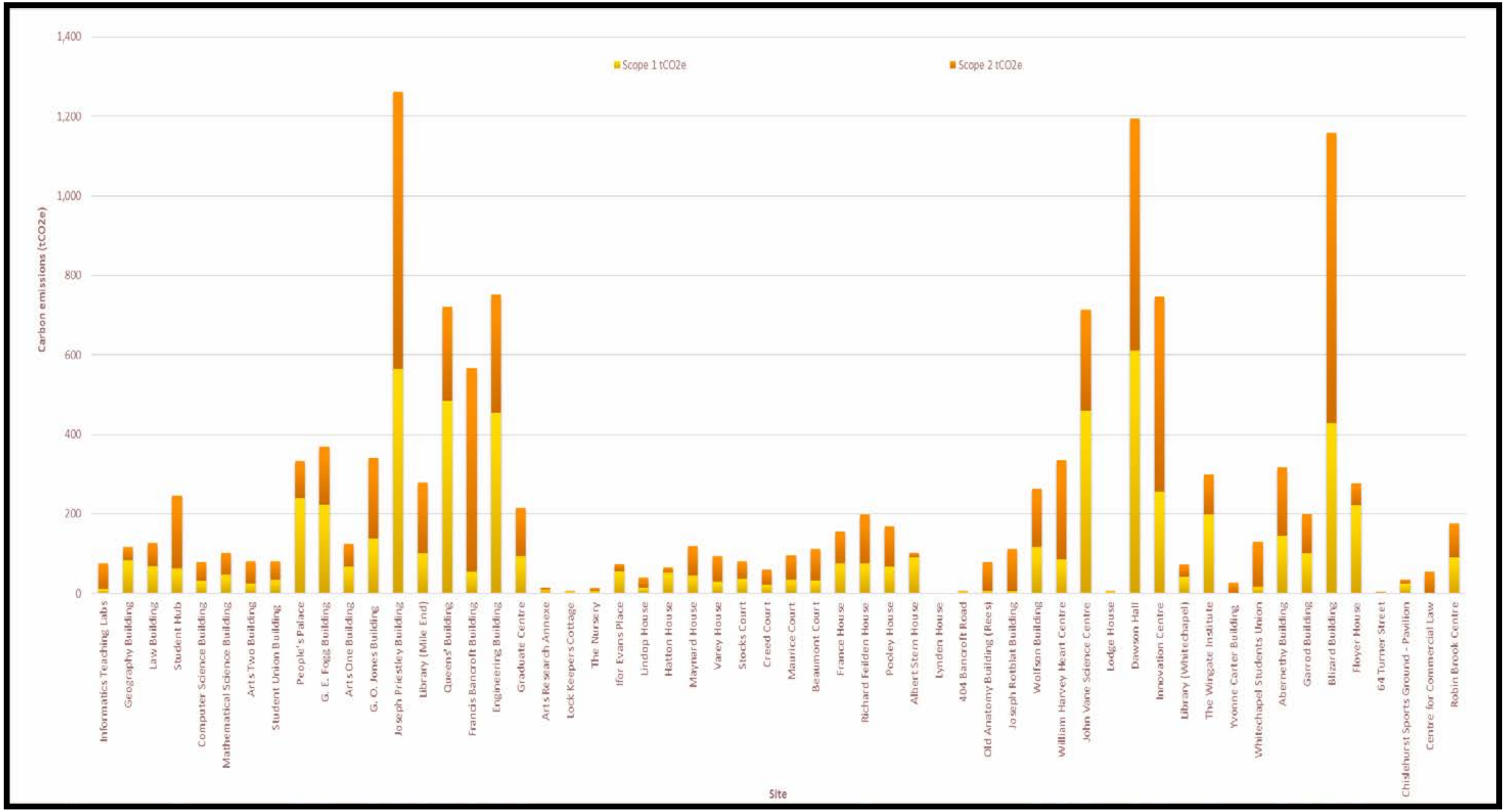
Building Name	Campus	Scope 1 (tCO_2e)	Scope 2 (tCO_2e)	Total (tCO_2e)
John Vane Science Centre	Charterhouse Square	460	253	713
Lodge House	Charterhouse Square	5	1	6
Dawson Hall	Charterhouse Square	612	583	1,195
Innovation Centre	Whitechapel	255	491	746
Library (Whitechapel)	Whitechapel	41	31	72
The Wingate Institute	Whitechapel	197	100	298
Yvonne Carter Building	Whitechapel	0	28	28
Whitechapel Students Union	Whitechapel	16	114	129
Abernethy Building	Whitechapel	144	172	316
Garrod Building	Whitechapel	101	99	200
Blizard Building	Whitechapel	429	730	1,159
Floyer House	Whitechapel	221	56	277
64 Turner Street	Whitechapel	3	0	3
Chislehurst Sports Ground - Pavilion	Chislehurst	26	8	34
Centre for Commercial Law	Lincoln's Inn Fields	0	53	53
Robin Brook Centre	West Smithfield	91	85	176
Total		6,246	7,224	13,472

The fossil fuel consumption and electricity purchased from the grid during the 2019/20 academic year correspond to 24% and 27% of the 2018/19 baseline carbon footprint, respectively. The 2019/20 carbon factors used in the analysis are as shown in Table 4. Figure 6 illustrates the associated the Scope 1 and 2 emissions of these 56 buildings.

Table 4: 2019/20 GHG conversion factors for Queen Mary

	Carbon Factor (tCO_2e)	Unit cost (p/kWh)
Natural gas	0.20374	4.25
Heating Oil	0.25964	5.86
Electricity	0.23314	16.79

Figure 6: 2019/20 Carbon Emissions



4. Resources

The Head of Sustainability with the support of the Sustainability and Energy Manager are responsible for managing energy consumption across Queen Mary's Estates. The technical Manager (Infrastructure and Maintenance) is responsible for the certification of all energy efficiency and decarbonisation projects. Whereas Director of Estates, Facilities and Capital Development has strategic oversight of the delivery of the HDP.

Personnel and Experience

The Sustainability and Energy Manager (Liudmyla Pasichnichenko) is a Certified Energy Manager (EUREM) with an MSc in Energy Management and a BSc in Electrical Engineering. Her over 9-years' experience in energy management is acquired from working in the energy consultancy sector. She is currently an Associate Member of the Institute of Environmental Management and Assessment (IEMA) and recently attended environmental compliance, environmental management system (EMS), environmental auditing, and environmental awareness courses. She has also attended webinars and sessions on heat decarbonisation and heating, ventilation, and air conditioning (HVAC) and the conference on Climate Emergency: Action Following COP-26 for universities. She is also scheduled to attend a training session on ISO 50001:2018 Energy Management System in March 2022.

The Head of Sustainability (Philip Tamuno) is a Lead Chartered Environmentalist and Full Member Institute of Environmental Management and Assessment Assessor and has over 10-years' experience developing and coordinating the delivery of energy efficiency and carbon management initiatives and projects across public sector organisations (Local Authority, NHS Trusts, and University). The Head of Sustainability have recently attended webinars and training sessions on heat decarbonisation and the challenges and opportunities associated with heat decarbonisation and attaining net zero.

The Technical Manager - Infrastructure and Maintenance (Timothy Lee) is a Member of the Institution of Engineering and Technology (MIET) and Member Chartered Institution of Building Services Engineers (MCIBSE). He has over 20 years' experience in delivering technical infrastructure and maintenance solutions.

HDP Delivery

We are aware that heat decarbonisation and associated technologies are comparatively new and emerging. The above three Officers of the University will continue to explore relevant continuing professional development (CPD) opportunities and wherever required it will commission external technical expertise to support the delivery of this HDP and its long-term net zero objective. The Head of Sustainability, Sustainability and Energy Manager and the Technical Manager (Infrastructure and

Maintenance) will continue to engage with all relevant internal and external partners and stakeholders to support the delivery of Queen Mary's HDP.

The need and requirement for additional human resources will be reviewed and business cases will be prepared as these needs arises. The areas where additional resources may be required could range from Capital Project (project management) and operations and maintenance (to ensure appropriate maintenance of installed technology / infrastructure). Currently, Queen Mary has no partnership arrangements in place. However, Queen Mary is a member of London Borough of Tower Hamlets Net Zero Climate Partnership, and they will use their membership to explore opportunities for collaboration.

Budget

Currently, Queen Mary has dedicated up to £750,000 from its Salix recycling loan fund to support the delivery of its HDP. We are aware that we will require significantly additional financial resources to deliver our fossil fuel decarbonisation and net zero aspirations.

We are also aware that the delivery of our current 30% six-year carbon reduction target we will require an investment of approximately £8 million. Therefore, in line with our energy efficiency commitments we currently have a four-year building management system (BMS) contract of £1.5 million for the purpose of improving energy efficiency across our UK campuses.

Procurement

The procurement and commissioning of all projects associated with this HDP will comply with all relevant guidelines, regulations, and laws as well as Queen Mary's procurement and financial standards. Below are a list of the relevant standards:

- Queen Mary's Standard Business Conduct 2018
- Queen Mary's Procurement Procedure 2020
- Queen Mary's Ethical Policy 2018
- Queen Mary's Anti Bribery and Corruption Policy 2018

The above list is not exclusive, and Queen Mary will ensure that all relevant government's anti-fraud and corporate social responsibility standards are strictly adhered to during the delivery of our HDP.

5. Completed Energy Efficiency and Low Carbon Projects

Our ESAP 2020-23 is the current framework on which we monitor and manage all significant areas in which we interact with the environment and respond to all relevant current and emerging environmental risks and opportunities. Table 5 contain a summary of energy efficiency projects that we completed and commissioned prior to developing our ESAP 2020-23 and Table 6 details our recently completed energy efficiency projects.

Table 5: Energy Efficiency Projects Completed prior to ESAP 2020-23

Project Tile / Description	Campus	Projected Savings / Increase (-)	
		Electricity (kWh)	Gas (kWh)
Graduate School Combine Heat and Power (CHP).	Mile End	621,601	-2,683,245
Arts 2: Ground Source Heat Pump (GSHP)	Mile End	34,533	133,200
Francis Bancroft Building Refurbishment	Mile End	484,039	484,039
Abernethy Building Refurbishment	Whitechapel	80,330	79,639
Maynard House BMS and Lighting Upgrade	Mile End	98,752	34,919
Varey House BMS and Lighting Upgrade	Mile End	95,500	34,919
Computer Science Building Management System (BMS)	Mile End	99,972	124,740
Richard Feilden House BMS and Lighting Upgrade	Mile End	41,977	34,919
Lindop House BMS and Lighting Upgrade	Mile End	35,726	52,113
Pooley House BMS and Lighting Upgrade	Mile End	48,772	317,998
Beaumont Court BMS and Lighting Upgrade	Mile End	33,949	79,665
Drapers Hall & QMotion Lighting Upgrade	Mile End	78,262	NA
Geography Pipework Insulation	Mile End	NA	53,626
Charterhouse Building Management System (BMS) Upgrade	Charterhouse	1,612,604	6,904,126
Dawson Hall Combine Heat and Power (CHP).	Charterhouse	1,770,700	-1,818,650
John Vane Combine Heat and Power (CHP).	Charterhouse	1,770,700	-1,818,650
Total Savings (kWh)		**6,907,417**	**1,710,999**

Table 6: Recently Completed Energy Efficiency Projects

Project Title / Description	Cost (£)	Projected Savings	
		Electricity (kWh)	Gas (kWh)
Joseph Priestley: Plate Heat Exchanger	£397,907	105,780	1,763,680
BMS Upgrade: Whitechapel Campus	£602,946	727,382	1,358,785
BMS Upgrade: Arts Two Building	£32,573	34,526	39,742
BMS Upgrade: Computer Science Building	£16,629	56,325	100,627
BMS Upgrade: Engineering Building	£83,025	201,279	400,434
BMS Upgrade: G. E. Fogg Building	£48,783	164,607	37,477
BMS Upgrade: G. O. Jones Building	£8,629	31,010	21,069
BMS Upgrade: Peoples Palace Building	£105,017	85,970	435,906
Whitechapel Lighting Upgrade	£1,170,000	914,929	NA

Project Title / Description	Cost (£)	Projected Savings	
		Electricity (kWh)	Gas (kWh)
Total	**£2,465,509**	**2,321,808**	**4,157,720**

In addition to the completed energy efficiency and low carbon projects, we are currently using £0.5 million Salix recycling funds to implement the projects below:

- Invested £51,137.92 to install 12.24 kWp photovoltaic panel on the roof our Queens' Building. This PV is projected to generate 14,021 kWh/year (electricity)
- Insulation of part of the roof of our Queens' Building at the cost of £101,554.42. This insulation is estimated to save approximately 101,762 kWh/year (gas).
- Upgrading the IT Server Room located within our Joseph Priestley Building costing £1,091,923.88 (partially funded from our recycling fund £358,558.66). Upgrading this server room has been projected to save 1,068,720 kWh/year of electricity.

6. Heat Decarbonisation Plan

This HDP has been developed on the basis of exploring, prioritising, and quantifying appropriate lower carbon heating systems and associated energy reduction initiatives. The associated initiatives encompass whole building approach aimed at improving building energy efficiency, reducing heat demand, as well as installing onsite renewable generation to support future electrification and continuing decarbonisation of our building stocks.

Improving the energy efficiency of existing buildings as well as setting high energy standards for new builds and refurbishment projects will contribute to reducing GHG emissions associated with the heating of our buildings reduce energy bills as well as improve health and wellbeing of staff and students. Building fabric improvements such as insulation and double / triple glazing reduces building heat loss and enhance the efficiency of heating systems. Smart building technologies and sensors are low-cost, which should be considered at the early stages of heat decarbonisation journey.

The proposed campus-level heat decarbonisation measures such as heat pump deployment and renewable energy generation via solar photovoltaics (PV) would contribute to reducing energy consumption across these campuses and reduce reliance on fossil fuel.

6.1 Building Level Decarbonisation

Reduction in base heat demand of buildings through improved energy efficiency is crucial for successful decarbonisation of heat and these measures should be incorporated alongside any technology solution. The HDP has been carried out to include the review of the energy use and decarbonisation options for those buildings identified as either fossil fuel intensive or high fossil fuel users. The purpose of this analysis is to provide an “immediate” action plan for decarbonisation of individual buildings which either have a long-term future on the estate or for which cost effective carbon reductions can be achieved within the planned building life. Each of the priority buildings is considered in turn and a hierarchy of measures applied.

6.1.1 Fossil fuel use analysis

The fossil fuel used across these 56 buildings during the 2019/20 academic year were used to rank these buildings in the order of total consumption (absolute usage in kWh/annum as seen in Figure 7) and relative performance (Specific / Usage Intensity in kWh/m^2/annum as seen in Figure 8).

Figure 9 show that the relationships between the Absolute Consumption against Specific Consumption of these 56 buildings. This implies that majority of these buildings consumes less than 500,000 kWh, at a rate of less than 200 kWh/m^2/annum. However, there are a number of notable exceptions, which have been prioritised and reviewed.

Figure 7: Absolute fossil fuel consumption by building in kWh/annum.

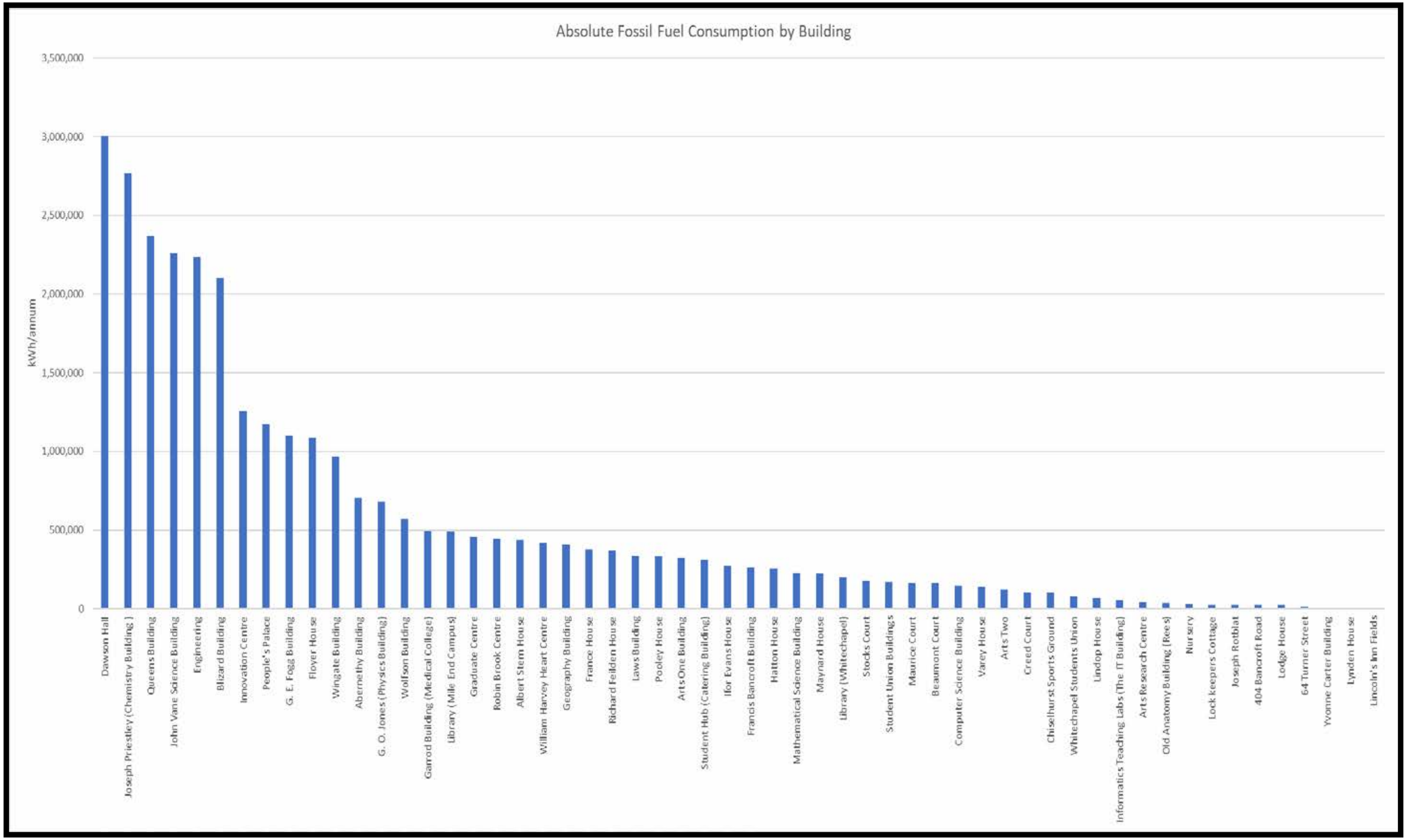


Figure 8: Relative fossil fuel performance in kWh/m²/annum (Intensity).

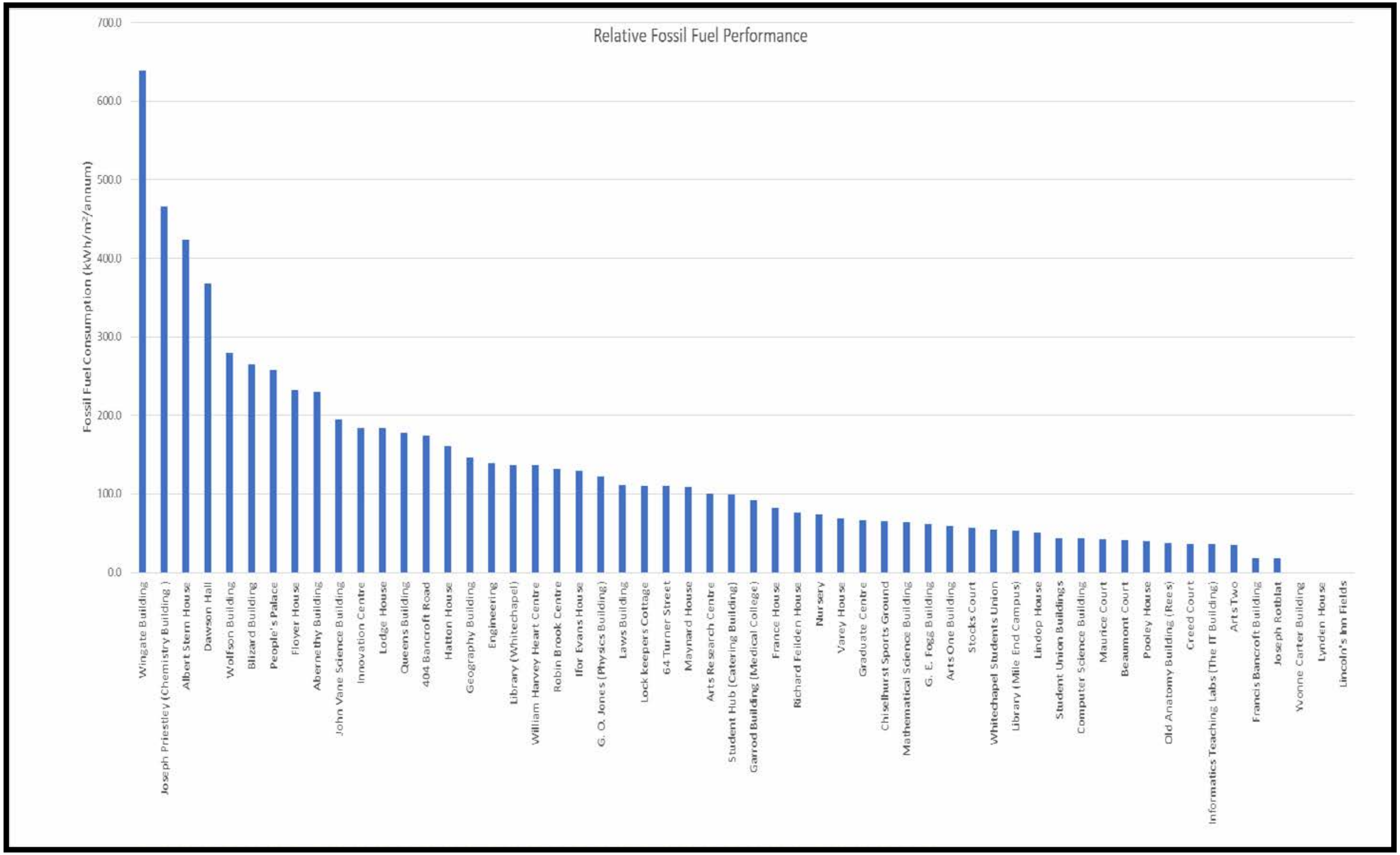
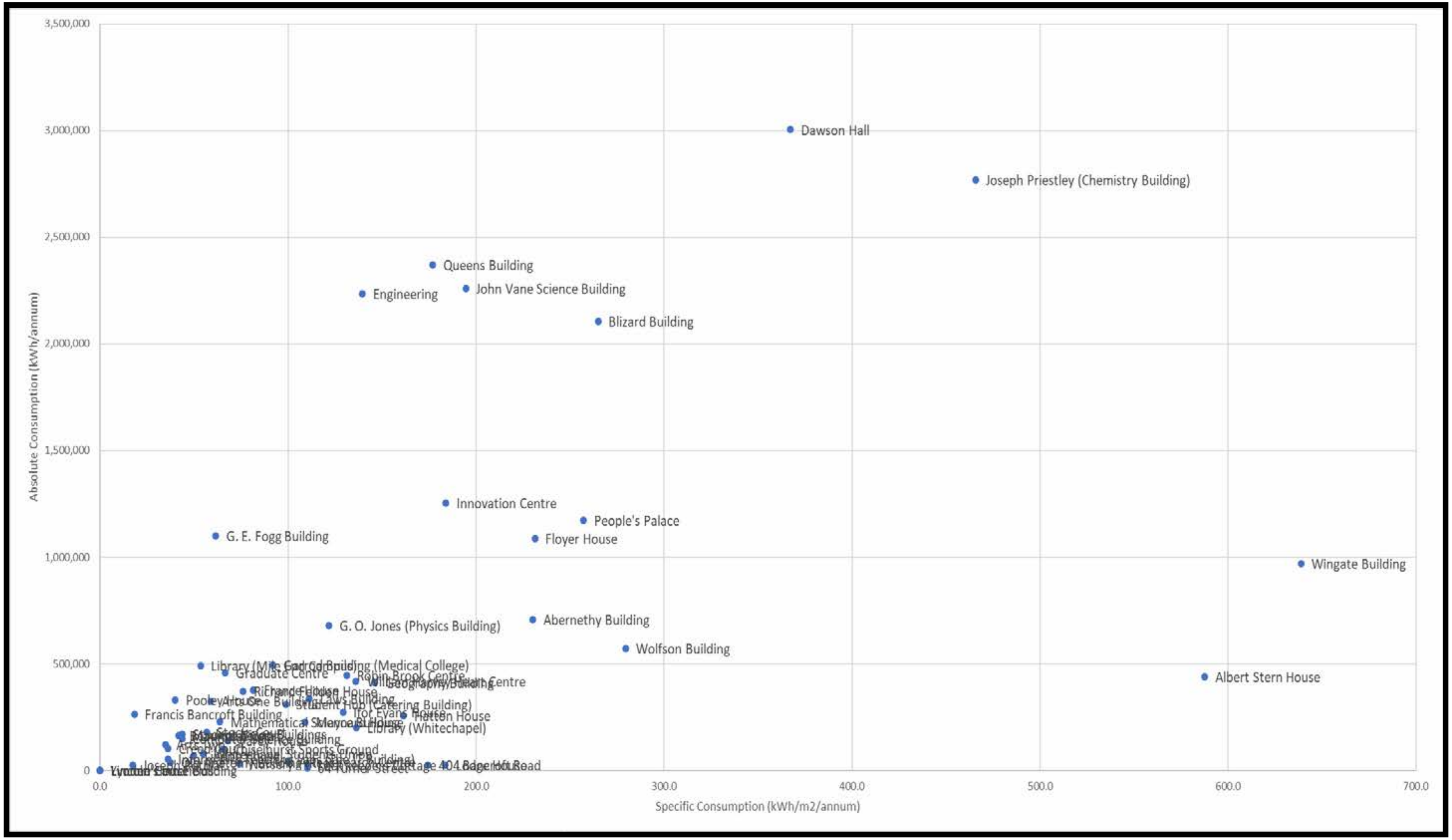


Figure 9: Absolute consumption against relative consumption.



A scoring system, which uses absolute and relative fossil fuel consumption, has been used to prioritise these 56 buildings. The prioritisation in Table 7 shows that 20 of these buildings have high heat decarbonisation potentials (buildings highlighted in Red).

Table 7: Building Priority List

Campus	Name of Building	Fossil Fuel (kWh/year)	Fossil Fuel (kWh/m^2/year)	Priority
Mile End	Joseph Priestley (Chemistry Building)	2,767,151	465.7	1
Charterhouse	Dawson Hall	3,003,761	367.3	1
Whitechapel	Wingate Building	968,796	638.9	3
Whitechapel	Blizard Building	2,104,358	265.0	3
Charterhouse	John Vane Science Building	2,258,434	194.5	5
Mile End	People's Palace	1,173,423	257.2	6
Mile End	Queens Building	2,370,612	176.9	7
Whitechapel	Floyer House	1,085,668	231.4	8
Whitechapel	Innovation Centre	1,252,765	184.0	8
Charterhouse	Wolfson Building	571,383	279.5	10
Mile End	Albert Stern House	438,313	587.6	11
Whitechapel	Abernethy Building	706,238	230.2	11
Mile End	Engineering	2,234,394	139.5	13
Mile End	G. O. Jones (Physics Building)	678,793	121.6	14
Mile End	Geography Building	411,167	146.2	15
West Smithfield	Robin Brook Centre	446,314	131.1	16
Charterhouse	William Harvey Heart Centre	416,681	136.10	17
Whitechapel	Garrod Building (Medical College)	495,340	92.0	18
Mile End	Hatton House	257,138	161.4	19
Mile End	G. E. Fogg Building	1,099,060	61.4	20
Mile End	Laws Building	336,143	111.1	21
Mile End	Ifor Evans House	271,393	129.3	22
Whitechapel	Library (Whitechapel)	199,866	136.2	23
Mile End	Graduate Centre	456,721	66.6	23
Mile End	France House	375,900	81.3	25
Mile End	Richard Feilden House	369,867	76.2	26
Mile End	Student Hub (Catering Building)	310,563	98.7	27
Mile End	Library (Mile End Campus)	491,128	53.4	28
Mile End	Maynard House	225,218	109.0	29
Charterhouse	Lodge House	24,050	183.6	30
Mile End	Arts One Building	323,520	58.9	30
Mile End	404 Bancroft Road	24,821	174.5	32
Mile End	Mathematical Science Building	227,343	63.8	33
Mile End	Varey House	140,388	67.9	34
Mile End	Pooley House	331,595	39.8	34
Mile End	Lock keepers Cottage	26,020	110.4	36

Campus	Name of Building	Fossil Fuel (kWh/year)	Fossil Fuel (kWh/m²/year)	Priority
Mile End	Arts Research Centre	42,192	100.2	36
Mile End	Stocks Court	178,374	56.8	36
Chislehurst Sports Ground	Chislehurst Sports Ground	100,416	65.2	39
Whitechapel	64 Turner Street	13,706	110.3	40
Mile End	Student Union Buildings	170,462	43.6	40
Mile End	Nursery	31,293	74.0	42
Mile End	Maurice Court	164,455	42.9	43
Mile End	Francis Bancroft Building	261,884	18.2	43
Mile End	Computer Science Building	147,594	43.6	45
Whitechapel	Whitechapel Students Union	76,875	54.7	46
Mile End	Beaumont Court	162,722	41.9	46
Mile End	Lindop House	69,917	49.7	48
Mile End	Creed Court	102,750	36.0	49
Mile End	Arts Two	122,263	34.9	50
Charterhouse	Old Anatomy Building (Rees)	37,697	37.3	51
Mile End	Informatics Teaching Labs	52,001	36.0	51
Charterhouse	Joseph Rotblat	25,874	17.3	53
Whitechapel	Yvonne Carter Building	167.5	0.0	54
Mile End	Lynden House	0	0.0	55
Lincoln's Inn Field	Lincoln's Inn Fields	0	0.0	55

The 20 buildings highlighted in Red (Ranked 1 – 20) have both high absolute and high specific energy consumption and are expected to have higher cost effect energy reduction opportunities. The buildings highlighted in Bright Green are heating via electricity and therefore do not have heat decarbonisation opportunities but may have energy efficiency / reduction opportunities. However, all buildings irrespective of their current priority ranking should be treated on a case-by-case basis.

6.1.2 Mile End: Priority Buildings

The buildings highlighted in Red in Figure 10, have been identified as having both high fossil fuel consumption and relatively poor performance compared to the other buildings across the Mile End Campus. Buildings which would be affected by the proposed / planned redevelopment are highlighted in Yellow.

Figure 10: Mile End Priority Buildings.

6.1.2.1 Joseph Priestley

The Joseph Priestley Building is a purpose built two-storey chemical sciences laboratory. This building was constructed in 2003/4 and was extensively refurbished in 2014. As part of the refurbishment works a large amount of the building services plant were replaced; this included the boilers and air handling units.

The Joseph Priestley Building currently has 30 fume cupboards and a high overall ventilation rate. Schematics in the main plant room suggest a supply air volume of around 40m^3/sec. This ventilation rate is required to ensure sufficient make up air to overcome the fume cupboard extracts and prevent build-up of hazardous fumes. Fume cupboards discharge into a high velocity induction / dilution exhaust system. The building has Cat 5 (softened) and general service domestic hot water calorifiers, which are served from the main boiler plant. The high fossil fuel used across this building is attributed to the high ventilation rates which are a safety requirement. Therefore, it will currently be unsafe to recommend the installation of heat recovery into the LEV extract systems.

The mechanical services are based on four-port control with variable speed pumps operating on a pressure control regime. It was observed that the domestic how water (DHW) plant is scheduled to run at weekends and that the LPHW plant is scheduled to operate 24/7, however this is expected as the ventilation plant is required to be in continuous operation. The exterior of the building fabric is relatively modern curtain wall and therefore would be difficult to improve. Therefore, it is unlikely that any additional energy efficiency or energy savings measures could be easily implemented in the Joseph Priestley Building.

Figure 11: Exterior of Priestley.

Figure 12: Main boiler plant.

Therefore, the heat carbonisation opportunities that could be explored for this building are alternatives to current domestic hot water system. It should be possible to **fit supplemental electric immersion heaters** into the existing storage tanks **and** to operate these from **Solar PV**, which could be installed on the large available roof area. Any generation output not used for hot water production could be used to partially offset the ventilation load associated with the plant.

6.1.2.2 People`s Palace

The People`s Palace dates back to 1936 and it is one of the original buildings on the site. It was constructed of solid brick and has the original steel framed, single glazed, windows. The building has Historic England Grade II listing for both interior and exterior architectural features as well as social history value. At the time of inspection, the boiler plant, which is located in the basement and accessed from the adjacent Graduate Centre, had been decommissioned and the building was operating on a temporary boiler pack.

Figure 13: Exterior of People`s Palace.

Figure 14: Decommissioned boiler plant.

Schematics show that the boilers originally cross-fed the Biology Building (G.E. Fogg), however it is unclear if this pipework remains in place. The building has extensive mechanical ventilation plant at the roof level. Where possible this plant has heat recovery, however the layout and age of the building imply that this may not be practicable. Consideration should be given to upgrading the heater batteries in older air handling plant to enable lower flow temperatures to be utilised. It is also recommended that all pumps and fans be upgraded to direct drive, variable speed units. As schematics for this building were unavailable, it was very difficult to accurately estimate the quantities, costs or savings associated with upgrading these pumps.

The listed status of this building may imply that it would be difficult to undertake any building fabric improvement. However, it has been recommended that steel framed single glazed windows be replaced with modern double-glazed casements. The roof of the People's Palace building is currently very congested with plant and pipework and there is insufficient space for the deployment of large-scale air source heat pumps (ASHP).

It may be possible to **retrofit small ASHP units on individual air handling units (AHUs)** to reduce the load on the main boiler plant. Therefore, a small ASHP unit has bene proposed to be installed on the ground floor where the teachers room AHU could be fed from a local ASHP as such a unit would be too far from the main heating run. It is anticipated that the heating supply of the People's Palace would be served from the Queens' building boiler house (a local heat network). This may help to improve the part load efficiency of the Queens' building boilers. There is limited suitable roof space for the installation of PV on this building.

Figure 15: Roof mounted chiller.

6.1.2.3 Engineering

The Engineering building is made up of three wings and it is one of the largest on the Mile End campus. The front of this building faces the Mile End Road and crosses over the Bancroft Road. The part of the building to the West forms one side of the Godward Square and has its own boiler plant. The part of the building to the East of Bancroft Road has been extended to the rear (known as Phase 2). This area also has a new boiler-house, located in a subterranean duct.

Figure 16: Mile End Road Façade.

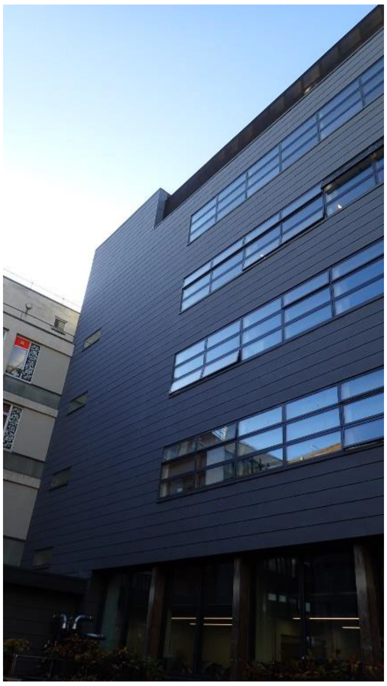


Figure 17: Phase 2.

The two boiler houses appear to be connected, although no system schematics were found.

Figure 18: Main boiler house pump sets.

Figure 19: Phase 2 boiler plant.

The boiler plant serves a large number of Variable and Constant temperature circuits. The new part of this building dates from 2017 and it is well insulated. The old parts of the building date back to the 1950's with the Western wing being granted planning permission in 1959. These areas are singled glazed with some secondary double glazing. Given the large window areas, **upgrades to the glazing and curtain walling** would help to reduce heat demand.

The roof of the building is congested with air handling and chiller plant units. It was observed that a sub-station of the United Kingdom Power Network (UKPN) was located on the roof of the Engineering Building. The chiller plant on the roof is understood to be associated with laboratory equipment rather than comfort cooling. It was also observed that the building previously had planning permission for a micro-wind turbine, however this permission has now lapsed, while the wind turbine was not installed. In any event it is unlikely that a micro-wind would be viable option in this location. Currently, no building- level heat decarbonisation or renewable energy measures have been recommended for this building because of lack of exterior plant space.

6.1.2.4 Queens' Building

The Queens' Building is a three-storey brick construction, which currently houses administrative functions and some teaching rooms. The North end of the building (known as the Octagon) dates back to 1890 and it is a Grade II listed building. The main entrance of this building is via the Mile End Road side of the building, the façade of which is clad in Portland Stone. The East and West wings are of later, probably 1930's, construction in red and yellow brick (as seen in the side elevation – Figure 20).

The listed status of this building may restrict improvement to the building fabric, however it would appear that the listing does not cover the wings and it may be possible to **replace the existing single glazed windows** to reduce heat demand / loss in these areas.

Figure 20: Side elevation.

Figure 21: Front elevation.

The basement of this building contains gas fired boiler plant of approximately 2 MW capacity. This boiler plant is labelled as serving multiple departments and adjacent buildings. It is unknown and it has not been verified if this labelling is current or historic. The pump sets are mostly direct drive, but are constant speed and controls are based on 3-port valves.

The schematics were not made available and therefore the exact number of circuits fed from this heating plant is unknown. **Variable speed, pressure controlled pumps** are recommended to be fitted in order to reduce pumping loads, and that, where possible, two port control should be implemented.

Figure 22: Main boiler plant.

There are plans to replace or supplement the heating plant to allow heat to connected / transferred to the Geography and People's Palace buildings, reforming the local heat network. It is recommended that sufficient infrastructure (i.e., pipework and pump sets) be put in place to support any plan to a low temperature primary loop which would support low carbon heat sources.

Currently, there is limited suitable locations to install ASHP of a suitable capacity to heat the Queens' Building, however the large basement plant area would be suitable for water source heat pumps if a campus-wide "ambient loop" is installed.

The building mostly has sloping roof pitches, with only a small area of flat roof on the West wing that may be suitable for installation of heat pump plant (such as condensers). The structure of this roof is unknown, and a structural survey would be required before exploring any installation of the roof of this building.

6.1.2.5 Albert Stern

Albert Stern building was constructed in 1913 and comprises the main four storey building and the Cottages which are three separate, two storey buildings. As such the ratio of Wall to Floor area is high, which taken together with the poorly insulated traditional building fabric are the probable cause of the high fossil fuel demand.

Both the main building and the cottages are Grade II listed. The listing specifically includes the windows, brickwork, stone dressings, and roof. It would therefore not be straightforward to make significant building fabric upgrades. It would be possible to install double glazed timber casements, however the associated costs would be a principal factor for the viability of such intervention.

Conversion of the existing domestic hot water calorifier tanks, from indirect to direct electric tanks would provide a direct carbon reduction, however there would likely be an increase in the operating costs.

The boiler plant room associated with the Cottages appeared to be in process of being replaced at the time of the survey. The replacement plant consists of condensing gas boilers. No evidence was noted that any of the internal pipework or radiators have been replaced to support low flow temperatures that would be beneficial for these boilers and would assist in moving to lower carbon heat sources.

Figure 23: Albert Stern Front elevation.

Figure 24: Newly installed boilers.

The listed nature of these buildings, together with limited available space imply that the installation of any on site renewable energy generation may not be practicable. The immediate options for this building are limited to:

- Double glazing (suitable for historic property).
- Replacement of radiators and pipework to support low flow temperature systems.

In the event of the new gas boilers reach their end of service life it is proposed these are replaced with air source heat pump. This should be after the implementation of the proposed two energy reduction measures.

6.1.2.6 G.O. Jones

G.O. Jones (aka Physics Building) is a 1960/70's structure comprising a long thin three-storey section and a six-storey tower.

Figure 25: G. O. Jones Front elevation.

Upgrading the **building fabric** represents the greatest opportunity to reduce the energy consumption of this building, particularly as it is likely to have a long-term future because it is currently part of Queen Mary's long-term. This work will be essential to support the deployment of any future low carbon heating systems.

The building is largely naturally ventilated, although there are two air handling units, one at roof level and one adjacent the rear of this building. There are eight air conditioning condensers mounted on the roof; these systems may be acting as supplemental heating as these are all capable of operating in heat pump mode.

The main boiler plant is located on the ground floor and provides a maximum of 660 kW of heat to at least four heating circuits, which supply radiators. It was observed that, on a cold day, some of the split air conditioning units were in heat rejection mode (i.e., cooling). Therefore, there is an opportunity to explore heat recovery. The areas served by these units should be reviewed to **ensure that heating and cooling are not simultaneously occurring**.

At the time of the survey of this building, the supply air temperature from the roof AHU was 21.5°C, which implies that **review of set-points** may be required to improve the energy efficiency of this building. Heat to the ground floor AHU is provided by a separate 30 kW boiler. This could easily be replaced by an **air source heat pump local to the AHU.** A similar measure may be possible on the roof AHU.

The lower roof area of this building is over-shaded to the south by the adjacent Queens' Building. However, it may be suitable for installation of air source heat pump condenser units, with the heat pump unit located in the ground floor plant rooms, or for PV arrays. The upper-level roof already has significant plant and also houses an astronomical observatory.

Figure 26: Main boilers.

Figure 27: Existing roof mounted VRF

6.1.3 Mile End Campus: Additional buildings

In addition to the priority buildings across the Mile End campus, other peripheral buildings associated with the Mile End campus have been surveyed. These surveys and the energy use profile are the basis on which practical energy and carbon reduction measures have been recommended for these buildings.

6.1.3.1 Ifor Evans

Ifor Evans comprises of two accommodation buildings, each of which comprises of eight, four storey townhouses. Each town house has its own gas fired condensing boiler (the flues from which are just visible in the photo on Figure 28) that provides instantaneous hot water and space heating. During the inspection there was evidence of poor user behaviours, with at least one space temperature set to 25°C. A **user behaviour campaign**, together with improved controls (or adjustment limits) is recommended.

It was noted that these buildings are scheduled for replacement in the campus current redevelopment plan, however this is likely to happen in a later phase of the plan. The buildings are therefore likely to have a further 15 – 20 years service life and would be suitable for lower cost decarbonisation measures. The building dates back to the late 1990's and is of blockwork cavity construction with double glazed windows.

Whilst the existing fabric does not meet current building regulations, or low carbon standards, it is not considered to be poor, and it is unlikely that improvements would result in a substantial saving or load reduction. Therefore, fabric improvement measures were not recommended as part of this HDP.

The roof of the building is an inverted steel panel system with a gutter running along the centreline of each building. Subject to structural survey, the south facing roof areas could accommodate ca. **120m^2 of PV panels,** which would contribute to immediate carbon reduction and could easily be removed and redeployed if the building is demolished before the end of life of life of the arrays.

Figure 28: Ifor Ivans' Mile End Road elevation.

Figure 29: Condensing Boiler.

Figure 30: Note set-point of 25ºC.

6.1.3.2 Francis Bancroft

The Francis Bancroft building was a purpose-built medical research facility. Over time the use of this building has significantly changed, and the main building users are now the Geography and Business Schools. It could not be determined during the site survey if the central plant has been altered to account for these changes in usage.

There is a possibility that parts of the building are still configured for medical research and therefore may be over-ventilated. It was not possible to log into the BMS outstation within the building and therefore data on time schedules, set points or the usability of any graphics pages were inaccessible. It is proposed that a full, **detailed ventilation survey** be undertaken of the building and that **ventilation rates should be set appropriately** for the current occupancy and usages. Consideration should be given to modifying the existing control strategy from three-port to two-port control with all existing pump sets being fitted with variable speed drives controlling on pressure.

There are two tiers of standing seem steel roof which are south-east facing, and which would potentially provide space to locate ca. **540m^2 of PV panels**. **Domestic hot water** load is not thought to be significant and there is no reason that the existing calorifiers could not be maintained as part of a **hybrid PV immersion-gas** system with the electric immersion elements operating from the PV panels. The current wider campus strategy includes the decarbonisation of heat of this building.

Figure 31: Exterior of Francis Bancroft.

6.1.3.3 Peter Landin

The Peter Landin building comprises of the Sports Centre and Student Union on the lower floors and the Computer Science department above. The roof of this building is currently used by the Biological Sciences department as a greenhouse research space. These greenhouses are currently under reconstruction. It is understood that the there is a plan that the south side, and possibly the lower floors, of the building would be reconstructed and extended.

If a significant proportion of this building is to be retained, then the **windows and curtain walling should be replaced** at the earliest opportunity. This predominantly affects the north and west façades which are not likely to be impacted by the refurbishment, but may be equally applicable to the upper floors of the southeast façades.

The existing windows are all single glazed and there is a large surface area of poorly insulated curtain walling. The use of an external façade system similar to that on the adjacent G.E. Fogg building may help reduce disruption to the occupants.

Due to the current utilisation of the roof of this building, there are no available space for the installation of renewable energy generation. Therefore, the source of heat decarbonisation of this building would have to be from campus level connections.

Figure 32: Peter Landin South Elevation.

6.1.3.4 Informatics Teaching Laboratories

The Informatics Teaching Laboratory is a three-storey building located on Godward Square adjacent to the Peter Landin building. The building was constructed in 1989 and is of load bearing concrete floor slabs supported by beams and columns. The external walls are of block work cavity construction and are insulated. The windows across this building are double-glazed but have poor thermal performance due to small air gaps and metal frames.

The building has a small (100 kW) modular gas boiler. If this building is part of Queen Mary's long-term estates strategy; it is recommended that the glazing be replaced, particularly within the main atrium, which is the full height of the building. The building has a flat roof where two air cooled chillers are located. There is currently sufficient roof space for a 100kW ASHP unit to be installed, which could replace the existing boiler plant. The installation of the ASHP should be considered at any stage in which the boiler plant is scheduled to be replaced.

The building is mechanically ventilated through "downflow" CRAC style air handling units located within the occupied space. This may reflect historic high cooling loads and legacy computer equipment, however nothing identified during the survey would justify the use of down-flow cooling.

It is recommended that an air-flow study be carried out and, subject to the results, it may be possible to replace the existing units with mechanical ventilation heat recovery (MVHR) units. This measure should be viable if the building has a service life in excess of 10 years, or if the ventilation plant is replaced for operational reasons.

Figure 33: Exterior of Informatics Teaching Laboratories.

Figure 34: Existing boilers.

6.1.4 Charterhouse Square Campus: Priority Buildings

The buildings highlighted in Red within Figure 35 have been identified as priority buildings, because of the high fossil fuel consumption and relatively poor performance compared to the rest of the portfolio.

The analysis of the building energy data indicated that the fossil fuel consumption of all of the four buildings connected to the existing network (John Vane (1), Wolfson Institute (2), Dawson Hall (4) and William Harvey Heart Centre (3)) was recorded by the main gas meter located within Dawson Hall Building.

To identify the priority buildings, the fossil fuel consumption was redistributed proportionally according to the heat load of these four buildings that are connected to this gas network. However, it is unlikely that those numbers would represent the heat distribution across the buildings. Dawson Hall, being mostly used as a student accommodation building, would naturally consume more fossil fuel for heating and domestic hot water on a 24/7 basis when compared to the other three buildings used for academic purposes. The building fabric in Dawson Hall is also poor which may be associated with relatively higher heat losses.

On that basis, although all of the four buildings were identified as priority due to the proportional distribution of fossil fuel consumption, the proposed heat decarbonisation projects were on Dawson Hall.

Figure 35: Identified Priority Buildings in Charterhouse Square Campus

6.1.4.1 Dawson Hall

Dawson Hall is a nine-storey student accommodation building with some academic and operational offices. This building was constructed during the mid-late 1970's with poorly insulated building fabric and single glazed steel frame windows. **Building fabric improvements are required to minimise heat loss**. The boiler plant located within this building serves other buildings across this campus via a district heat network.

Site schematics show that heat metering has been installed on the network. These meters need to be read and the energy correctly accounted for. The **installation of an automatic meter reading and data recording system** is recommended as a secondary measure to ensure that this gas network is effectively managed.

Figure 36: Exterior view of Dawson Hall.

Figure 37: Combine Heat and Power (CHP) Pack.

Figure 38: Single-glazed windows.

6.1.4.2 Wolfson Institute Building

The Wolfson Institute Building is a two-storey research building that was opened in 1991. The building's fabric is adequate, and it is unlikely to be financially viable to be improved, unless the work is done for aesthetic purposes.

The building is heated from the district heat network and does not have any installed gas fired heating plant. No evidence was found of heat metering, and it is therefore recommended that the **entire heat network be fitted with heat metering** and an automatic meter reading and data recording system to ensure effective heat demand and energy management of this building.

Figure 39: Exterior view of Wolfson Institute.

6.1.5 Whitechapel Campus: Priority Buildings

The buildings highlighted in Red within Figure 40 have been identified as priority buildings, because these buildings have high fossil fuel consumption and relatively poor performance compared to the rest of the portfolio.

Figure 40: Identified Priority Buildings in Whitechapel Campus.

6.1.5.1 Blizard Building

The Blizard building is a purpose built, modernist, four storey medical research facility. The building was constructed in 2009 and, above ground, is in two parts; the “plant wall” which contains reception and a 400-seat lecture theatre and the “glass pavilion” which contains office and desk space.

The two building halves are linked below ground by a Class 2 laboratory space. There are also Class 3 laboratory spaces in this area. A review of the site BMS showed that, where possible, plant is timeclock controlled and is not run unnecessarily.

As a relatively new construction, the thermal performance of the building envelope is good, and the nature of the materials (glass curtain walling) would make retrofit expensive with minimal benefit. These laboratories have high domestic hot water demand for both hand washing and washing of laboratory glassware. There is no centralised steam system, with any autoclaves having local steam generators.

It is unlikely that any significant energy saving, or efficiency measures can be directly implemented. There is no adequate plant space to allow the installation of air source heat pumps within the "plantwall". Some **heat recovery** may be achievable from the chiller plant. Recovered heat could be "upgraded" via heat pumps and used to pre-heat domestic hot water.

The roof of the glass pavilion may be suitable for the installation of **Photovoltaic arrays**. The high building energy demand is due to the laboratories within these buildings, which require high airflow rates in order to maintain biological containment.

Figure 41: Blizard Building Aerial View.

6.1.5.2 The Wingate Institute Building

The Wingate Institute Building was constructed in 1978 as a purpose-built research facility. The building was extensively refurbished in 2003 and was reopened in 2004. Although an additional floor was added to the building, most of the lower floors were untouched and at least 50% of the windows are currently single-glazed.

Replacement of single-glazed windows with double-glazed units has been recommended. The current use of the lower flow would require appropriate co-ordination of this upgrades to minimise disruption to the Containment Level 2 laboratories.

A preliminary review of the BMS settings did not reveal any evidence of obvious excessively high set-points. The ventilation, heating and cooling plant is also required all year-round for the purpose of the animal houses.

The building uses gas for space heating and for production of steam to serve autoclaves and sterilisation equipment. The gas supply is not sub-metered and therefore all the gas used are assumed to be for heating purpose. From a simple analysis of the building consumption profile, it is believed that approximately 50% of the gas used by this building (or 480,000 kWh per annum) could be attributed to the steam boiler unit.

Domestic hot water demand in the building is also higher than would be expected compared to a typical administrative or teaching building. This higher-than-expected domestic hot water demand is attributed to the cage wash, surgery and laboratory uses.

Currently the load bearing roof areas are quite congested, however there is an empty chiller compound across the Northwest corner that could be used to accommodate ASHP. The AHU frost coil is rated at 90 kW and the main heater batter at 204 kW at flow and return temperatures of 85/65^{o}C. It is unlikely that there would be sufficient space to operate the building entirely from **heat pump**s and therefore a **hybrid solution** would be required. The remaining roof areas are not thought to be load bearing, however, may be suitable for the installation of supplementary PV arrays.

Figure 42: Exterior of the Wingate Institute Building.

Figure 43: Heating Boilers.

Figure 44: Steam Boiler Plant.

6.1.5.3 Innovation Centre

The Innovation Centre was constructed in 2009 as a purpose-built commercial start-up space for biotech and chemical sciences companies. Although directly adjacent to the Blizard and Abernethy buildings it operates completely independently. The building is operated on a commercial letting basis and houses several small enterprises. There is also a freezer room and a lecture theatre, both of which are used by Queen Mary.

The building was designed to incorporate sustainable and recycled materials. The external rain-screen is recycled brass and sits over timber cladding with a significant insulation layer. The windows are all 10- 18-6 double glazing. The building uses gas for space heating and has a year-round cooling demand due to gains from laboratory equipment and a tenant data centre. The electrical supply is extensively sub-metered, and tenants are recharged for consumption.

Approximately 50% of the floor area is either Containment Level 2 or chemical laboratory spaces. Therefore, the building has high ventilation rates, which may be the reason this building has a high fossil fuel usage. The air handling plant already incorporates heat recovery, which has been optimised to also recover cooling during summer. During the survey, it was apparent that good energy housekeeping was observed across this building.

There may be some opportunity to recover heat from the roof-mounted chiller for use in pre-heating domestic hot water systems. The high density of roof mounted plant limits the opportunities for the installation of any significantly sized ASHPs. Therefore, the most effective heat decarbonisation for this building is the connection to a heat network or district heating system.

There is approximately **300 m^2** of flat roof, which is outside of the acoustically screened plant deck. This could be used for the installation of **Photovoltaic panels;** however, it is unlikely to be suitable for any appropriately sized ASHPs.

Figure 45: Innovation Centre's Building Exterior

6.1.5.4 Garrod Building

The Garrod Building is a large brick building that was constructed in 1854. It was redeveloped and enlarged in 1886 and there is evidence of more modern roof level extensions. This is not a listed building and houses administrative and office functions as well as a lecture theatre, seminar rooms and an ICT suite.

The building services reflect the age of the building and by modern standards are relatively crude. The Building Management System covers all of the main plant, however the information presented on the head-end is considerably basic and none of the control panel displays appeared to be working. **BMS upgrade** is therefore recommended.

There is a single roof mounted AHU which serves several the seminar rooms; however, this is very small (with a supply duty of 0.44m^3/s). The majority of the building is currently ventilated naturally.

The heating pumps are all fixed speed and controls are based on 3-port valves. It is recommended **upgrading pumps to pressure control, variable speed**, with 2-port valves.

A significant proportion of the windows within this building are single glazed in sliding sash casements. None of the windows were secondarily glazed. Taking into consideration the large window area, it is recommended that all the windows are replaced **with double glazed casements**. In addition, upgrading the roof-lights should be considered.

There are two large calorifier tanks located in the basement from where domestic hot water is generated. Taking into consideration the size and nature of this building, it has been recommended that decentralising the domestic hot water system and **installing point-of-use electric water heaters** would be the best option for this building.

From the site survey, it is unlikely that the roof would be able to support the weight of a mono-block heat pump unit of sufficient size to heat the building. However, it may be possible to install condensers on the roof with the heat pumps located within the existing basement plant-room.

Subject to structural survey, approximately **25m^2** of roof area would be available in the south-east corner for the installation of **PV arrays**.

Long-term strategic options include connection to the new Plot C site development or the adjacent redevelopment areas. This option is further explained in the Campus level decarbonisation section.

Figure 46: Garrod Building Exterior.

Figure 47: Modular Boiler.

Figure 48: Ground Mounted VRF

6.1.5.5 Floyer House

Floyer House is a student accommodation building, specifically for medical students. The original building was constructed in the 1930s and was extended to the rear during the 1960's/70's. The rear extension has particularly poor building fabric, which includes metal framed single glazing and uninsulated curtain wall.

Figure 49: Floyer House Front of Building.

Figure 50: Floyer House Rear Extension.

It is understood that the rear extension will be demolished and therefore any fabric improvements such as replacement of the façade may not be appropriate. However, **replacement of single glazed windows** in the 1930's block section has been recommended.

The main heating plant within the building comprises four cast iron atmospheric gas boilers rated at ca. 100kW each. These are in poor condition and are well past the end of their useful service life.

As the building is residential, it is assumed to have a high domestic hot water demand. This is served by brand new, gas fired, calorifiers, which were still being commissioned at the time of the site survey. **These new calorifiers could form a hybrid system if used in conjunction with PV powered immersion heaters.**

Aerial photographs show that the building has a flat roof, which should be able to accommodate a **140m^2 PV array**. This measure will provide immediate short-term carbon offset and should be implemented even if the building has a limited lifespan, on the basis that the array could be relocated at a future date. Subject to structural survey and power availability, it may be possible to install an ASHP at roof level to provide base load heat, with a gas boiler providing peak capacity.

An alternative option would be to connect this building to the adjacent Royal London Hospital Site as the adjacent pathology building is noted to have extremely large roof mounted heat rejection plant, which could serve as a useful heat source for Floyer House. In addition, connection to the new Plot C site development should be considered as part of a campus-wide strategy.

Figure 51: Heating Boilers.

Figure 52: New DHW Calorifiers.

6.2 Campus Level Decarbonisation

There are greater opportunities for decarbonisation of the campus sites using improved infrastructure, such as on-site energy networks or connections to adjacent, non-university networks. Some of the strategic options included here require organisational level co-ordination as well as cooperation with neighbouring external organisations, such as Transport for London, NHS Hospital Trusts, and London Borough of Tower Hamlets.

Below is a list of energy efficiency improvements recommended on a campus level for buildings put forward for strategic proposal. The measures are high-level, and these are proposed because of its capacity to improving the heating system of individual buildings as well as to allow for flow and return temperatures to be reduced to 60/30°C.

Building Energy Management Systems (BEMS) monitor and control services such as heating, ventilation, and air-conditioning, ensuring the building operates at optimum levels of efficiency and removing wasted energy usage and associated costs. The optimal level of efficiency could be achieved by continuously maintaining the correct balance between operating requirements, external and internal environmental conditions, and energy usage. BEMs control upgrade may include additional sensor points, resetting of time clocks, use of temperature compensation, additional metering, and improved plant sequencing

Building Fabric improvements are key to the decarbonisation of buildings and achieving net-zero carbon, as they can significantly reduce the energy demand of buildings. Therefore, where possible a ‘fabric first’ approach should be explored before considering changes to any electrical or mechanical building services systems. This approach ensures that the performance of the components and materials that make up the building fabric are optimised. This will result in a reduction in thermal losses, energy use and carbon emissions, thereby potentially reducing the scope of required electrical and mechanical works and associated capital and operational costs. Cavity wall insulation survey should be carried out to assess the current insulation properties of the buildings where applicable.

Insulation covers are removable and can be added later to improve the thermal insulation properties for valves, flanges and pipework. They offer an effective and convenient solution to reduce heat losses and lower energy bills.

Variable Speed Drives (VSDs) vary the speed of a normally fixed speed motor. In HVAC systems, they are used primarily to control fans in variable air volume systems instead of other devices such as inlet vanes, pumps and discharge dampers. Variable speed drives provide effective speed control of AC motors by manipulating voltage and frequency. Controlling the speed of a motor provides users with improved process control, reduced wear on machines, increased power factor and energy savings.

Field control improvements may include replacement of three-port with two-port control valves, resizing coils for lower water-side operating temperatures and eliminating bypasses and low loss headers.

6.2.1 Mile End Campus

The Mile End Campus is located in the east-end of London between Stepney Green and Mile End underground stations. It is the largest of the Queen Mary sites and comprises teaching, research, administration, and accommodation buildings. The age of these buildings ranges from those built during the mid-1800’s to 2016 and the building styles vary from early Victorian terrace houses to brutalist multi-storey concrete tower blocks. The Mile End campus was expanded significantly in the late 1960’s and 1970’s. Most of these older multi-storey buildings have been substantially refurbished.

The **buildings highlighted in black have been excluded from the scope** of this decarbonisation plan in Figure 53. These are either temporary buildings, low energy sites, scheduled for demolition or are leased. This take into account buildings that are covered by the Queen Mary long-term estates strategy.

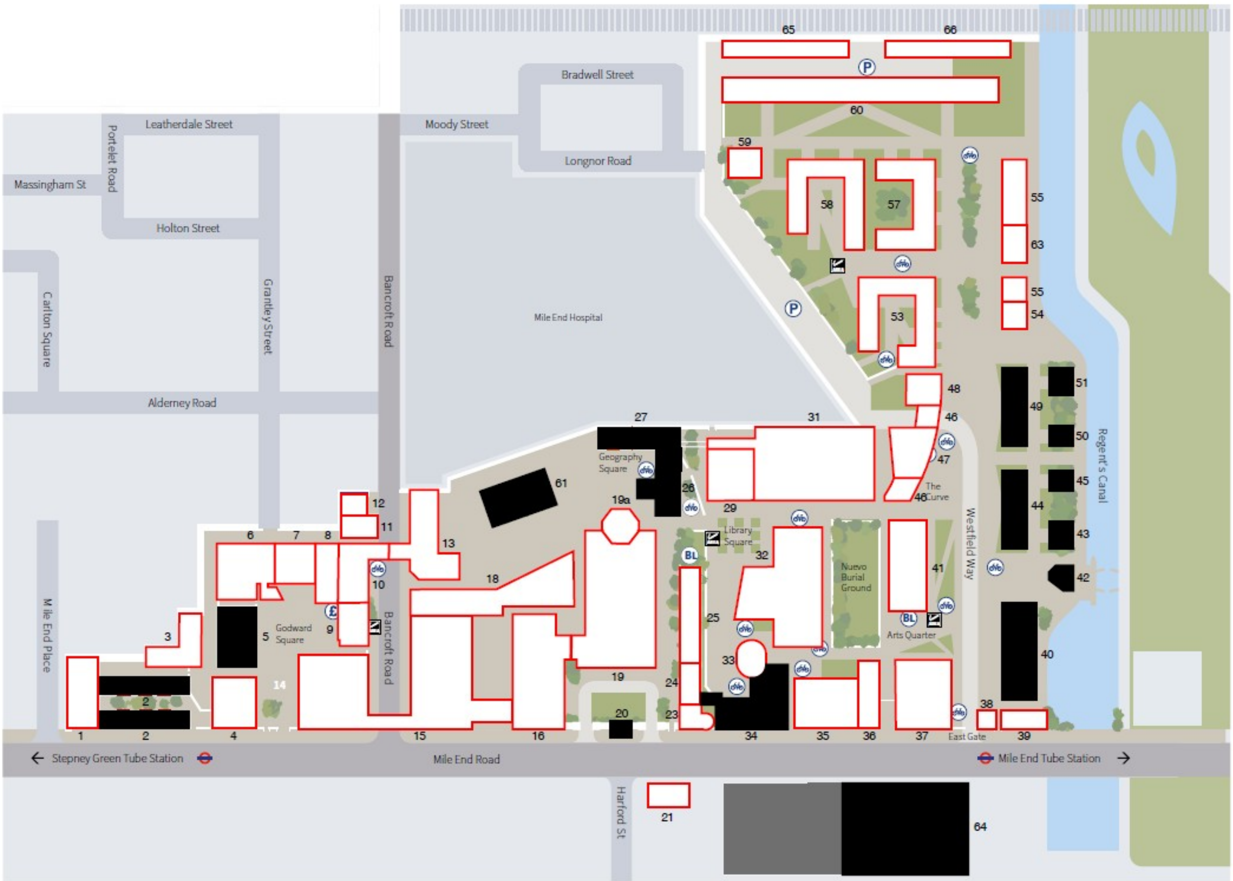


Figure 53: Mile End Campus Layout.

In general, majority of the building across the Mile End campus have dedicated heating plants. These are generally gas fired boiler plant, except for the student accommodation buildings which are electrically heated.

Domestic hot water (DHW) is mainly gas fired generated with a few buildings having electric point of use. In addition, the CHP was designed to supply a proportion of the DHW load in the buildings connected to the heat network via plate heat exchanger systems.

Ventilation is generally natural for most of the buildings, with mechanical extraction in kitchens and bathrooms. Some of the mechanically ventilated buildings have high ventilation rates due to the presence of Cat 2 and 3 laboratories and fume cupboards.

Comfort cooling is mostly provided by several split VRF systems. In some buildings, chillers deliver chilled water to air handling units (AHUs) and fan coil units. There are no installed heat recovery systems to some of these chillers.

Below is a summary of the ongoing or planned campus level decarbonisation initiatives:

- a new 200 kW heat pump is planned to serve the SRIFF Room IT load, which is increasing in capacity to 600kW within the next 5 years. This project is designed to replace chiller units with free-cooling technology
- DHW services to France House and the proposed School of Business Management (currently where the Hatton House is located) site via an extension to the current heat distribution heating network
- it is anticipated that the current electrical infrastructure would be upgraded to improve capacity and resilience. A 11kV ring main is planned to be installed under Phase 1 (Hatton House) redevelopment with incoming supply from the proposed School of Business Management
- the planned extension of the district heating to Residential Buildings which would be fed by SRIFF Room and or CHP and or Queens' Building
- DHW services to France House and the proposed School of Business Management / Hatton House site via an extension to the current distribution heating network
- it is anticipated that the Queens' Building Boilers would be connected to the District Heating by the end of March 2022, therefore reducing fossil fuel used to heat the following buildings: Engineering, Bancroft, and Richard Feilden House
- there is a plan to remove the Temporary gas-fired Boiler that serves the People's Palace, which could contribute to decarbonising this building
- it is anticipated that the district heating would be connected to Richard Feilden House and the gas-fired boiler will be replaced with Thermal Stores

Queen Mary intends to retain the installed gas-fired CHPs with a view to mothballing them to coincide with the campus' 5-year development horizon associated with development of the School of Business Management.

6.2.1.1 Priority Buildings

The buildings highlighted in red in Figure 54 have been identified as having both high fossil fuel consumption and relatively poor performance compared to the rest of the portfolio. Buildings which would be affected by the redevelopment plan of the Mile End campus are highlighted in Yellow.

Figure 54: Mile End Campus Priority Buildings

The costs associated with implemented each of the proposed building level projects are based on industry benchmarks and previous project experience (see Table 8). The proposed measures for each building with additional information and assumptions are included in Table 18 within the Appendix.

Table 8: Indicative costs for Mile End Campus' Priority Buildings

Building	Indicative Capital Cost	Cost Saving	CO_2e Saving (tCO_2e/year)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC (Simplified) [£/tCO_{2e}]	Rank
Queens' Building	£759,000	£12,884	43.7	1,093.8	58.9	£693.94	4
Albert Stern House	£150,000	£4,579	22.0	368.9	32.8	£406.67	1
G. O. Jones Building (Physics)	£1,385,000	£14,409	74.7	2,055.3	96.1	£673.86	3
Ivor Evans Place	£96,000	£3,459	4.8	108.1	27.8	£888.39	6
Francis Bancroft Building	£459,000	£18,075	32.0	720.3	25.4	£637.23	2
Peter Landin	£1,260,000	£ 12,104	58.0	1,624.7	104.1	£775.53	5
Informatics Teaching Labs	£251,000	-£411	8.0	180.8	-	£1,388.29	7

6.2.1.2 Immediate and Short-term Proposals

The buildings highlighted in red in Figure 55 are student accommodation and are electrically heated. Domestic hot water to these buildings is generated from gas-fired direct calorifier tanks, hence do have a fossil fuel load, and are not included in the prioritisation list. In addition, these buildings have separate fiscal electrical intakes.

Figure 55: Electrically Heated Student Accommodation Buildings in Mile End Campus

Photovoltaic (PV) panels have been proposed for all buildings that have adequate roof space for plant installation. Similarly, Solar Thermal water heating is proposed to reduce or eliminate the gas demand for domestic hot water generation. In these cases, immersion coil or the existing gas-fired heaters would only serve as back-up.

Alternatively, PV-T (Photovoltaic Thermal) panels, that operate simultaneously as Photovoltaic panel and solar thermal panels, could be used for electricity and hot water generation. It is known that PV cells present reduced efficiency when the temperature is above 25ºC. Therefore, PV-T panels would optimise electricity generation as the panel temperature is reduced in the process of transferring heat to the water tanks.

It is proposed that electric immersion heaters be fitted to the domestic hot water calorifier / store tanks and that these be used as the primary heat source when the PV or PV-T is generating. Gas would then be used to provide top up during periods of peak demand or when there is insufficient solar power generation. Incorporating control systems, which ensures that the immersion heaters do not use grid electricity.

Any power generated from PV / PV-T that are not absorbed by the immersion heaters would be used to reduce the power demand from the grid. Table 9 shows the likely area available for solar energy generation by building. It should be noted that buildings 42-45 and 49-51 are scheduled for redevelopment within the next ten years. Therefore, these buildings have been excluded from this part of the analysis.

Table 9: Available roof area for solar energy generation

Building	Pooley House	Lynden House	Maurice Court	Creed Court	Beaumont Court	France House	Feilden House
Roof Area for PV (m^2)	180	10	50	50	50	60	100

Table 10: Cost of Proposals

Options	Description	Building(s)	Estimated Solar PV Capacity (kW)	Estimated Cost (£)
ME Short Term Proposal 3	Installation of solar panels onto student accommodation rooftops, consisting of electrical only, hot water heating only, combined electrical/ hot water units or a mixture of these. Generated electricity will be used on site with excess export to grid. Gas boilers retained for backup.	42, 44, 46-49, 52-55, 57-60, 63	96	£176,000
Building Energy Efficiency Improvements	BEMS improvements, building fabric, insulation covers, VSDs, field control	42, 44, 46-49, 52-55, 57-60, 63	-	£2,600,000

6.2.1.3 Interim Proposals

Figure 56 shows buildings that share heat or domestic hot water services. The buildings shown in green were originally connected to Hatton House (building 40 in Black) which is scheduled for demolition for the proposed School of Business Management. These buildings have been connected to two local DHW generation pods in order to maintain service whilst the area around buildings 38, 39 and 40 is redeveloped.

The Queens' Building (19) contains a large gas-fired boiler plant which provides heat to the Octagon (19a) and the Geography Building (26). These buildings are both been identified as priority buildings, however the Geography building does not have its own plant.

The final notable category is made up of: the G.E. Fogg (13) and Peter Landin buildings (6) which share a roof mounted boiler plant. The recent refurbishment of G.E. Fogg significantly improved the thermal performance of its fabric; however, Peter Landin still has large areas of single glazing.

Figure 56: Shared heating and hot water services in Mile End Campus

Cluster 1: Although the Informatics Teaching Laboratories building (5) is scheduled for demolition and redevelopment, it is not known when these will take place. Therefore, it is proposed that, subject to demolition timescales and technical feasibility assessment, an ASHP be installed on the roof of the Informatics Teaching Laboratories to serve this building and the adjacent interconnected buildings (6, 7, 8, 9, 10 and 13). As an interim decarbonisation measure, this ASHP could be extended to serve Westfield Nursery (11) and Occupational Health and Safety Directorate Building (12). The current distribution network should be extended, upgraded and/or replaced as necessary to serve the newly connected loads.

Figure 57: Cluster 1 buildings in Mile End campus

A Hysopt model has been created using the peak load to size the equipment. The proposed system provisionally comprises of:

- 01 no. 500kW ASHP unit which, coupled with a thermal store will contribute approximately 90% of the annual demand
- 10,000L wet thermal store (or alternatively PCM equivalent) to provide operational flexibility
- balance of plant, as required.

Further capacity analysis and optimisation is recommended at the next stage of the design and implementation of these initiatives.

The dimensions of a 500kW ASHP are approximately 1.40m (W) x 4.65m (L) x 2.20m (H), with 1.50m around each edge and 0.50m above the unit for maintenance space. Based on an initial desktop review, there is sufficient space available on the roof of the Informatics Teaching Laboratory (5) to accommodate this heat pump.

The average dimensions of a 500kW ASHP are approximately 1.40m (W) x 4.65m (L) x 2.20m (H), with 1.50m around each edge and 0.50m above the unit for maintenance space. Based on an initial desktop review, there appears is sufficient space available on the roof of the Informatics Teaching Laboratory(5) to accommodate this heat pump.

The peak load of each of the existing buildings has been estimated based on building fabric uplifted U-values, the element areas, ventilation heat load, and domestic hot water (DHW) as a fraction of the heating load (estimated using the Energy Performance of Buildings Directive: Second Cost Optimal Assessment for the United Kingdom (excluding Gibraltar); Ministry of Housing, Communities and Local Government; Section 8, Table 8.5a p. 123).

The interim proposals for Cluster 1, if implemented, would serve as enabling works for the eventual implementation of the long-term strategic proposals across the Mile End campus.

Table 11: Mile End Campus Cluster 1 Option

Options	Description	Buildings	Estimated Heat Pump Capacity (kW)	Estimated Cost (£)
ME Interim Proposal: Cluster 1	Construction of local heat network serving buildings 6-13 with an air source heat pump located on the rooftop of the Informatics Teaching Laboratories building. Alternatively, Cluster 1 may be connected to the energy centre and become merged with the Cluster 2 proposal.	6-13	500	£1,240,000 - £1,590,000
Building Energy Efficiency Improvements	BEMS improvements, building fabric, insulation covers, VSDs, field control	6-13	-	£1,700,000

Cluster 2: Queen Mary recently installed a heat network and a newly established energy centre (2020/21) at Mile End campus. The energy centre is supplied from a gas-fired CHP unit with top up boilers. The CHP is rated at 600 kW_{th}, which is significantly lower than either the heating or the domestic hot water load of the connected buildings. As a result, its contribution towards the energy supply mix to the cluster is very low. Existing network is highlighted in red and energy centre in yellow in the figure below.

Figure 58: Cluster 2 buildings in Mile End campus

It is proposed, subject to technical feasibility, that for the CHP to be replaced by or supplemented with an air source heat pump (ASHP), to upgrade of the distribution pipework and ancillary equipment to serve the connected buildings, and to repurpose and potentially supplement the existing thermal storage to provide operational flexibility.

The replacement of the CHP with an ASHP has been modelled in Hysopt to size the equipment, and the system provisionally comprises:

- 01no. 1800kW ASHP unit (or 03no. 600kW units) which, coupled with a thermal store, will contribute to approximately 80% of the annual demand
- 30,000L thermal store to provide operational flexibility

- the system would retain the existing gas-fired boilers for top up during peak loads and as backup during periods of maintenance downtime or unplanned outages of the heat pump
- Balance of plant, as required.

It is noted that further capacity optimisation is required at the next stage of design.

The average dimensions of a 600kW ASHP are approximately 1.40m (W) x 4.65m (L) x 2.20m (H), with 1.50m around each edge and 0.50m above the unit for maintenance space. The heat pump(s) should be located within the Energy Centre, subject to space availability. An alternative possible location could be on the roof of Richard Feilden House (46) or neighbouring buildings (47 and 48).

Please note that the peak load was used in the Hysopt model to size the heat pump and has been estimated based on building fabric uplifted U-values, the element areas, ventilation heat load, and domestic hot water (DHW) as a fraction of the heating load (estimated using the Energy Performance of Buildings Directive: Second Cost Optimal Assessment for the United Kingdom (excluding Gibraltar); Ministry of Housing, Communities and Local Government; Section 8, Table 8.5a p. 123).

The interim proposals for Cluster 2, if implemented, would serve as enabling works for the eventual implementation of the long-term strategic opportunity by making the Engineering Building (15), People`s Palace (16), the Graduate Centre (18) and Queens' Building (19) ready for the implementation of the long-term strategic masterplan.

Table 12: Mile End: Cluster 2 Option

Options	Description	Buildings	Estimated Heat Pump Capacity (kW)	Estimated Cost (£)
ME Interim Proposal: Cluster 2	Modification of the existing energy centre currently serving buildings 13, 15-16, 18-19, 29, 31, 41, 46-48. A new air source heat pump will be installed to lead the heat generation, with the CHP either retained for supplementary heat or stripped out. Alternatively, the air source heat pump could be sited on the rooftop of Feilden House pending feasibility investigations. The existing thermal storage will be repurposed and possible upgraded to provide operational flexibility.	13, 15-16, 18-19, 29, 31, 41, 46-48	1,800	£4,330,000 - £4,680,000

Options	Description	Buildings	Estimated Heat Pump Capacity (kW)	Estimated Cost (£)
Building Energy Efficiency Improvements	BEMS improvements, building fabric, insulation covers, VSDs, field control	13, 15-16, 18-19, 29, 31, 41, 46-48	-	£5,500,000

6.2.1.4 Mid-term Proposals

Waste heat recovery opportunities from the London Underground, which passes underneath the campus, were investigated. However, Transport for London (TfL) it was uncertain when this opportunity would become available. Despite the status of this option, it would worth exploring in the immediate and near future.

In addition, there is currently an opportunity to recover heat as a 1,125mm x 675mm of combined sewer runs in front of the campus alongside the Mile End Road. Although this sewer is of sufficient size, further investigation, analysis, prioritisation, and quantification should be carried to ascertain if this sewer was sized for storm events only. It was apparent that this sewer runs under the pavement, potentially reducing traffic management cost during construction.

Further opportunity under investigation includes the potential of linking to the adjacent Mile End Hospital site.

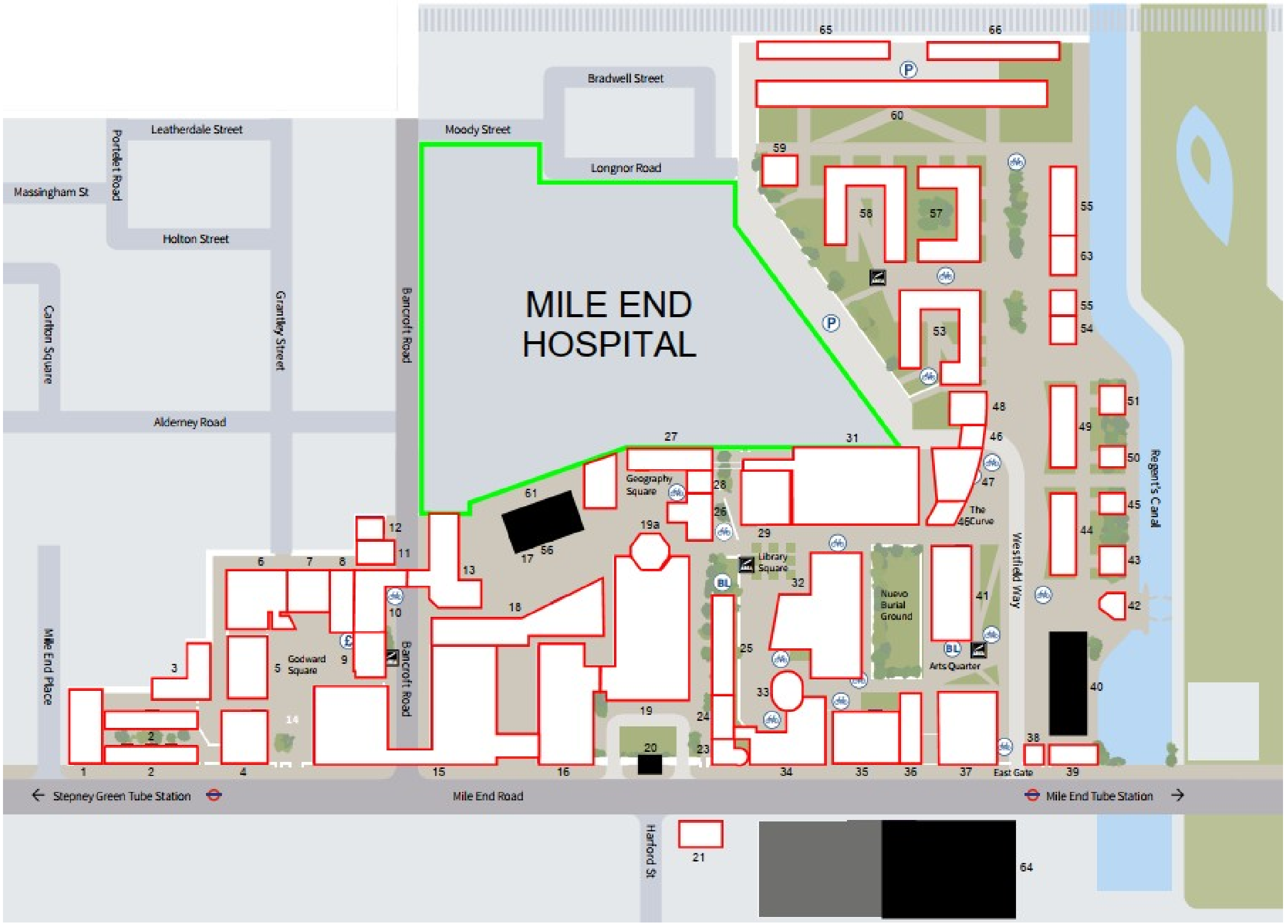


Figure 59: Mile End Hospital Area and Mile End Road.

6.2.1.5 Strategic Proposals

As part of the current redevelopment and strategic masterplan plan of the Mile End campus, the Informatics Teaching Laboratories (5), Ifor Evans Place (2), Temporary Building (61), Geography (26), Advice and Counselling Service (27), Clock Tower (20), Student Union Hub (34), Lock-keeper`s Cottage (42), Maynard House (44), Chesney House (45), Varey House (49), Lodge House (50) and Selincourt House (51) are scheduled for demolition redevelopment.

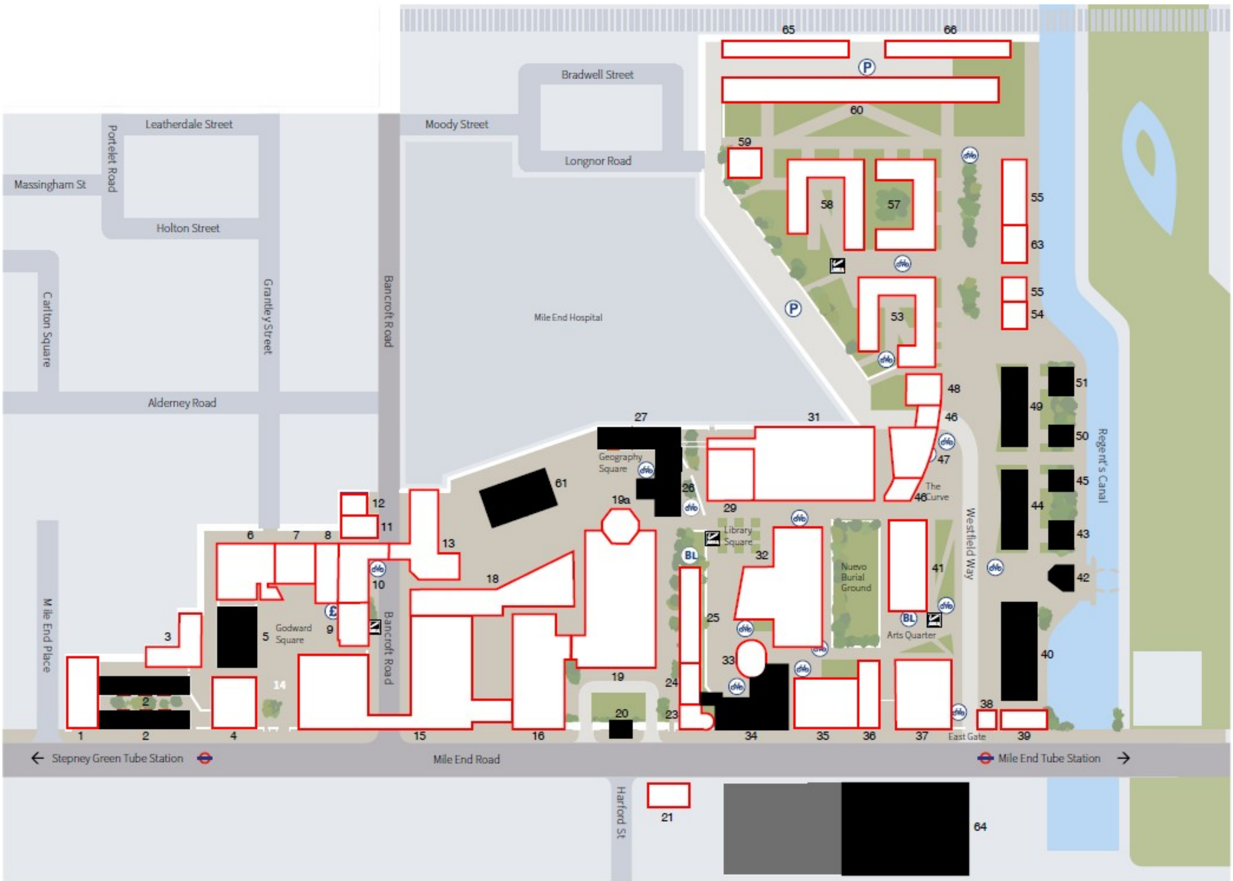


Figure 60: Buildings scheduled for demolition and redevelopment.

This redevelopment is anticipated to be implemented in the long-term, hence the short-term and interim proposals. These short-term and interim proposal would serve as enabling works for the eventual implementation of the long-term proposals. Figure 61 show projected Mile End Campus' energy projection, while Figure 62 details the carbon emissions projection of the Mile End Campus.

Longer-term strategic opportunities exist for a site-wide integrated energy system at Mile End campus. A major campus development masterplan underway at the site with a strategic ambition of doubling of student capacity to 50,000 by 2030. This will largely comprise additional residential accommodation and academic buildings on site.

This strategic vision is expected to include the following attributes:

- A hybrid arrangement of energy sources comprising renewable heat / waste heat recovery from a subset of sources identified as part of the current scoping exercise
  - Sewer Heat
  - Adjacent Mile End Hospital site
  - Regent`s Canal – canal source heat recovery

    - Low grade waste heat recovery on site (e.g., SRIFF Room IT load, other sites under masterplan redevelopment)
    - Transport for London: Vent shaft (Bancroft Road area) and pumped water station
    - Open Loop Borehole
    - Supplementary electric boilers
- recycling / prosuming energy between buildings, search that low grade waste energy is recovered as opposed to being emitted into the atmosphere
- distributed energy storage, with the possibility of inter-seasonal storage via the London aquifer in order to unlock value through electricity market participation
- Integrated Electric Vehicle charging
- Strategic delivery partner to realise any commercial or large-scale opportunities

It is envisaged that the campus masterplan would be based on decentralised and decarbonised district networks. In addition, Energy Centres are expected to be situated within new developments, which will be driven by current and emerging planning guidelines.

Further feasibility appraisal and concept design would be required to determine the most appropriate heating network configuration for the Mile End Campus. A 5th generation ambient loop/two stage temperature lift network may be the optimal approach, although it is noted that a wide range of technical, techno-economic, and strategic considerations would have to be taken into account in determining the best way forward. However, it is important to state that if the short-term and interim proposals were not implemented, the long-term proposals would still contribute to decarbonising the Mile End campus. This would be subject to coordinated implementation of the masterplan with the proposed energy solution.

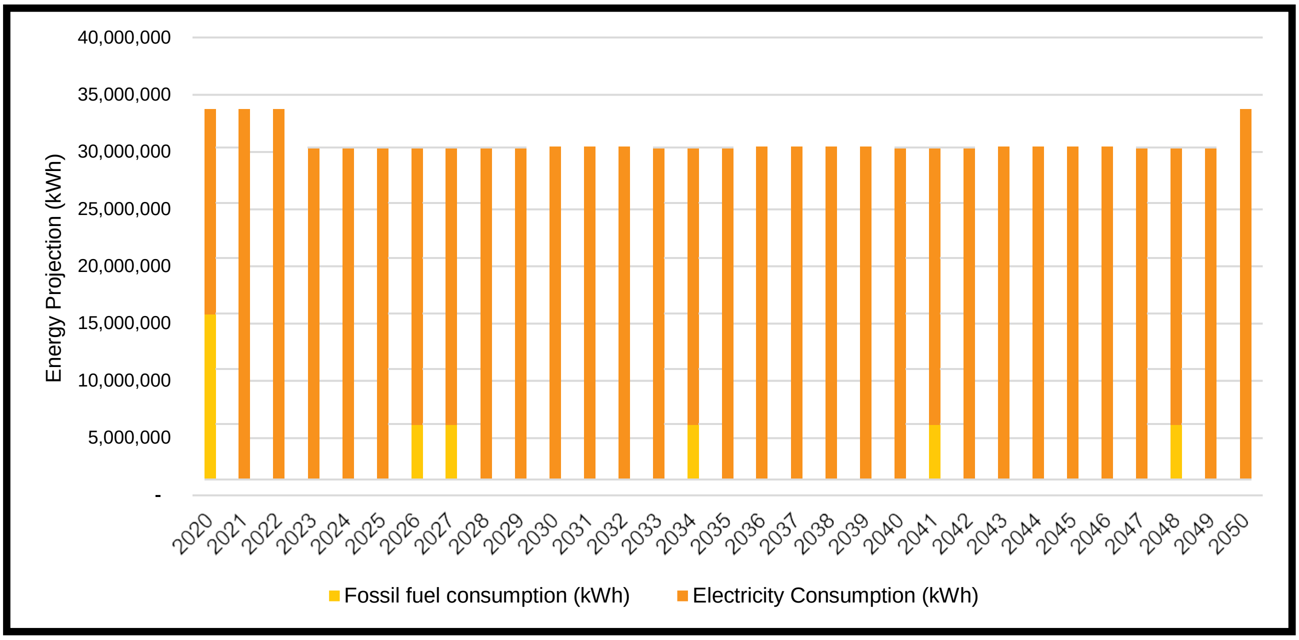


Figure 61: Mile End Campus’ Energy Consumption Projection

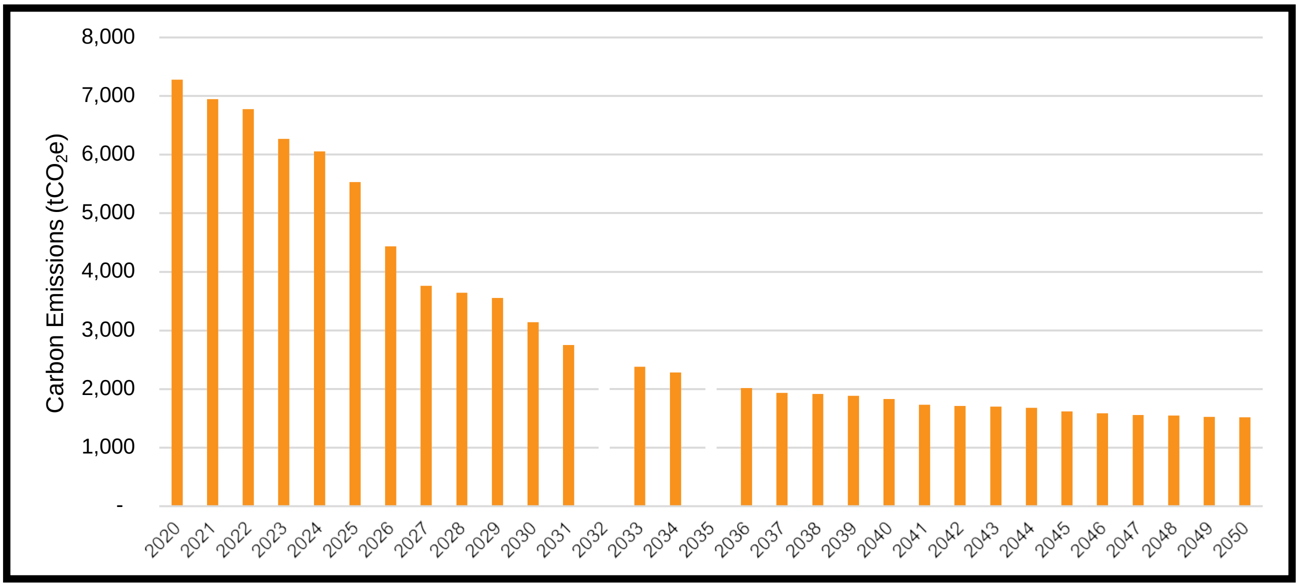


Figure 62: Mile End Campus Carbon Emission Projection

6.2.2 Charterhouse Square Campus

The Charterhouse Square Campus is located between Clerkenwell Road, and Goswell Road in the Farringdon area of London and the campus is enclosed within private land. All the buildings within this campus are leased, with a further 12 years remaining on the current lease. A significant proportion of this campus is dedicated to clinical research, with some onsite accommodation, in Dawson Hall (4), for medical students.

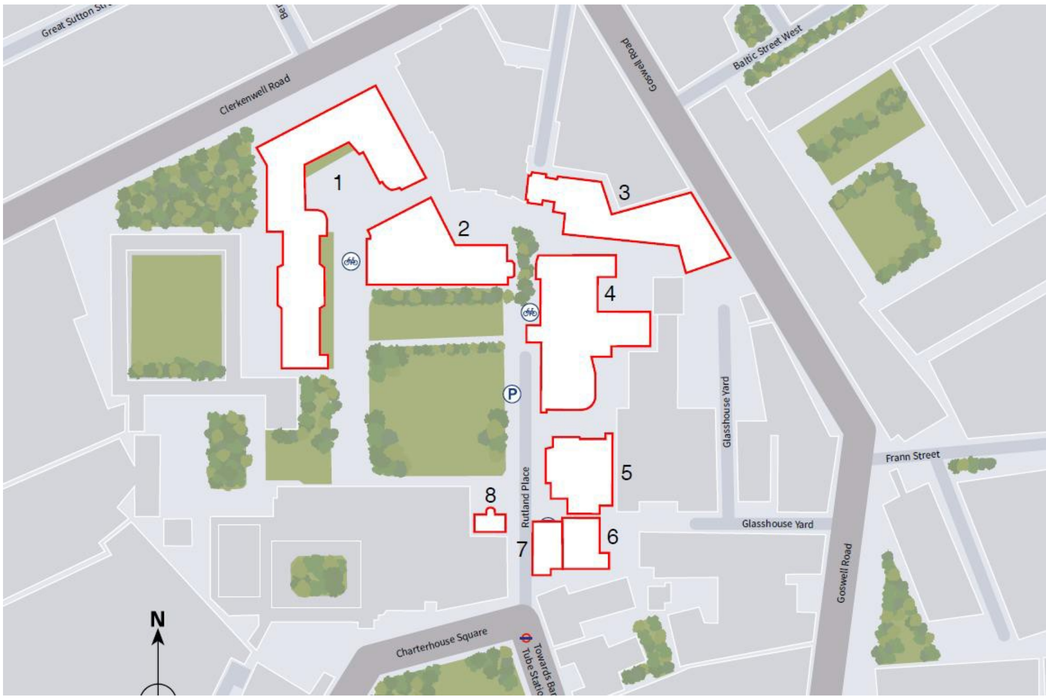


Figure 63: Charterhouse Square Campus Layout.

A heat network has been installed across the Charterhouse Square campus, which connects the buildings highlighted in red in Figure 64.

Figure 64: Existing Heat Network in Charterhouse Square campus.

The heat sources within this campus are a combination of gas-fired boilers plant and gas-fired CHP units. These CHP units are located within Dawson Hall (4) and the John Vane Science Centre (1). The other buildings have to some extent their own gas-fired boiler plants. All DHW across this campus are generated via gas-fired boilers. Ventilation is generally natural, with mechanical ventilation present in one of the buildings only. Cooling is provided by a combination of split units and a small number of chillers distributed across the site and currently there is no heat recovery from the chillers. It is understood that a capital investment budget of £2.5 million per year has been allocated for a period of 5 years for this campus.

A number of campus level decarbonisation projects are currently underway or being planned:

- Replacement of the life expired chiller in John Vane Science Centre (which supports BSU) with an Absorption Chiller, this would add thermal load to the CHP through the connection of existing CIAT Chillers to a newly installed CHW loop served by the absorption chiller
- Using the CHPs to store energy and setup a UPS central network is being explored
- Ventilation system upgrades

- Replacing the gas fired steam generators with electric boilers at life expiry
- Further consolidation of existing VRF systems to connect into the centralised cooling system

Several priority buildings for decarbonisation have been identified in that they have high fossil fuel consumption and relatively poor performance compared to the rest of the portfolio.

Figure 65: Charterhouse Square Campus Priority Buildings.

The indicative costs in Table 13 are based on benchmarks and previous project experience. The proposed measures for each building and additional information about these measures are included in Table 18 within the Appendices.

Table 13: Charterhouse Square Campus Options (Dawson Hall and Wolfson Building)

Building	Indicative Capital Cost (£)	Cost Saving (£)	Annual CO_{2e} Saving (tCO_{2e}/year)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC (Simplified) [£/tCO_{2e}]	Rank
Dawson Hall	£972,000	£21,930	105.1	2,943.6	44.3	£330.20	-
Wolfson Building	£3,000	£-	-	-	-	£-	-

Strategic options for decarbonisation of the existing Charterhouse Square Campus' heat network have been considered. These include:

- **On-site solution:** air or ground source heat pumps.
- **Offsite Solution:** Connection to existing energy network or to a local data centre.

On-site solution: To the North and East of the site are residential properties and to the West and South are historically important buildings. The centre of the site contains a green space. However, this is highly likely that this would be a sufficient space to install the required number of closed loop boreholes that could serve the buildings within these sites. Open loop ground source may be an option, but this requires investigation and modelling to assess viability. ASHP is therefore considered to be the default proposal at this stage. The ASHP would operate as the lead heat source with gas-fired boilers as top-ups and back-ups.

The hybrid ASHP and boilers arrangement has been modelled using the Hysopt hydraulic model using the peak load to size the equipment. The system provisionally comprises of:

- 01no. 500kW ASHP unit which, coupled with a thermal store, will contribute approximately 80% of the annual demand
- 16,000L wet thermal store (or equivalent PCM alternative) to provide operational flexibility (the existing thermal store can potentially be used)
- Gas-fired boilers for top-up during peak loads and as back-up during periods of maintenance downtime or unplanned outages of the ASHP
- Balance of plant, as required.

The average dimensions of a 600kW ASHP are approximately 1.40m (W) x 4.65m (L) x 2.20m (H), with 1.50m around each edge and 0.50m above the unit for maintenance space. In addition, an allowance of 2.00m between heat pumps should also be included. The roof of the Wolfson Institute Building has been identified as a potential location and based on a desktop review; these dimensions accommodate the requirements for a 500 kW ASHP. The boilers would be placed either at the Wolfson Institute (roof mounted or in the existing plantroom) or in individual building plantrooms if neither solution can be realised.

The CHP units could potentially be integrated, although the technical and techno-economic viability of retaining them as part of the solution would need to be assessed. This seems an unlikely solution due to distance constraints and limited space availability at the Wolfson Institute. On this basis it would most likely be that in the longer-time that the CHPs would be decommissioned and removed.

It was noted that that the peak load used in the Hysopt model has been estimated based on building fabric uplifted U-values, the element areas, ventilation heat load, and DHW as a fraction of the heating load (estimated using the Energy Performance of Buildings Directive: Second Cost Optimal Assessment for the United Kingdom (excluding Gibraltar); Ministry of Housing, Communities and Local Government; Section 8, Table 8.5a p. 123).

In addition, there is opportunity to recover heat as sizable sewers are located to the north and east of the campus on Clerkenwell Road and Goswell Road. Furthermore, a 1100mm x 600mm of combined sewer runs under Charterhouse Square at a depth of circa 5m, which is shallow for London and positive in terms of civil engineering costs.

Table 14: Charterhouse Square Mid-term Proposal

Options	Description	Buildings	Estimated Heat Pump Capacity (kW)	Estimated Cost (£)
CHS Mid Term Proposal 1	On-site solution. New air source heat pump located on Wolfson Institute roof to become primary heat source of existing heat network, with possibility of more efficient open loop ground source heat pump pending detailed feasibility study. The existing CHP units will likely need to be decommissioned. Enables options for heat recovery from cooling systems, sewers located on Clerkenwell Road and Goswell Road, and a combined sewer underneath the site.	1-8	500	£980,000 - £1,080,000
Building Energy Efficiency Improvements	BEMS improvements, building fabric, insulation covers, VSDs, field control	1-8	-	2,000,000

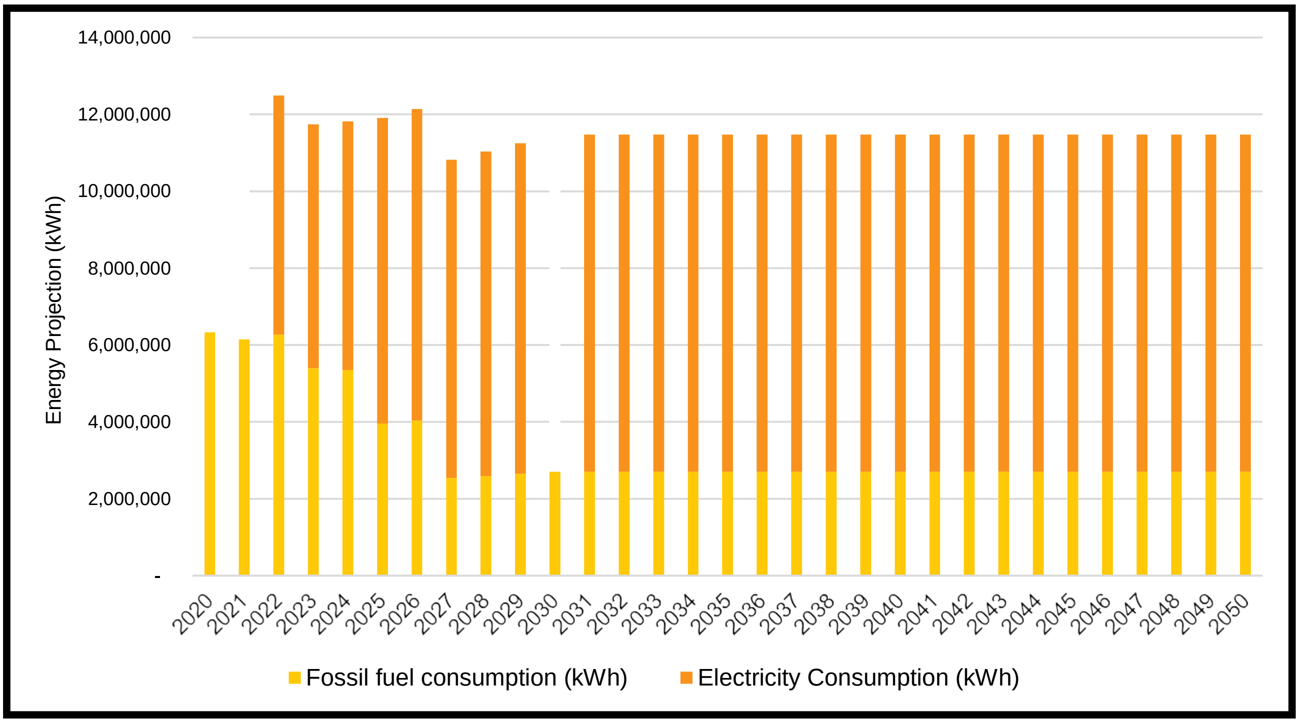


Figure 66: Charterhouse Square energy consumption projection (Onsite)

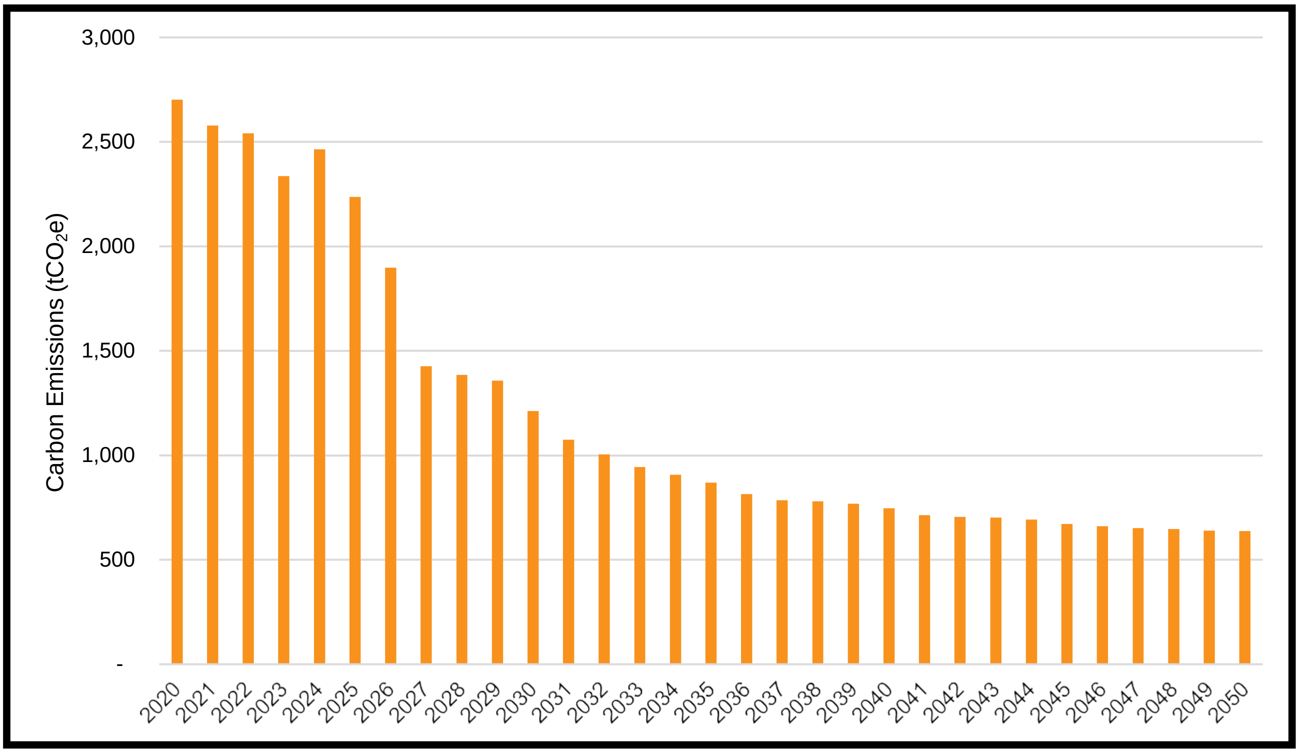


Figure 67: Charterhouse Square carbon emissions projection (Onsite)

Figure 66 and Figure 67 illustrate the energy consumption and the associated carbon emissions for the buildings within the Charterhouse Square campus. The remaining fossil fuel consumption projected are due to natural gas consumption from boilers to meet peak load.

Off-site solution: The campus is situated in proximity of current and planned district energy schemes:

a. Citigen
b. Bunhill
c. GreenSCIES

The map shows the site location relative to the existing Citigen (Orange) and Bunhill (Purple) heat networks and the proposed GreenSCIES (Red) ambient loop network. Citigen also has a district cooling network. Connection to one of these networks would provide a means to decarbonise the campus without additional significant investments on plant within the site.

Negotiation with the energy service providers will be required to determine whether the carbon factors, energy tariffs and commercial connection terms would be favourable over an on-site solution. An evaluation of technical feasibility will also be required, along with design and agreement of the terms of interconnection, prior to implementation of the Works. Initial engagement has taken place with Citigen on this basis and outline proposals can be accessed from EOn.

Various investment and ownership models could be explored. A mutually favourable scenario is likely to involve the energy service provider owning and maintaining assets delivering heat to the campus, with Queen Mary retaining ownership and control over existing boiler assets. The energy tariff is likely to involve a fixed and variable component along with a connection charge and potential future linking to campus operating temperature requirements.

Figure 68: Nearby District Heating Networks.

Heat exchanger substations would be the means of connection under the Citigen or Bunhill options. Under the GreenSCIES options, a heat pump with thermal storage would be the means of connection. All on-site solution should be in anticipation of a prospect of connecting these to the planned GreenSCIES network, this could become adopted by the energy services provider at the point of connection, subject to agreement of terms.

Volta Data Centre is situated near the campus, situated in Great Sutton Street, the other side of Clerkenwell Road. This has roof mounted chiller plant, which could potentially lend itself to heat recovery for supply to the campus from a newly installed water source heat pump on campus.

Table 15: Charterhouse Square Campus: Mid-Term Proposal

Options	Description	Building(s)	Estimated Heat Pump Capacity (kW)	Estimated Cost (£)
CHS Mid Term Proposal 2	Off-site solution. Existing heat network to be connected to one of the nearby local district heating networks, which are Citigen and Bunhill, or the planned GreenSCIES network. Thermal substations will be required. Additionally, a connection to the nearby Volta data centre could be constructed to utilise their waste heat. Citigen operate a nearby district cooling network which could serve the campus cooling requirements.	1-8	750	£1,190,000 - £1,310,000

Heat Recovery cooling can be provided by a combination of split units and a small number of chillers distributed across the site. Heat recovery from the chillers does not currently appear to be present. It is anticipated that the cooling system within the John Vane Science would be replaced. An initial desktop investigation of benchmark values based on CIBSE Guide A (Table 6.2 Benchmark allowances for internal heat gains in typical buildings – Education – Lecture theatres) shows that the plant should be sized to meet the estimate peak demand of 1,500kW. It is noted that this capacity selection is provisional and further capacity optimisation would be required at the next stage of design.

Any future upgrading of cooling systems should consider centralising the services through chiller plant. This would provide the opportunity for useful heat recovery. Indeed, the chiller plant could potentially be substituted with heat pumps and thermal storage to provide such an opportunity. Heat recovery would generally be compatible with each of the off-site solutions. Additionally, there may be an opportunity to recover heat from sewer heat recovery as previously stated.

6.2.3 Whitechapel Campus

The Whitechapel Campus is located across the streets that are close to the Royal London Hospital, opposite Whitechapel underground station. It is approximately 20-minute walking distance from the Mile End Campus. It is a medical research and teaching campus, which is closely associated with the nearby Royal London Hospital and Royal London Dental Hospital. The ages of the buildings range from the late 1880's to 2005. Except for the Library, Yvonne Carter, and 64 Turner Street, these are purpose-built buildings. Although classed as a campus, most of the buildings are separated by public roads, which potentially would restrict or complicate infrastructure projects that would interconnect these buildings.

The buildings highlighted in Black in Figure 69 have been excluded from the scope of this decarbonisation plan as these are not strictly part of Queen Mary's portfolio.

Figure 69: Whitechapel Campus Layout.

All the buildings across the Whitechapel campus are standalone and not interconnected. The Yvonne Carter Building (8) is "all electric" with heating being provided by roof mounted air source heat pumps. All other buildings are predominantly heated by gas-fired boilers.

The main medical research buildings (Abernethy (4), Blizard (5), The Wingate Institute Building (7)) have high ventilation loads due to the presence of Containment Level 2 and 3 Laboratories. These buildings have process loads in the form of steam generators and autoclaves. These three buildings also have high domestic hot water loads, associated with the laboratory areas and, in the case of Wingate, cage wash facilities. The Floyer House (10) is a hall of residence and has comparatively high domestic hot water load.

There is limited cooling demand on campus. The Library (2) and Wingate Institute (7) have VRV systems.

There are several development areas around the campus and the Figure 70 show the plots which form the Whitechapel Road Masterplan, as well as the demise and ownership of each of the existing buildings.

Figure 70: Whitechapel campus development map

Plots A, B, D1 and D2 indicate areas in the domain of the Department of Health and Social Care (DHSC). Similarly, the areas demarcated in Blue are in the domain of Barts Health NHS Trust and Yellow represents London Borough of Tower Hamlets. The areas in Purple are Queen Mary's Buildings.

Plot C was acquired by Queen Mary in November 2021. The current building on Plot C (former Dental Hospital) and the BSLA Students Association Buildings are scheduled for demolition and redevelopment. The proposed new buildings on Plot C will be used for life sciences/research purposes as well as teaching space across eight floors and it is expected to have a gross internal area (GIA) of approximately 15,500m^2.

Considering the development areas, there is the potential to install a centralised energy centre, located on Plot C, which could be made up of ASHP that can serve all Queen Mary's buildings within this campus.

Several priority buildings for heat decarbonisation have been identified and highlighted in Red in Figure 71. These buildings have high fossil fuel consumption and relatively poor performance compared to the rest of the portfolio.

Figure 71: Whitechapel Campus Priority Buildings.

The indicative costs of the initiatives list in Table 16 are based on standard benchmarks and project experience. Additional information about these measures are included within Table 18 in the Appendices.

Table 16: Whitechapel Campus Priority Buildings

Building	Indicative Capital Cost (£)	Cost Saving (£)	Annual CO2e Saving (tCO_2e/year)	Lifetime Carbon Abated (tCO2e)	Simple Payback (years)	MAC (Simplified) [£/tCO_2e]	Rank
Blizard Building	£317,000	£11,954	16.6	464.8	26.5	£682.03	4
The Wingate Institute	£80,000	£1,254	6.0	135.2	63.8	£591.57	3
Innovation Centre	£238,000	£8,966	12.4	348.6	26.6	£682.75	5
Garrod Building	£538,000	£16,891	68.5	1,762.5	31.9	£305.25	1
Floyer House	£517,000	£13,413	49.8	1,329.9	38.5	£388.77	2

A Hysopt model has been used to size the equipment and the system will therefore comprise:

- 01 no. 1200kW ASHP unit (or 02no. 600kW units) which, coupled with a thermal store, which will contribute to approximately 80% of the annual demand
- 20,000L thermal store to provide operational flexibility
- Gas-fired boilers for top-up during peak loads and as back-up during periods of maintenance downtime or unplanned outages of the heat pump
- Balance of plant, as required.

The average dimensions of a typical 600kW ASHP are approximately 1.40m (W) x 4.65m (L) x 2.20m (H), with 1.50m around each edge and 0.50m above the unit for maintenance space. In addition, an allowance of 2.00m between heat pumps should be allowed for. These dimensions should be considered to accommodate the heat pump(s) in the energy centre of the new building on Plot C.

It is noted that the peak load used in the Hysopt model for the buildings across the Whitechapel campus have been estimated based on building fabric U-values, the element areas, ventilation heat load and DHW as a fraction of the heating load (estimated using the Energy Performance of Buildings Directive: Second Cost Optimal Assessment for the United Kingdom (excluding Gibraltar); Ministry of Housing, Communities and Local Government; Section 8, Table 8.5a p. 123). To estimate the peak load of the new building on Plot C, the Wingate Institute has been used as a benchmark due to similarities in terms of use and activities between Wingate and the buildings that will be constructed on Plot C.

Alternatively, connecting to external energy centre / supply source has been recommended.

Queen Mary University of London

SILVER Energy Management Solutions

Table 17: Whitechapel Campus Mid-term Proposal 2

Options	Description	Building(s)	Estimated Heat Pump Capacity (kW)	Estimated Cost (£)
WC Mid Term Proposal 2	Connection of 11 buildings to new DHN fed by new ASHPs and boilers.	1-2 ,4-7, 9-11	1,200	£3,710,000 - £4,060,000
Building Energy Efficiency Improvements	BEMS improvements, building fabric, insulation covers, VSDs, field control	1-2 ,4-7, 9-11	-	£2,950,000

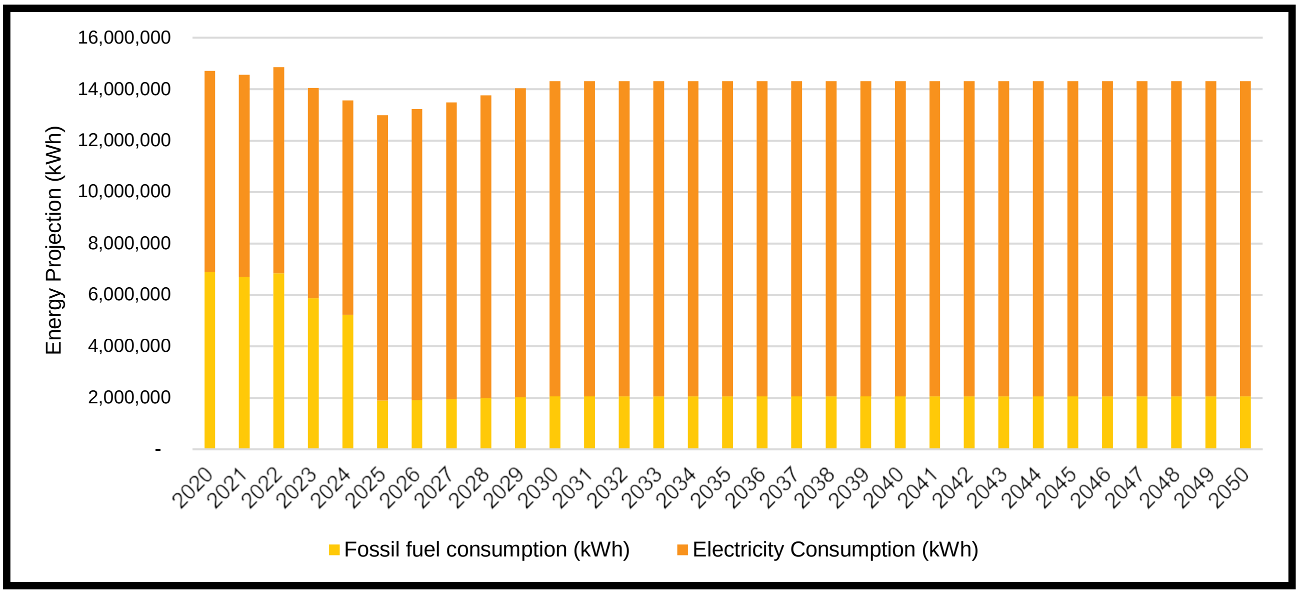


Figure 72: Whitechapel Energy Consumption Projections

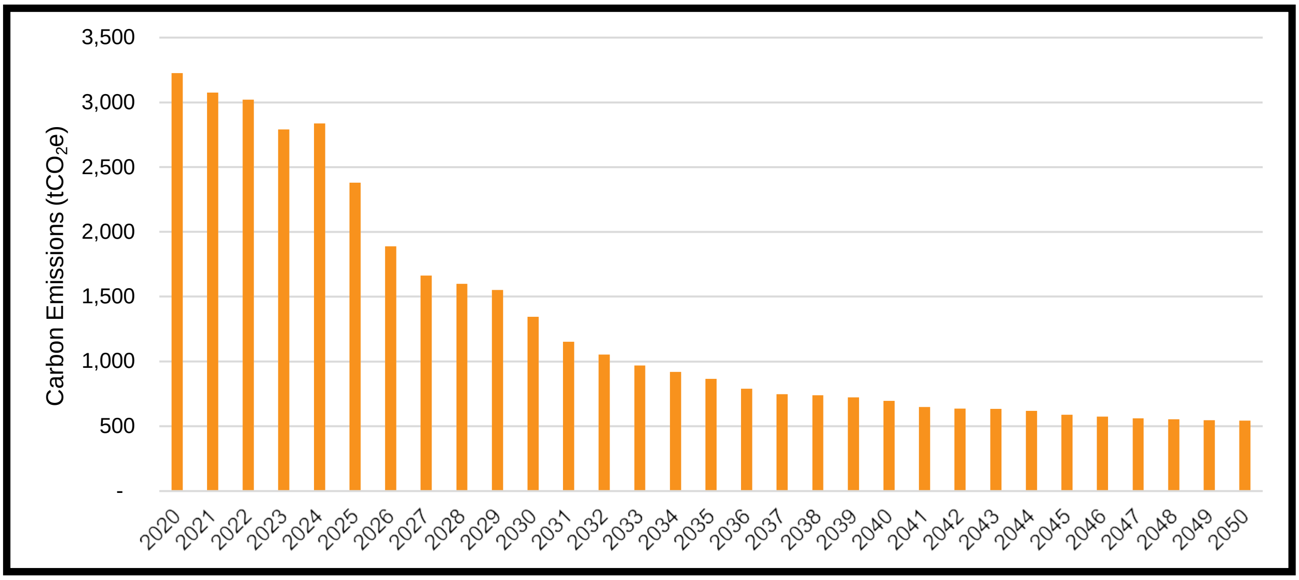


Figure 73: Whitechapel Carbon Emissions Projection

6.2.4 West Smithfield

West Smithfield is a cluster of four buildings; however the site is currently undergoing significant redevelopment. The Pathology and Museum block (1) is part of a major redevelopment that is managed by Barts Health NHS Trust who own the building. Queen Mary has 7 years remaining on the lease for this building. For the purposes of the decarbonisation strategy only the Robin Brook Centre (2) was considered. Therefore, buildings 1, 3 and 4, highlighted in Black in Figure 74 have been excluded from the scope of this plan.

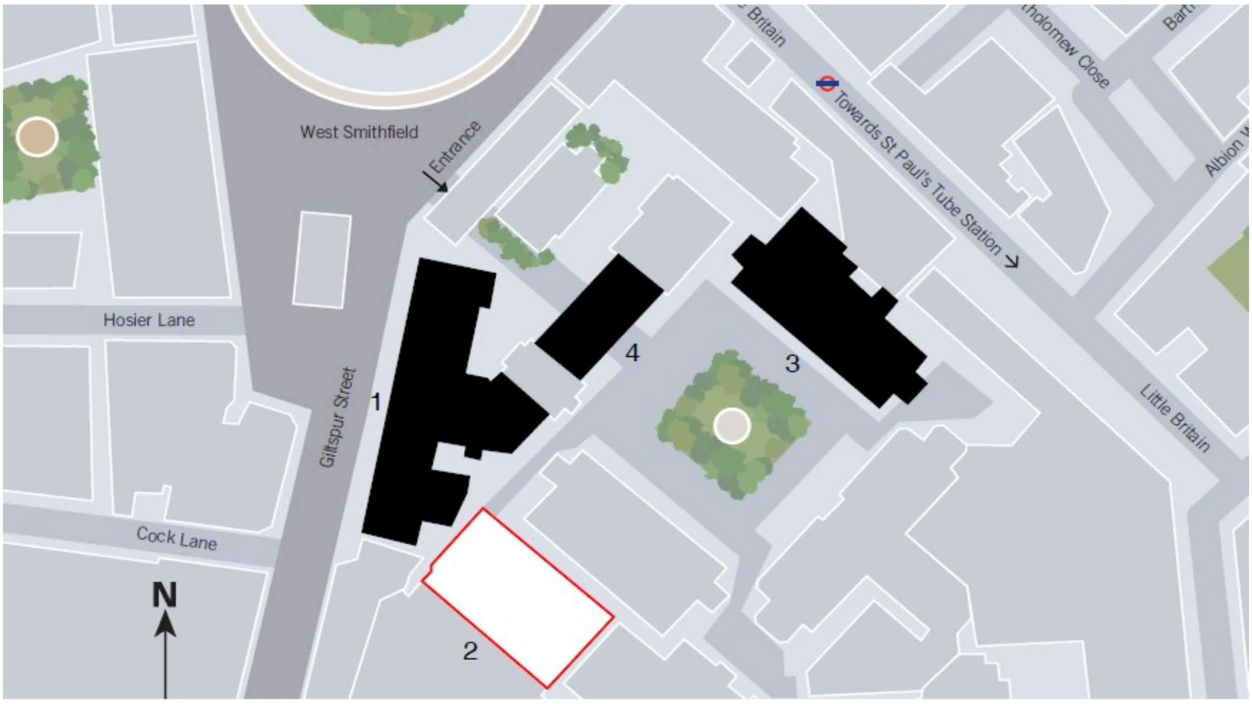


Figure 74: West Smithfield Campus Layout

Figure 75: Robin Brook Exterior.

The Robin Brook Centre has its own gas-fired boiler plant, located in the basement. Although the boilers were recently replaced, the boiler plantroom is not in a good condition. Domestic hot water is produced by gas-fired direct calorifiers. Cooling and some supplemental heating are provided by VRV units, the condensers for which are located within the roof of the plant room. As part of the wider site redevelopment the surrounding buildings have been extensively rebuilt and the hospital energy infrastructure upgraded. **Queen Mary should explore the possibility of connecting the Robin Brook Centre to the heating network of the adjacent redevelopment areas**.


Figure 76: Robin Brook gas boiler plant.

Figure 77: Robin Brook with adjacent New Energy Centre.

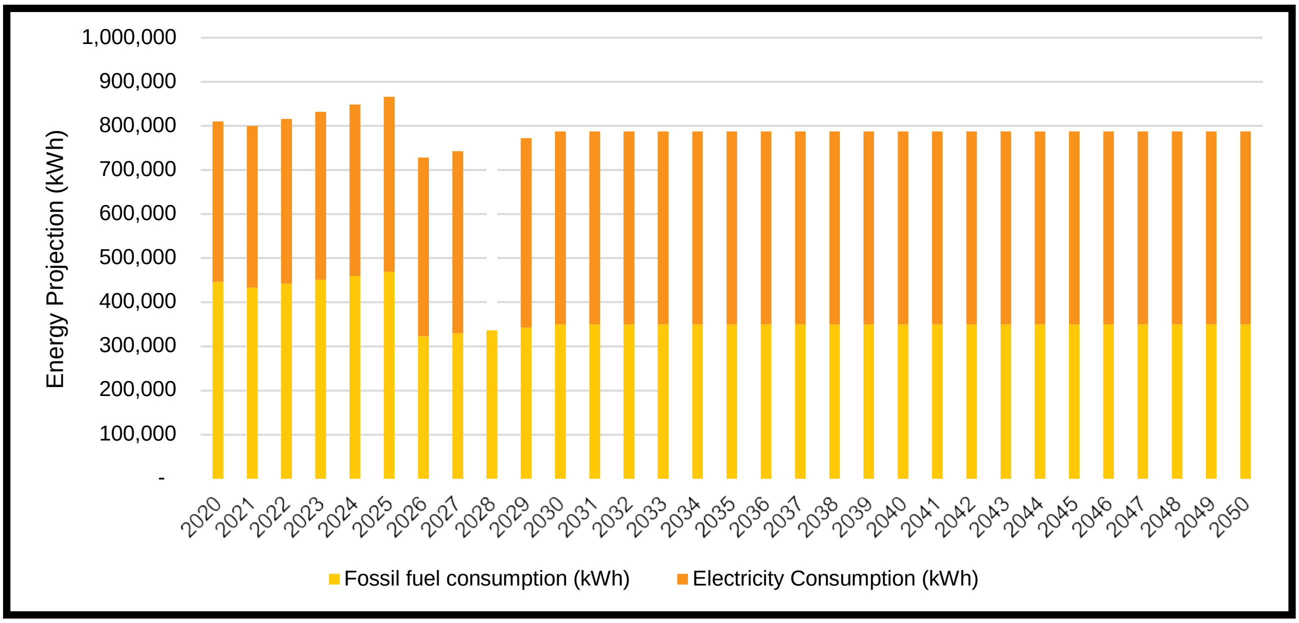


Figure 78: West Smithfield Energy Consumption Projection

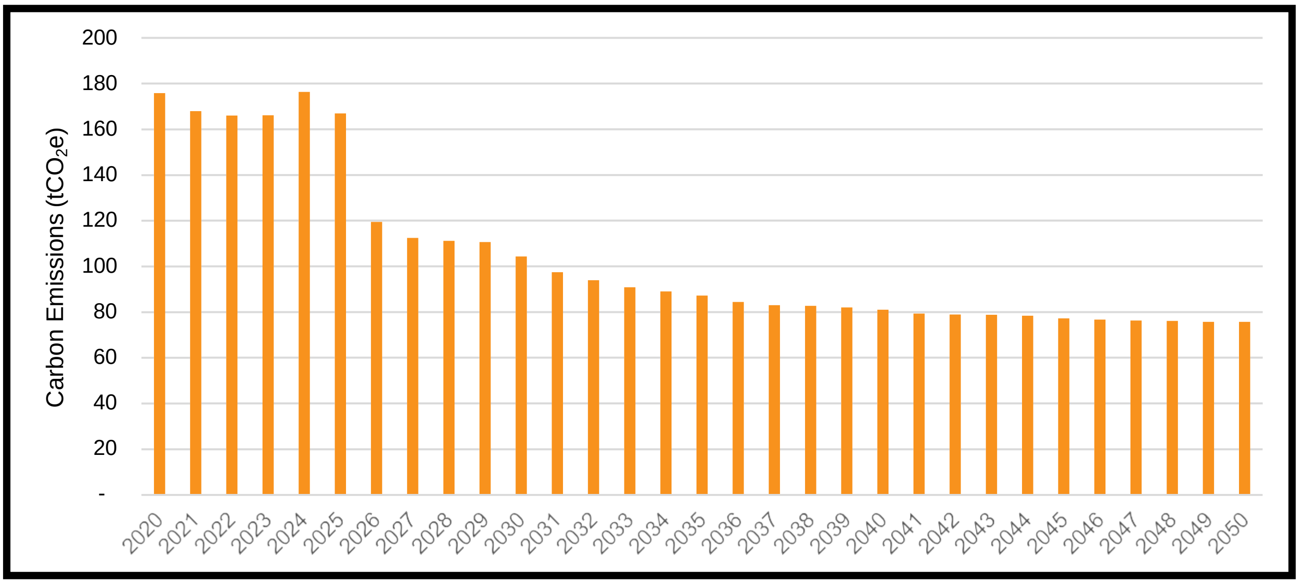


Figure 79: West Smithfield Carbon Emissions Projection

6.2.5 Lincoln's Inn Fields

Lincolns Inn Fields is a single building located behind Kingsway in Holborn. The building is leased and there are approximately 5 years left on the current lease agreement.

Figure 80: Lincoln Inn Field Layout.

Figure 81: Lincoln Inn Field Building Exterior.

This building has no fossil fuel usage. Heating is provided by reversible VRV heat pumps, the condensers for which are roof mounted in an acoustic enclosure. Mechanical ventilation with heat recovery has been fitted across most areas of the building. Further decarbonisation will rely on energy efficiency and **good operational practice** rather than capital investment.

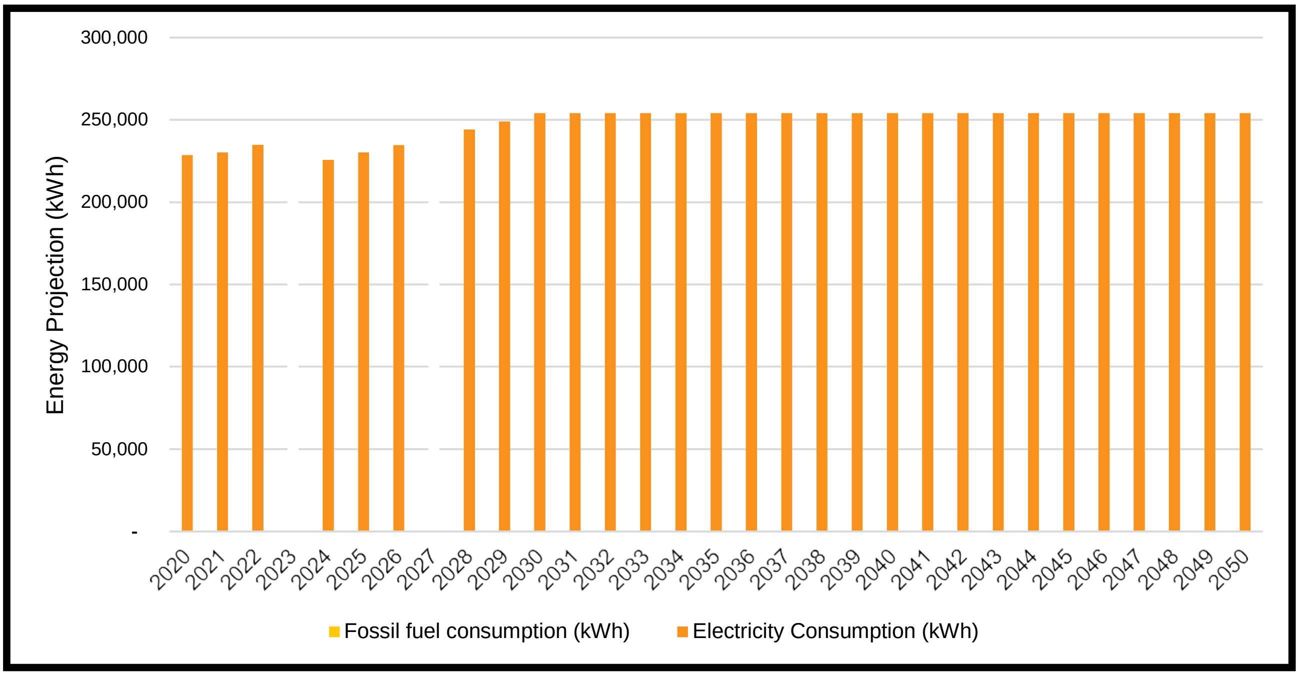


Figure 82: Lincoln's Inn Field's Energy Consumption Projection

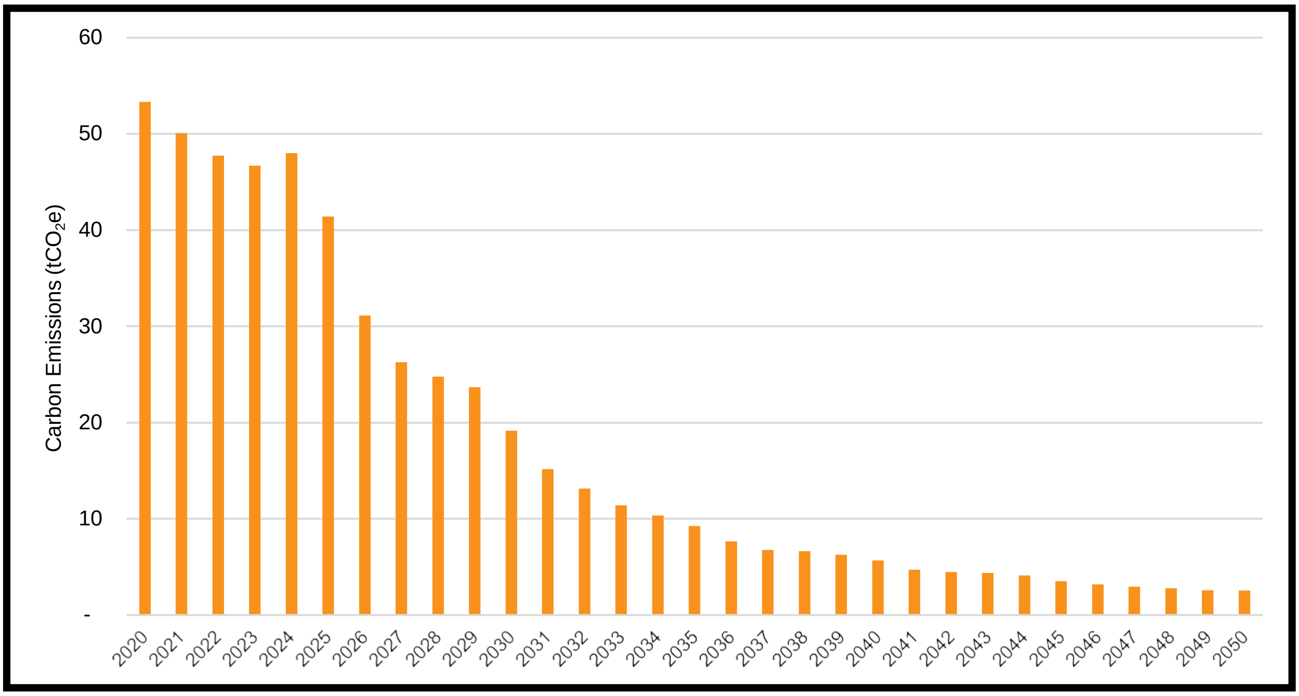


Figure 83 : Lincoln's Inn Field's Carbon Emissions Projection

6.2.6 Chislehurst Sports Ground

The Chislehurst site comprises three properties located at a sports ground to the Southeast of London in Kent. One of these properties, highlighted in Black in Figure 84, is wholly residential and has been excluded from the scope of this plan.

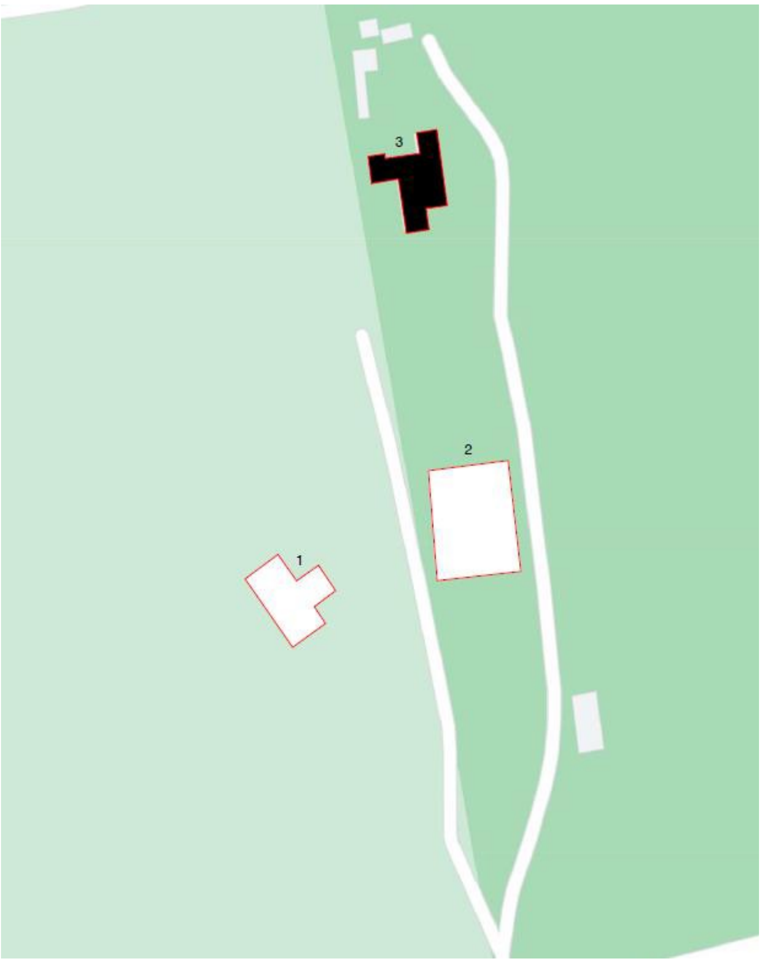


Figure 84: Chislehurst Sports Ground Layout.

The East Pavilion (2) is fitted with gas-fired boiler plant which provides heating service only, with Domestic Hot Water being generated from gas-fired direct calorifiers. The West Pavilion (1) has two areas. The residential area is supplied from a domestic gas boiler. The Pavilion and changing rooms are supplied from oil-fired plant.

It is proposed that the oil-fired plant within the West Pavilion be replaced with a with heat pump-based solutions. The heat pump should be sized for a peak load of approximately 150kW to supply space heating and domestic hot water.

The peak load has been estimated based on building fabric uplifted U-values, the element areas, ventilation heat load, and DHW as a fraction of the heating load (estimated using the Energy Performance of Buildings Directive: Second Cost Optimal Assessment for the United Kingdom (excluding Gibraltar); Ministry of Housing, Communities and Local Government; Section 8, Table 8.5a p. 123).

No fabric improvements have been proposed for this site. Therefore, the U-values used to calculate the peak load were the current ones, estimated based on building age.

Figure 85: East Pavilion

Figure 86: West Pavilion

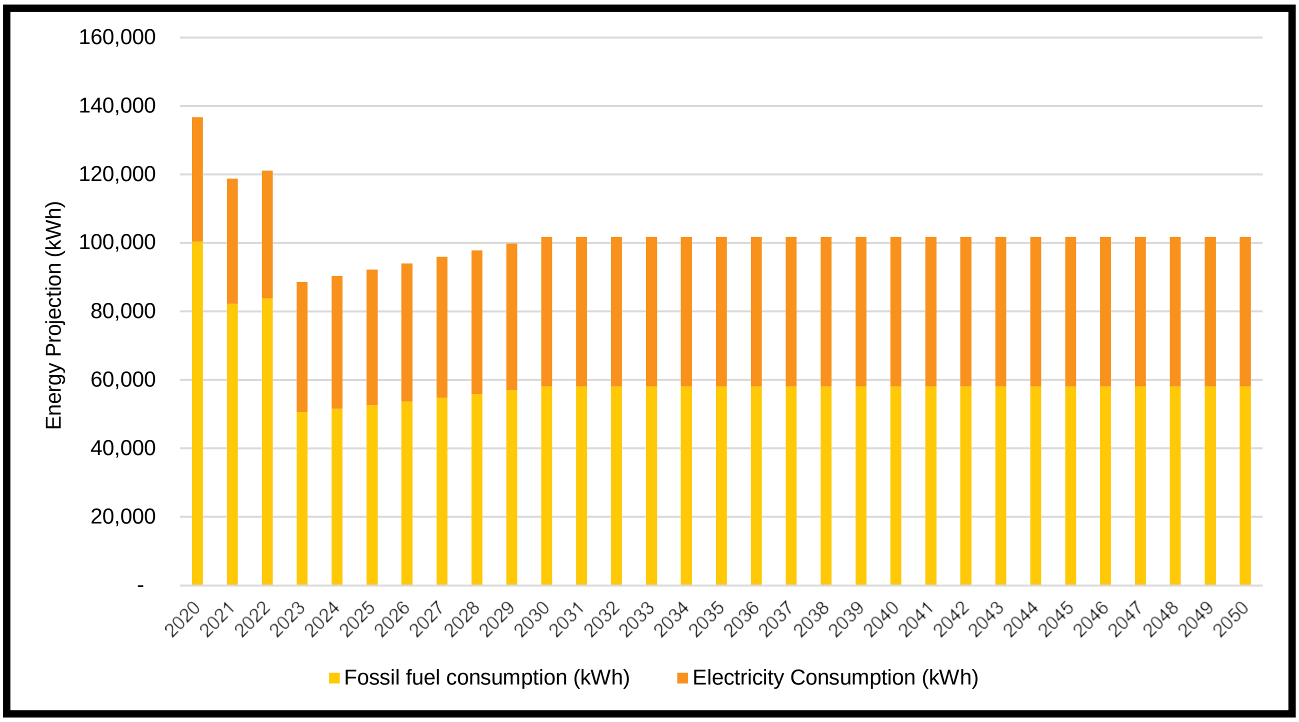


Figure 87: Chislehurst Energy Consumption Projection

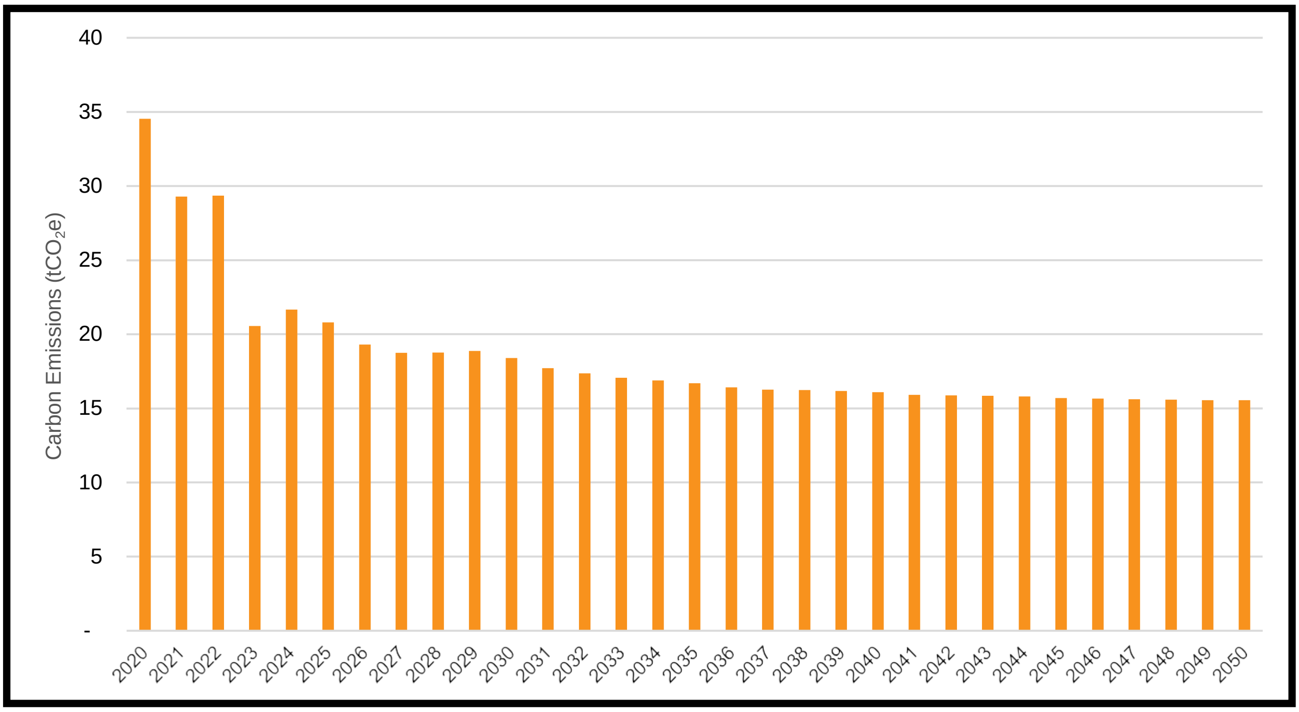


Figure 88 : Chislehurst's Carbon Emissions Projection

6.3 Wider Estate Decarbonisation

Consideration has been given to wider decarbonisation measures over and above the measures identified as part of this heat decarbonisation plan. There are further measures such as building integrated fabric solutions, lighting, HVAC, and controls that may be applicable and will require further investigation to assess suitability for each building. These measures are explained in the following sub-sections.

6.3.1 Building Fabric

Building integrated and renewable energy solutions are increasingly playing vital role in carbon reduction, particularly buildings use approximately 40% of energy generated. The global market for zero-carbon buildings is expected to continue to become dominant over the next decades compared to traditional architecture. Thermographic surveys should be carried out where possible to assess current insulation, thermal bridges, and air leakage paths within building fabric.

PV curtain walls

One innovative building fabric improvement that could be considered is the utilisation of PV curtain walls as the outer covering of a building. Curtain walls do not carry any structural loads of the building and can be incorporated to buildings by using PV glass. Building Integrated Photovoltaics (BIPV) are photovoltaic materials that are used to replace traditional building materials in parts of the building envelope such as the roof, skylights, or façade. BIPV has the advantage of energy generation potential, and the cost of material is competitive compared to conventional materials such as stone, ceramics, and glass. Where conventional Building Adopted Photovoltaics (BAPV), are installed to building envelope with the sole purpose of producing renewable energy, BIPV can be used as an integral building component in which the technology is a functional unit as well as a construction element in the building make-up.

Translucent Granular Aerogel

Translucent Granular Aerogel is a translucent material that can improve the thermal insulation performance of buildings without compromising daylight transmission. These can be applied to single glazed windows resulting in reductions in heat losses of up to 80%. This material can be a lower cost solution compared to upgrading to double-glazed windows or secondary glazing. Translucent granular aerogel could be applied to a variety of materials such as steel, plastic, carbon fibre and glass. There are currently some commercially available options in the market.

Cladding

Cladding is the application of a layer of material on another on the outer building fabric to attain thermal insulation, weather resistance and to improve the appearance of a building. These may be in different material types, styles, and properties. Timber cladding is generally considered as an environmentally friendly option due to its thermal insulation properties as well as, being vital in the reduction of carbon dioxide both during its lifetime and even when felled and cladded to a building timber continues to absorb and store CO_2. Using wood instead of other building materials saves an average of 0.9 tonnes of CO_2 per cubic metre.

Stone is another choice as a material for cladding. There are various companies that aims to use stone to make sustainable products, transforming the appearance of buildings and improving the insulation efficiencies of the buildings. Recently, Engie has acted as the main contractor for the façade for Eyot House, Bermondsey, London where stone cladding was preferred with faster installation times and lower cost for the material.

Cladding improvements require strict requirements on fire safety of materials intended to be used. Following the fire at Grenfell Tower in London in 2017, it is essential to understand the materials and their properties before any cladding materials should be considered. Suitable cladding material should have low calorific value and a very good reaction to fire performance.

6.3.2 Lighting

Light-emitting diodes (LED) are semiconductors that offer efficient alternatives to incandescent and compact fluorescent lamp (CFL) bulbs when turning energy into light. Upgrade to LED lighting offers significant electricity savings, which can free-up capacity for electrification of heat.

Lighting control can offer significant electrical savings. It is good practice that lights are switched off when areas are not in use either manually or via sensors. Smart controls can be used to ensure lights are controlled in logical groups taking into account sunlight and activity being undertaken.

6.3.3 Heating Ventilation and Air Conditioning (HVAC)

Flushing of heating systems can be carried out to remove build-up of sludge and sediments in a central heating system to improve efficiency.

Heat recovery is the reuse of heat and cooling within the same system or integrated with nearby systems. It is a cost-effective way to recycle the heating or cooling used by ventilation systems. For example, the Wingate Institute is naturally ventilated except for an air handling unit serving the basement and ground floors. The unit is designed for 100% fresh air (no recirculation) with a heat recovery (run around) coil between the supply and extract sides. This has been disconnected and the unit now runs 100% fresh air with no heat recovery. The coils themselves have been retained, and it would be cost effective to install the necessary plant to reinstate this system. The ventilation system is understood to operate continuously through the day and night, and it is typical for a correctly sized run around coil to recover at least 60% of the thermal energy utilised by the ventilation system. Similar opportunities may be present across Queen Mary's estates.

Maintenance of ventilation and air conditioning equipment is important to ensure that components are clean and functioning ensuring efficient operation. Checks should be carried out to ensure heating and cooling is not occurring at the same time, which can be avoided by setting a temperature 'dead band'. Doors and windows should also be kept closed when air conditioning is in use.

Cooling optimisation ensures temperature stability and dynamic response to change in heat load, delivering energy savings. Optimisation can be achieved by installing an artificial intelligence-based energy optimisation thermostat. These thermostats are used for commercial direct expansion-based air conditioning and refrigeration systems.

6.3.4 Controls

Smart thermostatic radiator valves (TRVs) are devices that are designed to provide an individual, room-by-room heating control. They work in conjunction with the existing thermostat kit and creates zones for heating systems, which can easily be managed through an application for smartphones, tablets or computers.

Timeclocks and passive infrared (PIR) controls for water heaters in kitchens save energy by ensuring that water system is on only when required.

Point of use (POU) water heaters produce hot water close to the point at which it would be used such as sink or shower, instead of a central heat source in a building. For domestic hot water consumption POU heaters reduce heat loss within the distribution system.

6.3.5 Behaviour Change Programmes

Energy consumption of a building is dependent on the building use as well as the patterns and behaviours of occupants, which in the context of Queen Mary includes staff, students, and visitors. Various behaviour change techniques can be explored to reduce energy wastage through engagement such as fact sheets, training, events, and competitions.

6.3.6 Thermal Storage

Thermal storage is simply the storage of heat in a container, such as hot water cylinder, for the purposes of space heating or hot water demand. The most common example of this is a domestic hot water tank where water is stored to ensure that there is enough supply for peak heat demand of a dwelling. The main advantage of thermal storage is that it offers flexibility to the any energy generation technologies it is coupled to work with. When the energy generation technology is not operating or it is not producing sufficient heat to meet the demand, the thermal storage would turn on to assist. With the integration of a smart control system, thermal storage can unlock access to flexible electricity tariffs. The thermal storage would be topped when the electricity is cheap and used up when it is expensive.

Thermal storage can vary in size to provide for heat for sudden changes in demand, hours, days or even seasonal storage depending on coupled energy generation technologies and the heating demand. The most common medium for storing heat is water; however, there is growing research and commercialisation efforts for phase change materials (PCM). PCM acts as heat batteries where heat or electricity is used to convert a PCM from solid to liquid, capturing more energy compared to water.

An important parameter for thermal storage is the difference in temperature between the flow and return temperature of a heating system. The greater the temperature difference, the more energy can be stored in the same unit. Hence, heating systems should have a good control strategy and operate effectively to ensure as low return temperatures as possible. Thermal stores should be considered where heat pumps, electric boilers, solar thermal panels, solar photovoltaics, or heat networks are examined as pathways to heat decarbonisation.

6.4 Overall Projections

Figure 89 illustrates the projected energy consumption for all the buildings. This figure includes projected increase in energy demand due to rise in student population and, energy reduction and conversion - as in electrification of heat - with the implementation of proposed projects. Projected carbon emissions are presented in Figure 90. The emissions reduction over the years takes into account the change in energy consumption as well as decarbonisation of the electricity grid, in line with greenhouse gas reporting: conversion factors 2021 published by UK government[6].

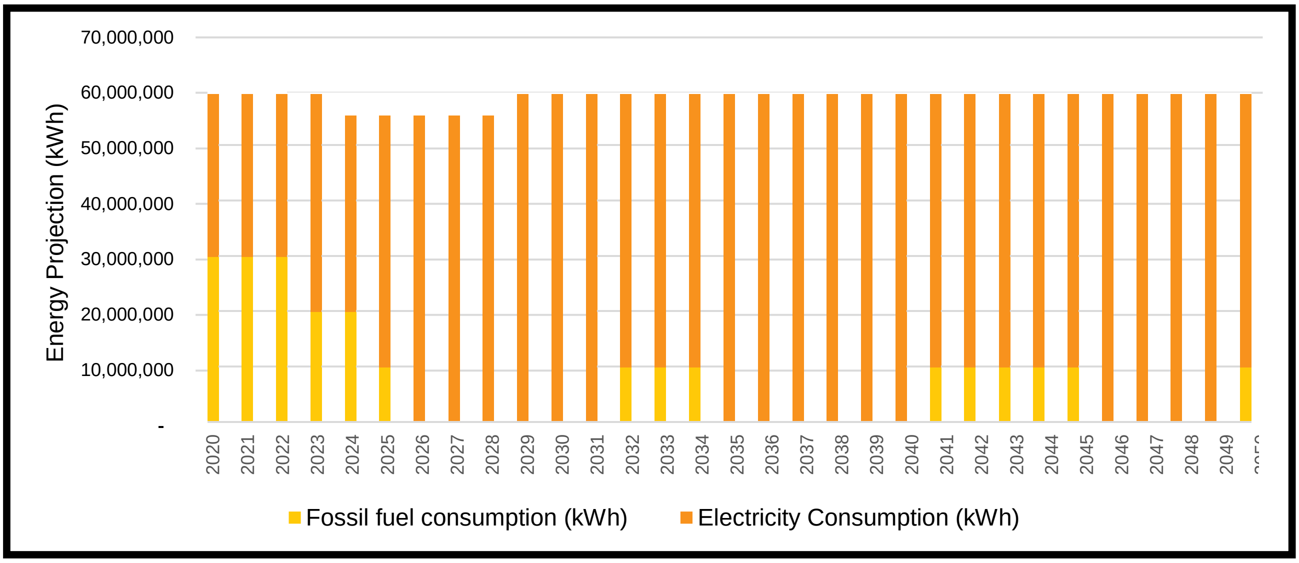


Figure 89: Queen Mary's Building Energy Projection Profile

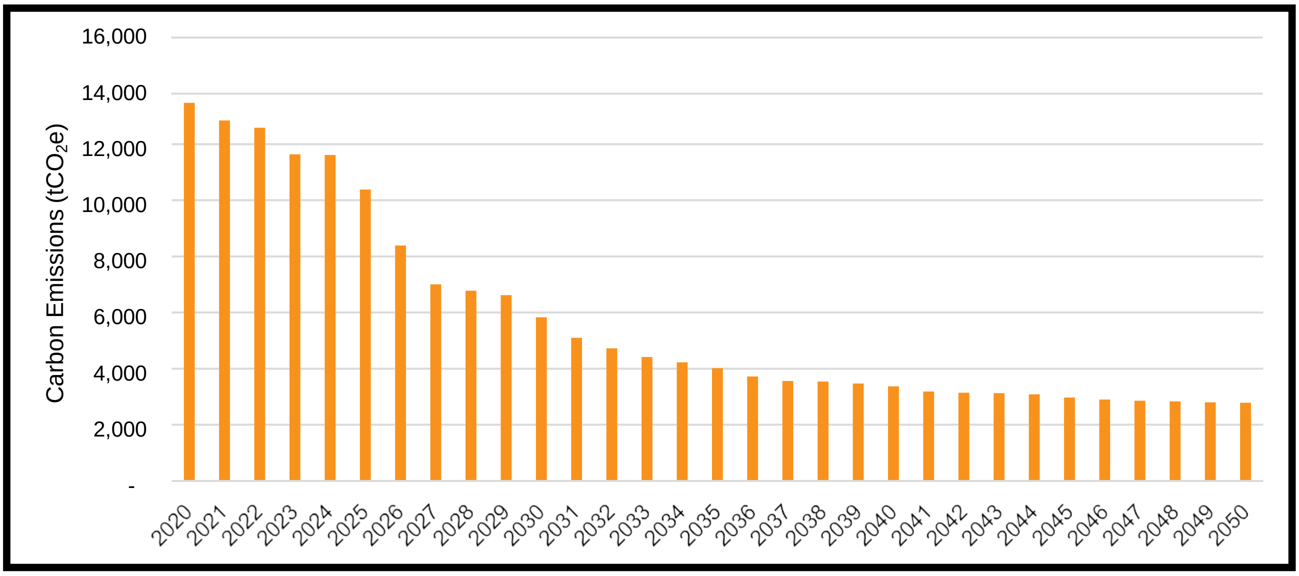


Figure 90: Queen Mary's Trend of Scope 1 and 2 Carbon Profile

[6] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021

7. Electricity Loading Capacity

7.1.1 Mile End Campus

The electrical infrastructure at the Mile End campus currently consists of six radial networks with distributed MPANs serving the campus. Plans are underway under Phase 1 (Hatton House) redevelopment to improve capacity and resilience by installing an 11kV ring main to be fed via an incoming supply at Hatton House/future School of Business Management. However, this upgrade is limited to current known requirements at this campus, and it may not be sufficient to manage implementation of the various identified campus level project opportunities.

Further upgrading of the electrical infrastructure is anticipated under the campus development masterplan. Capacity upgrading proposals and timescales were not known as at the time of writing this report.

It is anticipated that the emerging proposals will be insufficient to meet the needs of the strategic proposals set out in this plan. A key recommendation is that the campus utilities infrastructure aligns with strategic proposals set out in this plan, particularly with respect to electrical infrastructure since this will be significantly affected by the energy network and capacity.

7.1.2 Charterhouse Square Campus

The electrical infrastructure at Charterhouse Square currently consists of distributed MPANs serving each building across the campus. The supply to Dawson Hall currently represents a constraining factor on the ability of the existing CHP to operate. The connection to the John Vane building has recently been upgraded to a capacity of 1.5 MVA. This connection also supports the Wolfson Building.

Further work is necessary to assess whether there is residual capacity in the upgraded connection to meet the requirements of the on and off-site connection opportunities, particularly those requiring the integration of heat pumps.

Prior to further assessment being undertaken and any subsequent quotation application to UKPN, a more detailed opportunity (feasibility) assessment of the options should be carried out. The available capacity and access to heat network will be key determinants to the implementations of the most viable heat decarbonisations options.

7.1.3 Whitechapel Campus

The electrical infrastructure at the Whitechapel campus currently consists of distributed MPANs serving each building across the campus.

No assessment has been carried out in relation to available capacity of the site. Prior to further assessment being undertaken and any subsequent quotation application to UKPN, a more detailed opportunity (feasibility) assessment of the options should be carried out.

It is recommended that, once the options have been developed further and the strategic proposition is clearer further assessment of the capacity of the connection is carried out. Further work is necessary to assess whether there is residual capacity in the upgraded connection to meet the requirements of the on and off-site connection opportunities, particularly those requiring the integration of heat pumps.

8. Plans for the Sites

8.1 Building Level Projects

The timeline for the implementation of the building level projects set out in this report will be determined by available funds and a range of other determining factors including:

- Coordination of the Works with campus activities
- Sequencing of the works under a single or multiple framework contracts and Queen Mary's internal approvals and procurements processes
- Timescales for receipt of planning permission

Queen Mary should generally be exploring implementing building level measures between 2022 and 2024 and in any case at the earliest opportunity after attracting any internal or external funds.

Although not strictly a requirement ahead of campus level measures, coordination of these measures will result in a more cost-efficient outcome and should therefore be a strategic objective. Indicative timelines for typical building scale efficiency retrofit projects of the scale envisaged at Queen Mary are expected to be implemented between 3 and 6 months per building project from the point of tender issue.

Common building measures can potentially be implemented across multiple buildings within each campus under a single Works contract. Projects grouped in this way and secured under an existing framework or through a competitive tender process will de-risk delivery and reduce costs by ensuring appropriate specialisms are used for the full suite of projects.

8.2 Campus Level Projects

Implementation time scales for campus level projects will be driven by several factors including:

- Coordination of the Works with campus activities
- Coordination of the Works with existing capital works programmes for replacement and upgrading of existing infrastructure
- Coordination of the Works with strategic masterplan proposals
- Sequencing of the Works under a single or multiple framework contracts
- Queen Mary's internal approvals and procurements processes
- Timescales for receipt of planning permission
- Timescales for receipt of external approvals (where relevant)
- Timescales for negotiation of commercial agreements (where relevant)

Implementation time scales may therefore vary significantly according to the project type, for example whether air, ground or waste heat recovery sources are being proposed. Queen Mary will generally be looking to progress campus level measures at the earliest opportunity beyond successful receipt of funding and between 2023 and 2025.

Although not strictly a requirement for implementation ahead of campus level measures, coordination of building level measures proposed in this plan will result in a more cost-efficient approach outcome and should therefore be a strategic objective. These measures include improvements to heating and cooling systems to enable operation at lower and higher temperatures respectively thereby improving heat pump operating efficiencies.

An indicative timeline for typical heat pump retrofit project of the scale envisaged at Queen Mary and involving also upgrading of existing community heat networks or installing these as new is shown below.

The timeline assumes feasibility design and RIBA Stage 2+ or Stage 3 design being undertaken ahead of going to tender for a design, build contract, and includes provision for application funding periods as well as procurement of consultancy services and a design and build contract and a soft landings year post practical completion.

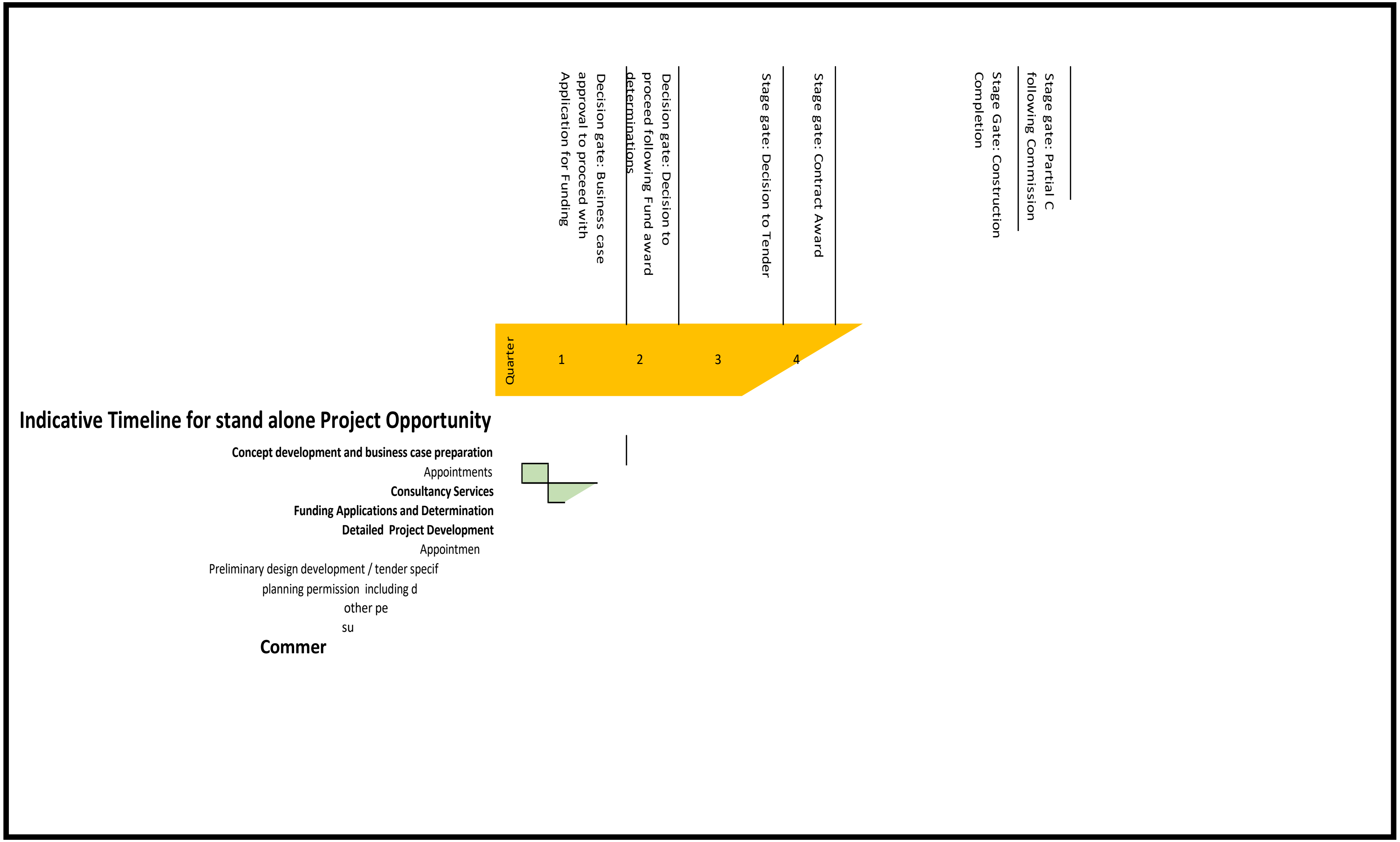


Figure 91: Indicative Timeline for Stand-alone Project Opportunity

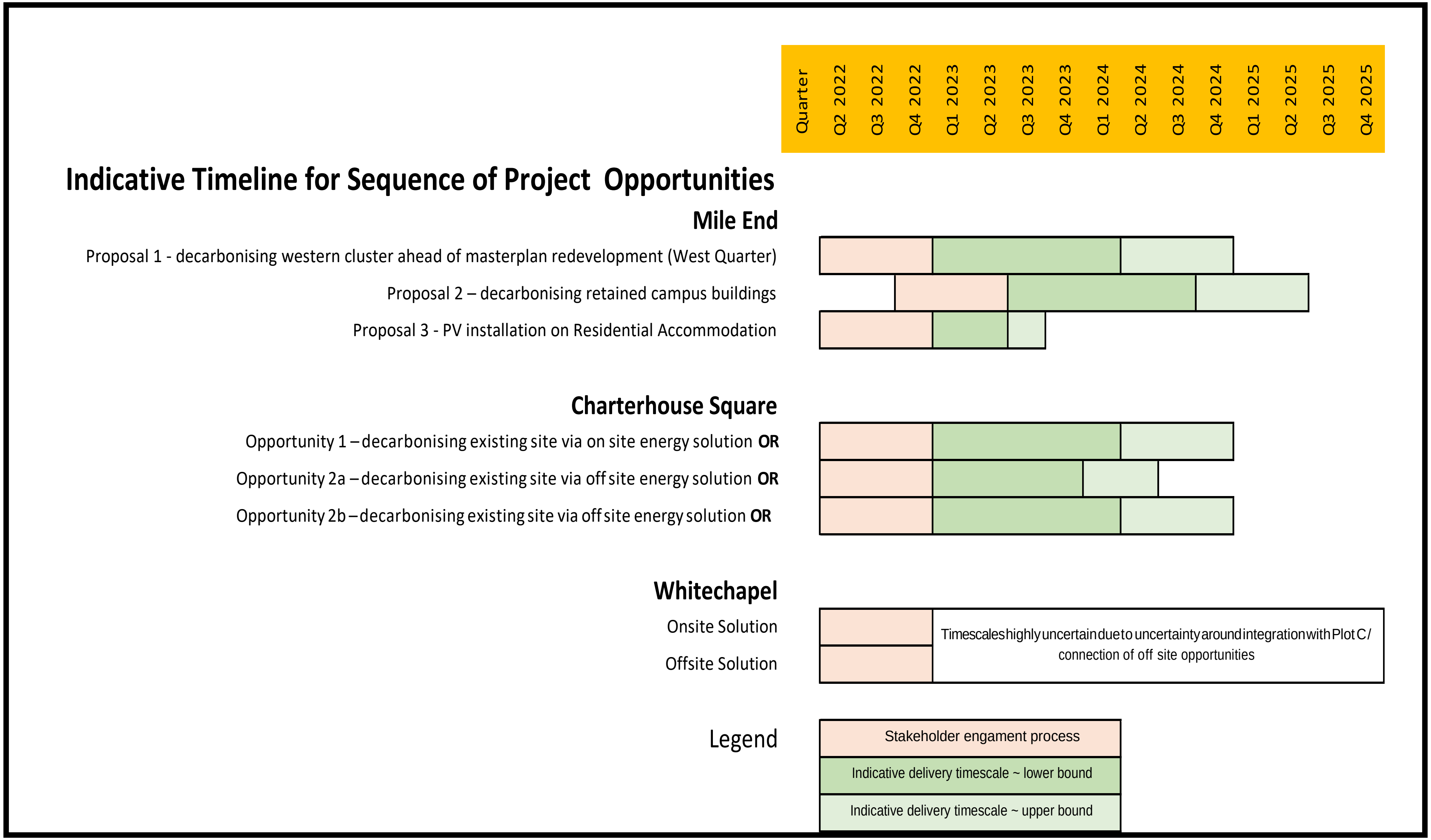


Figure 92: Indicative Timeline for Sequence Project Opportunities

Indicative implementation time scales to practical completion for the various campus level opportunities identified in this plan are set out in Figure 92. Expected upper and lower bounds have been added to the timelines in order to reflect uncertainties in project development timescales and expected variations of each project. These estimates exclude a soft landings year, which is assumed to also apply.

Actual project start and completion dates will depend on many factors, which are not possible to fully capture at this stage. However, an estimate has been made based on coordination of the projects within each campus to reflect:

- Likely project mobilisation timescales, factoring in development and internal sign off processes (with respect to business case approval)
- Staggering of project opportunities to manage supply chain implementation risk and to provide effective resourcing of internal project management function by Queen Mary's appointed representatives
- Known funding timescales as well as funding application process
- Integration with wider masterplan proposals and / or campus projects
- Avoidance of changeover and commissioning activities during peak winter demand period.

In the case of Whitechapel Campus there may be an opportunity to integrate the strategic proposals with the redevelopment of Plot C under the existing campus masterplan, which would therefore be served by the Energy Centre being considered. The existing energy strategy for the campus will need to be reassessed/realigned in the context of the current proposals. There may be case for serving the existing campus from an energy centre located within Plot C, subject to plot C project development proposals and time scales, it is understood that that Plot C is expected to be built by Q4 in 2026.

In the cases of Whitechapel and Charterhouse Square campuses, implementation time scales for connections to an offsite energy centre will largely be determined by:

- Third party development time scales
- Commercialisation of the arrangements, including negotiation of connexion agreements heat supply agreements and the like

The same applies to connections to off-site heat sources at Mile End, for example with Thames Water or TfL for sewer heat recovery or low-grade waste heat recovery, respectively. Current, it is understood that no significant level of negotiation has been started with any 3rd party across all the campuses.

A further indicative timescale is shown Figure 93 for the Mile End campus. This highlights the interaction of the identified project opportunities with the wider Campus Masterplan.

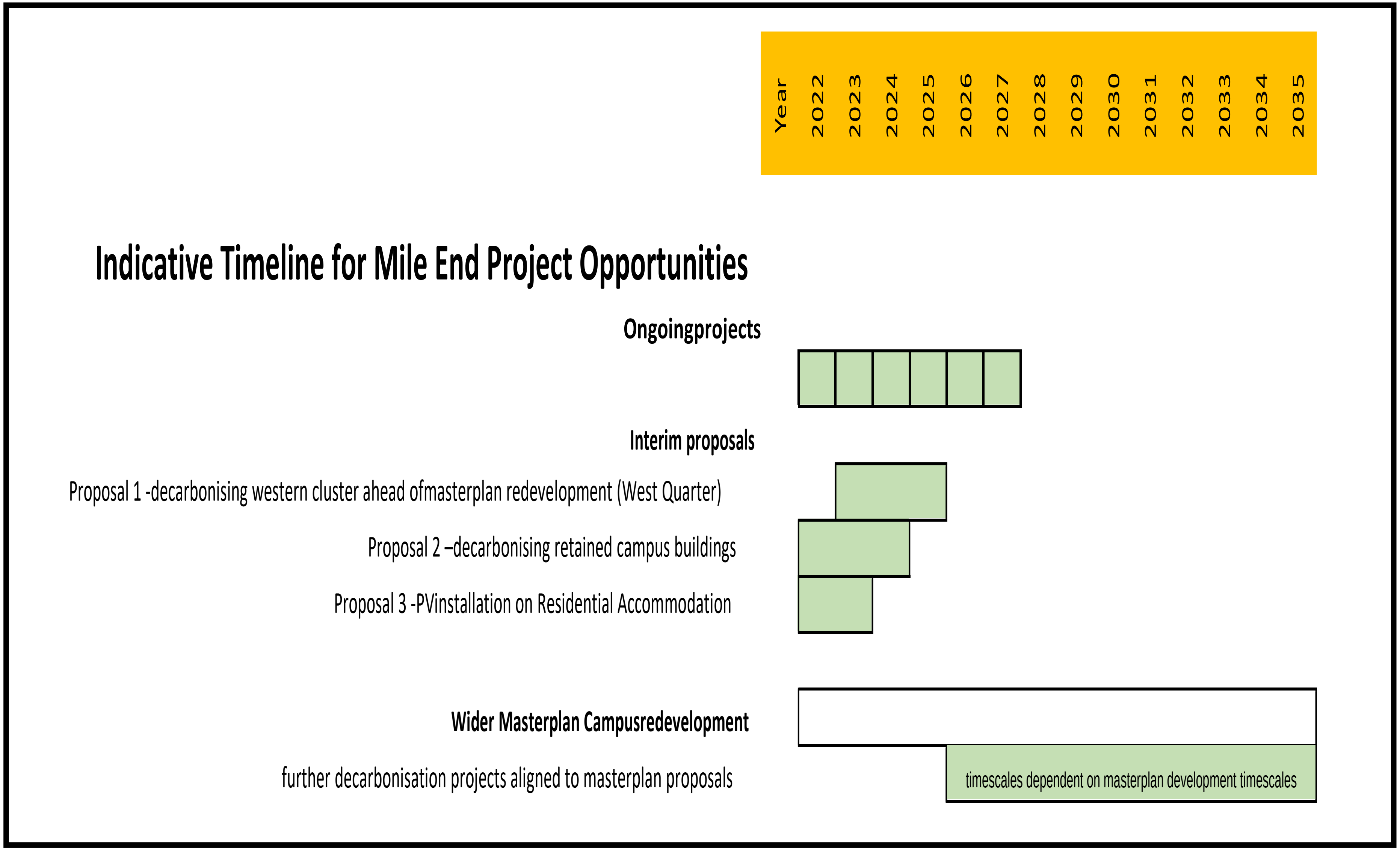


Figure 93: Indicative Timeline for Mile End Campus Project Opportunities

9. Key Challenges

9.1 Building level

The key challenges associated with implementing the building level decarbonisation proposals include:

- Sequencing of the Works across the various campuses within the required implementation timescales and under a limited number of framework contracts
- Coordination of the Works with campus activities
- Various timescale, cost uncertainty delivery and implementation risks including:
  - Project management and contract administration of Construction Contract(s), given the extent of the project opportunities identified
  - Obtaining planning permission, where relevant
  - CDM Health and Safety
  - Contractor's supply chain affecting delivery programme
  - Terms of funding grants

9.2 Campus Level

9.2.1 Mile End Campus

The key challenges associated with implementing the campus level decarbonisation proposals are:

- Risks identified as per building level projects
- Aligning and coordinating the strategic proposals to the campus development masterplan
- Obtaining permits and approvals for heat recovery from selected sources (London Aquifer, Canal);
- Negotiating commercial agreements with potential project partners (e.g., TfL, Thames Water for sewer heat recovery). Protecting Queen Mary's commercial position in relation to energy price escalation and energy supply resilience, including over the longer term
- There is limited space on site to integrate an on-site heat pump-based project. Although space for a heat pump has provisionally been identified physical integration (spatial, structural, electrical upgrading requirements etc) have yet to be formally assessed and there may be significant technical challenges to overcome
- There may be a case for repurposing the existing CHP under the proposals. Repurposing of the existing network will be required to increase its capacity and new network infrastructure will also be required
- Large scale thermal storage should ideally be integrated into the concept in order to provide a flexible, cost -efficient solution over the operating life of the scheme. No space has currently been identified for locating thermal stores on site. This will need to be accommodated at the next stage. There may be an opportunity to integrate phase change material thermal storage. This should be investigated along-side conventional wet thermal storage
- There may be an opportunity for borehole heat recovery and a campus wide aquifer thermal energy storage system. Implementation of such a scheme will add to development cost and timescales

but may ultimately deliver a robust and significantly more cost-efficient outcome. Assessing the strategic value of this opportunity will require additional project planning at an early stage, together with consideration of and coordination with the emerging campus masterplan

- Obtaining planning permission for energy system proposals
- Developing strategic concept to the point that interim project opportunities can be tendered without risk of compromising strategic vision
- Identifying project partners capable of delivering measures with sufficient technical safeguarding for strategic vision
- Implementing building heating and cooling system retrofit measures within required timescales
- Delivering an efficient solution until such time as the energy efficiency of the existing building stock has been improved
- Financing and obtaining internal business case approval for project opportunities which may deliver strategic value over the longer term, but which present additional risk to Queen Mary in the shorter term is likely to require significant up-front investment and coordinated internal resourcing
- Space availability for wastewater heat recovery infrastructure, and although the area around the Clock Tower would be a potential location, it would involve disruption during construction. The sewer runs along Mile End Road, which is a busy road, and this would be a factor regarding costs, timescales, and complexity. There is limited data on the manhole invert and cover levels, and therefore the sewer depth is difficult to determine. In addition, as the London Underground runs under the campus, the costs of gaining permission to excavate might be a crucial factor
- Public and private roads separating the buildings might hinder infrastructure projects to provide interconnectivity

9.2.2 Charterhouse Square Campus

The key challenges associated with implementing the campus level decarbonisation proposals at Charterhouse Square are:

- Risks identified as per building level projects
- Negotiating commercial agreements with potential project partners (e.g., Citigen, Volta, Bunhill). Protecting Queen Mary's commercial position in relation to energy price escalation and energy supply resilience, including over the longer term
- There is limited space on site to integrate an on-site heat pump-based project. This applies to the on-site solution opportunity as well as the Volta opportunity, where a heat pump on site will also be required, although space for a heat pump has provisionally been identified physical integration (spatial, structural, electrical upgrading requirements etc) have yet to be formally assessed and there may be significant technical challenges to overcome
- There may be a case for repurposing the existing CHP under the proposals. Current proposals for integration of an absorption chiller are however counter-productive and should be reviewed in light of the identified opportunities

- Large scale thermal storage should ideally be integrated into the concept in order to provide a flexible, cost -efficient solution over the operating life of the scheme. No space has currently been identified for locating a thermal store on site. This will need to be addressed at the next stage.
- There may be an opportunity to integrate phase change material thermal storage. This should be investigated alongside conventional wet thermal storage
- There may be an opportunity for borehole heat recovery and a campus wide aquifer thermal energy storage system. Implementation of such a scheme will add to development cost and timescales but may ultimately deliver a robust and significantly more cost-efficient outcome, Assessing the strategic value of this opportunity will require additional project planning at an early stage
- The Charterhouse campus is leased by Queen Mary. The current 25 lease is due to run out in 2033. Although Queen Mary has an existing capital budget which can potentially be accessed to help with funding of the proposals, lease renewal is likely to be viewed as a prerequisite to any significant investment plan to transform the campus energy systems. Obtaining planning permission for energy system proposals. In particular noise emissions will be a challenge to address. This applies to the on-site solution opportunity as well as the volta opportunity, where a heat pump on site will also be required
- Delivering an efficient solution until such time as the energy efficiency of the existing building stock has been improved
- Financing and obtaining internal business case approval for project opportunities which may deliver strategic value over the longer term, but which present additional risk to Queen Mary in the shorter term is likely to require significant up-front investment and coordinated internal resourcing

9.2.3 Whitechapel Campus

The key challenges associated with implementing the campus level decarbonisation proposals at Whitechapel Campus are:

- Risks identified as per building level projects
- Negotiating commercial agreements with potential project partners (offsite energy centre option)
- Integrating proposals into planning permission for current site redevelopment, including opportunity to locate energy centre at Plot C
- Physical integration (utilities, existing development plans for plot C)
- Public roads separating the buildings might hinder infrastructure projects to provide interconnectivity

Appendices: Additional Drawings and Information

For costing exercises the following routes have been assumed for buried district heating networks:

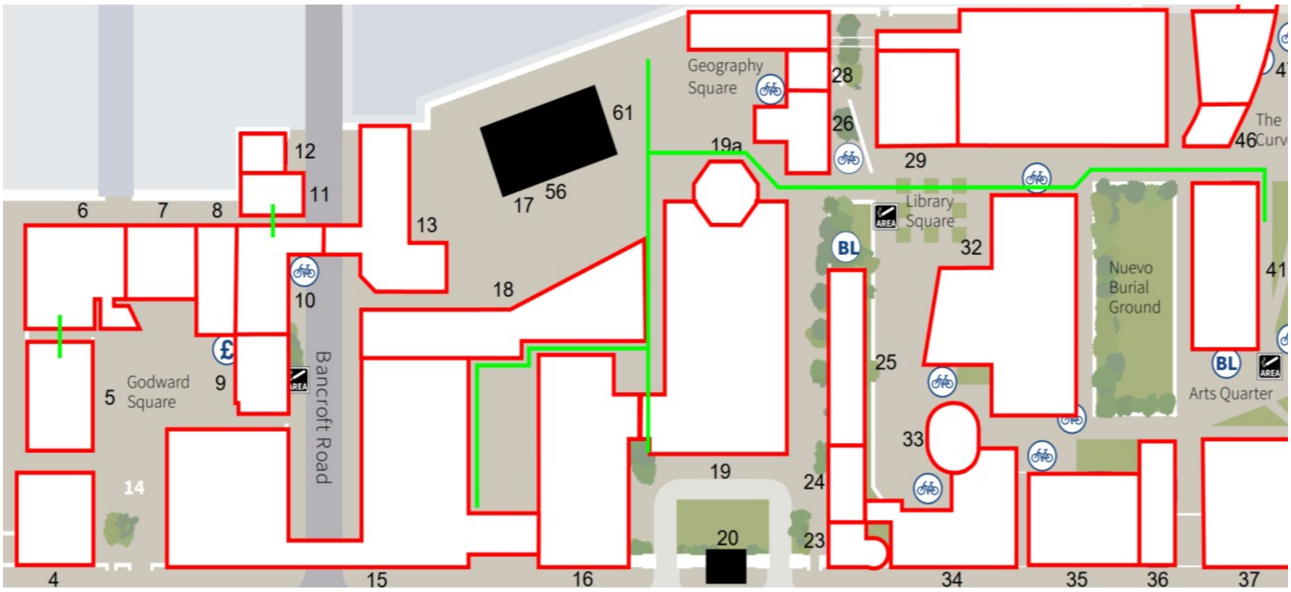


Figure 94: Assumed Mile End Clusters 1 & 2 Buried District Heating Pipework.

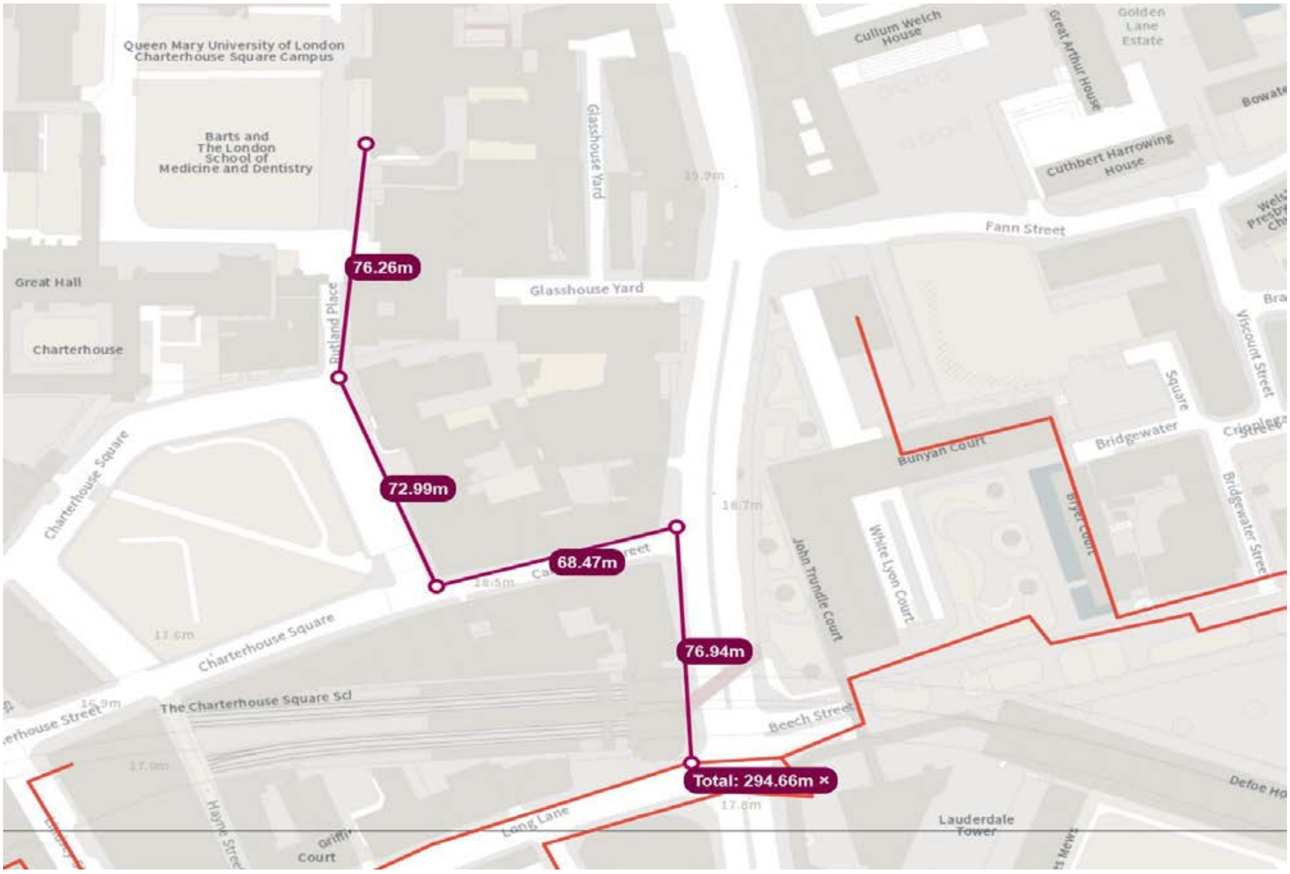


Figure 95: Assumed Charterhouse Square Buried District Heating Pipework.

Table 18: Building Level Decarbonisation Projects Summary

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving (tCO_{2e})	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
Mile End	Joseph Priestley Building	200 m^2 Solar PV (38.13 kWp)	4,178	38.13	£159,000	Electricity	35,600	£5,977	8.3	22.5	186.8	26.6	£851.41	Output from RETScreen for Voltacon Solar Eging 310 W panels. Cost based on benchmark derived from Queens' Building 12.24 kWp solar PV quotation circulated in Heat Decarbonisation Plan Workshop Action Log: 11 October 2022.	South facing, 20° slope, output offsets electricity only
Mile End	Joseph Priestley Building	Hybrid DHW (Electric Immersions)	9,853	4	£39,000	Gas	17,800	£757	3.6	22.5	81.6	51.6	£477.95	Cost based on replacing 4 calorifiers with new units sourced from Spon's Mechanical and Electrical Services Price Book 2022 p. 294 heading "Indirect cylinders; mild steel welded throughout, galvanized, with connections. Tested to 4bar, 95C. Includes sensors.	50% of PV energy generation being used to offset gas DHW generation. £2,500 added as nominal figure for strip out.

[7] Indicative capital costs have been rounded

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving (tCO_{2e})	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
														Includes delivery" Item "4021 litre nominal content".	
Mile End	People's Palace	Retrofit small ASHP on roof AHUs	2,513	50	£126,000	Gas	19,128	(£182)	3.7	20	73.3	-	£1,719.47	Price based on Spon's A&B Price Books. Fuel savings account for increased electrical usage at Queen Mary rates. Includes installation costs, excludes cranage.	1 x 50kW ASHP for a single AHU heater coil - RETScreen suggests 23,000 kWh per annum at 6000m3/hr, heating schedule 18hr per day, 21C supply. Assume SCoP of heat pump is 2.9.
Mile End	Engineering Building	Glazing and wall panel upgrade on West Wing	1,006	1,017	£1,020,000	Gas	109,100	£4,637	22.2	28	622.4	220.0	£1,638.86	Cost based on benchmark derived from "Secondary Glazing" sheet contained in Excel workbook "Windows replacement costs.xlsx" attached to an email sent from Queen Mary's Sustainability Team to Anthony Riddle dated 14 February 2022 14:37.	Actual window areas - whole of south façade otherwise west block only. Existing window single glazed metal with secondary glazing U=2.9. Calcs from Retscreen.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
Mile End	Queens' Building	Glazing upgrade	1,006	737	£741,000	Gas	178,500	£7,586	36.4	28	1,018.3	97.7	£727.69	Cost based on benchmark derived from "Secondary Glazing" sheet contained in Excel workbook "Windows replacement costs.xlsx" attached to an email sent from Queen Mary's Sustainability Team to Anthony Riddle dated 14 February 2022 14:37.	
Mile End	Queens' Building	VSD Pump upgrades	3,600	5	£18,000	Electricity	31,550	£5,297	7.4	10.26	75.5	3.4	£238.51	Price based on Spon's A&B Price Books. Cost excludes pipework modification, VSD pump integrated control.	5 pump sets rated at 1.5kW motor size, 75% load factor, 85% eff pump. Upgraded to VSD, 18 hr per day operation.
Mile End	Albert Stern House	Glazing upgrade	1,006	72	£72,000	Gas	13,500	£574	2.8	28	77.0	125.5	£934.90	Cost based on benchmark derived from "Secondary Glazing" sheet contained in Excel workbook "Windows replacement costs.xlsx" attached to an email sent from Queen Mary's	Approximate glazed area only (due to multiple window sizes) - Timber frame, single glazed large frame area.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving	Lifespan (years)	Lifetime Carbon Abated	Simple Payback	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
														Sustainability Team to Anthony Riddle dated 14 February 2022 14:37.	
Mile End	Albert Stern House	Replacement radiators and pipework	75	1,035	£78,000	Gas	94,237	£4,005	19.2	15.2	291.8	19.5	£267.27	Savings based on applying a rule of thumb stating that a 10°C reduction in flow & return temperatures results in a 10% reduction of system energy usage. Cost based on a floor area benchmark under heading "Elemental Rates for Alternative Engineering Services Solutions – Hotels" line items "5.6 Space Heating and Air Conditioning LPHW Heating Installation; ASHP" located in Spon's Mechanical and Electrical Services Price Book 2022 p. 128.	Reduction of LTHW system temperatures from 82/71 F/R to 65/45 F/R.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving	Lifespan (years)	Lifetime Carbon Abated	Simple Payback	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
Mile End	G. O. Jones Building (Physics)	Glazing upgrade	1,006	1,300	£1,310,000	Gas	344,100	£14,624	70.1	28	1,963.0	89.6	£667.35	Cost based on benchmark derived from "Secondary Glazing" sheet contained in Excel workbook "Windows replacement costs.xlsx" attached to an email sent from Queen Mary's Sustainability Team to Anthony Riddle dated 14 February 2022 14:37.	Equal window area in east and west walls. 21 internal 12hr occupancy M-F, External from RETScreen, improvement in U-value and air tightness, 85% boiler eff.
Mile End	G. O. Jones Building (Physics)	Local ASHP on ground floor AHU	2,513	30	£75,000	Gas	22,656	(£215)	4.6	20	92.3	0.0	£812.40	Price based on Spon's A&B Price Books. No sub-meter data exists to accurately assess carbon savings for this heat source, but in principle converting a boiler to an ASHP at this capacity will reduce carbon emissions.	Conversion of 30kW boiler to ASHP with SCoP 2.9.
Mile End	Ivor Evans Place	120 m^2 Solar PV (22.94 kWp)	4,178	22.94	£96,000	Electricity	20,600	£3,459	4.8	22.5	108.1	27.8	£888.39	Output from RETScreen for Voltacon Solar Eging 310W panels. Cost based on benchmark derived from	South facing, 20° slope, output offsets electricity only.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving (tCO_{2e})	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
														Queens' Building 12.24 kWp solar PV quotation circulated in Heat Decarbonisation Plan Workshop Action Log: 11 October 2022.	
Mile End	Francis Bancroft Building	540 m^2 Solar PV (102.61 kWp)	4,178	102.61	£429,000	Electricity	95,560	£16,045	22.3	22.5	501.3	26.7	£855.82	Output from RETScreen for Voltacon Solar Eging 310 W panels. Cost based on benchmark derived from Queens' Building 12.24 kWp solar PV quotation circulated in Heat Decarbonisation Plan Workshop Action Log: 11 October 2022.	South facing, 20° slope, output offsets electricity only.
Mile End	Francis Bancroft Building	Hybrid DHW (Electric Immersions)	9,853	3	£30,000	Gas	47,780	£2,031	9.7	22.5	219.0	14.8	£136.97	Cost based on replacing 3 calorifiers with new units sourced from Spon's Mechanical and Electrical Services Price Book 2022 p. 294 heading "Indirect cylinders; mild steel welded throughout,	50% of PV energy generation being used to offset gas DHW generation. £2,500 added as nominal figure for strip out.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving (tCO_{2e})	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
														galvanized, with connections. Tested to 4bar, 95C. Includes sensors. Includes delivery" Item "4021 litre nominal content".	
Mile End	Peter Landin	North Façade Glazing + Curtain wall replacement	1,050	1,200	£1,260,000	Gas	284,800	£12,104	58.0	28	1,624.7	104.1	£775.53	Costs from Spon's (A&B price book).	Assumes curtain walling and windows will be done as one piece of work. Includes fire stopping. Wall average U-Values.
Mile End	Informatics Teaching Labs	100 kW ASHP	2,513	100	£251,000	Gas	43,245	(£411)	8.0	22.5	180.8	0.0	£1,388.29	Price based on Spon's A&B Price Books.	Replace existing boilers with 100 kW HT ASHP, assume sufficient electricity supply, no other upgrades, SCoP = 2.9, existing gas = 52,000 kWh.
Whitechapel	Blizard Building	400 m^2 Solar PV (75.95 kWp)	4,178	75.95	£317,000	Electricity	71,200	£11,954	16.6	28	464.8	26.5	£682.03	Output from RETScreen for Voltacon Solar Eging 310 W panels. Cost based on benchmark derived from Queens'	South facing, 20° slope, output offsets electricity only.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
														Building 12.24 kWp solar PV quotation circulated in Heat Decarbonisation Plan Workshop Action Log: 11 October 2022.	
Whitechapel	The Wingate Institute	Glazing upgrade	1,006	80	£80,000	Gas	29,500	£1,254	6.0	22.5	135.2	63.8	£591.57	Cost based on benchmark derived from "Secondary Glazing" sheet contained in Excel workbook "Windows replacement costs.xlsx" attached to an email sent from Queen Mary's Sustainability Team sent to Anthony Riddle dated 14 February 2022 14:37.	West façade only. Excludes scaffolding. Based on Aluminium framed, double glazed secondary glazing.
Whitechapel	Innovation Centre	300 m^2 Solar PV (57.04 kWp)	4,178	57.04	£238,000	Electricity	53,400	£8,966	12.4	28	348.6	26.6	£682.75	Output from RETScreen for Voltacon Solar Eging 310 W panels. Cost based on benchmark derived from Queens' Building 12.24 kWp solar PV quotation circulated in Heat Decarbonisation	South facing, 20° slope, output offsets electricity only.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving (tCO_{2e})	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
														Plan Workshop Action Log: 11 October 2022.	
Whitechapel	Garrod Building	VSD Pump upgrades	3,600	4	£14,000	Electricity	17,250	£2,896	4.0	10.26	41.3	4.8	£339.29	Price based on Spon's A&B Price Books.	4 pump sets, 1.5 kW motors, improve to VSD, change motors to EFF1. Assume 18 hours per day operation, 365 days, includes installation, assume no pipework mods required.
Whitechapel	Garrod Building	Glazing upgrade	1,006	495	£498,000	Gas	273,000	£11,603	55.6	28	1,557.4	42.9	£319.77	Cost based on benchmark derived from "Secondary Glazing" sheet contained in Excel workbook "Windows replacement costs.xlsx" attached to an email sent from Queen Mary's Sustainability Team to Anthony Riddle dated 14 February 2022 14:37.	Equal window area in each wall. 24°C internal (from survey), 24hr occupancy. External from RETScreen, improvement in U-value and air tightness, 85% boiler eff. Excludes scaffolding, Based on aluminium framed, double glazed secondary glazing.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving (tCO_{2e})	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
Whitechapel	Garrod Building	DHW Decentralisation	838	8	£7,000	Gas	38,103	£1,619	7.8	18	139.7	4.3	£50.09	Cost based on installing a nominal 10 local point of use units priced for the mean of section "Unvented multipoint water heater; providing hot water for one or more outlets; used with conventional taps or mixers; factory fitted temperature and pressure relief valve; externally adjustable thermostat; elemental 'on' indicator; fitted with 1 m of 3 core cable; electrical supply and connection excluded" located in Spon's Mechanical and Electrical Services Price Book 2022 p. 294.	Move DHW from centralised gas to Electric PoU. DHW load taken from annual gas meter consumption data, assumption for Space Heating/DHW split using reference existing office building as approximation (Energy Performance of Buildings Directive: Second Cost Optimal Assessment for the United Kingdom (excluding Gibraltar); Ministry of Housing, Communities and Local Government; Section 8, Table 8.5a p. 123). Minor pipe mods and electrical works included, 8 multipoint heaters. This

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
															strategy should be reviewed in the context of an energy network that may be installed in the future. Strip out costs of current system not included. Electrical supply and connection excluded, assumes no significant electrical upgrades required to local distribution board.
Whitechapel	Garrod Building	25 m^2 Solar PV (4.65 kWp)	4,178	4.65	£19,000	Electricity	4,600	£772	1.1	22.5	24.1	24.6	£787.40	Output from RETScreen for Voltacon Solar Eging 310 W panels. Cost based on benchmark derived from Queens' Building 12.24 kWp solar PV quotation circulated in Heat Decarbonisation Plan Workshop Action Log: 11 October 2022.	South facing, 20° slope, output offsets electricity only.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving (tCO_{2e})	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
Whitechapel	Floyer House	Glazing upgrade (all windows)	1,006	339	£341,000	Gas	183,000	£7,778	37.3	28	1,044.0	43.8	£326.64	Cost based on benchmark derived from "Secondary Glazing" sheet contained in Excel workbook "Windows replacement costs.xlsx" attached to an email sent from Queen Mary's Sustainability Team to Anthony Riddle dated 14 February 2022 14:37.	Equal window area in each wall. 21°C internal, 24hr occupancy, external from RETScreen, improvement in U-value and air tightness, 85% boiler eff. Excludes scaffolding, Based on aluminium framed, double glazed secondary glazing.
Whitechapel	Floyer House	Upgrade of in-fill panels	350	100	£35,000	Gas	20,000	£850	4.1	30	122.2	41.2	£286.31	Cost (Spon's A&B Pricebooks) is based if done as part of window upgrades. Existing wall is uninsulated. New wall meets current regs.	Equal wall areas. 21°C internal, 24hr occupancy, external from RETScreen, improvement in U-value and air tightness, 85% boiler eff.
Whitechapel	Floyer House	140 m^2 Solar PV (27 kWp)	4,178	26.66	£111,000	Electricity	25,300	£4,248	5.9	22.5	132.7	26.1	£836.38	Output from RETScreen for Voltacon Solar Eging 310 W panels. Cost based on benchmark derived from Queens' Building 12.24 kWp solar PV quotation	South facing, 20° slope, output offsets electricity only.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving (tCO_{2e})	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
														circulated in Heat Decarbonisation Plan Workshop Action Log: 11 October 2022.	
Whitechapel	Floyer House	Hybrid DHW (Electric Immersions)	9,853	3	£30,000	Gas	12,650	£538	2.6	12	30.9	55.8	£970.00	Cost based on replacing 3 calorifiers with new units sourced from Spon's Mechanical and Electrical Services Price Book 2022 p. 294 heading "Indirect cylinders; mild steel welded throughout, galvanized, with connections. Tested to 4bar, 95C. Includes sensors. Includes delivery" Item "4021 litre nominal content".	50% of PV energy generation being used to offset gas DHW generation. £2,500 added as nominal figure for strip out.
Charterhouse Square	Dawson Hall	Glazing upgrade	1,006	963	£969,000	Gas	516,000	£21,930	105.1	28	2,943.6	44.2	£329.18	Cost based on benchmark derived from "Triple Glazing" sheet contained in Excel workbook "Windows replacement costs.xlsx" attached to an email sent from	Excludes scaffolding, Based on Aluminium framed, double glazed, RETScreen improvement.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving	Lifespan (years)	Lifetime Carbon Abated	Simple Payback	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
														Queen Mary's Sustainability Team to Anthony Riddle dated 14 February 2022 14:37.	
Charterhouse Square	Dawson Hall	Heat Metering	3,000	1	£3,000				0.0	7				Installation of ultrasonic heat meters + AMR system - inc portal costs per annum (Spon's A&B Price Books)	
Charterhouse Square	Wolfson Building	Heat Metering	3,000	1	£3,000				0.0	7				Installation of ultrasonic heat meters + AMR system - inc portal costs per annum (Spon's A&B Price Books)	
Chislehurst	West Pavilion	Replace Oil fired boilers with ASHP (350 kW)	2,513	350	£954,000	Oil	82,549	£48,704	18.3	20	366.8	19.6	£2,601.17	Price based on Spon's A&B Price Books. Excludes increased electricity consumption.	Replacement of oil with ASHP, SCoP assumed at 2.9, based on existing Oil consumption (100,400 kWh, annum @ 80% eff = heat demand of 80,330 kWh). This includes distribution modernisation for lower temperature operation.

Campus	Building	Description of Measure	Benchmark	Quantity	Indicative Capital Cost (£)[7]	Saving Fuel Type	Annual Saving (kWh)	Annual Cost Saving (£)	CO_{2e} Saving (tCO_{2e}/year)	Lifespan (years)	Lifetime Carbon Abated (tCO_{2e})	Simple Payback (years)	MAC [£/tCO_{2e}]	Savings Based On	Assumptions
Total					£9,323,000			£199,400				46.8[8]			

[8] Average payback

![Queen Mary University of London logo]
![SILVER Energy Management Solutions logo]

Table 19: Heat Loss Calculations

				Estimated Current U-Values (W/m2K)									Element Areas (m2)						Current Heat Loads (W)							
Campus	Name of Building	Total Approx Floor Space (m2)	Construction Date	Roof	Roof Lights	External Wall	Windows	Floor	Storeys	Storey Height (m)	Ceiling Height (m)	Glazed Area %	Roof	Roof Lights	External Wall	Windows	Floor	Volume (m3)	Roof	Roof Lights	External Wall	Windows	Floor	Thermal Bridges (%)	Air Infiltration	Current Heat Load (kW)
Mile End	Informatics Teaching Labs	1443	1989	0.45		0.69	4.75	0.17	3.0	3	2.6	18%	536		778	166	536	4181	6030	0	13421	19713	2278	20%	20060	83.75
Mile End	Geography Building	2812	1840	2.50		2.00	6.60	1.50	3.0	3	2.6	7%	1019		1867	145	1019	7946	63671	0	93330	23851	38203	4%	38127	319.13
Mile End	Laws Building	3025	1939	2.50	6.60	2.00	4.80	1.50	4.0	3	2.6	26%	770	25	1351	471	770	8008	48125	4125	67542	56506	28875	4%	38424	302.16
Mile End	Student Hub (Catering Building)	3146	1991	0.25		0.50	3.50	0.25	2.0	3	2.6	14%	1363		1649	268	1363	7085	8516	0	20618	23458	8516	4%	43269	128.19
Mile End	Computer Science Building	3382	1999	1.80		1.60	6.29	0.58	5.0	3	2.6	11%	1473		3435	427	1473	19149	66285	0	137400	67146	21359	4%	91880	474.91
Mile End	Mathematical Science Building	4003	1979	0.45		0.69	4.75	0.17	6.0	3	2.6	22%	475		2601	721	475	7404	5339	0	44875	85610	2017	4%	35525	214.66
Mile End	Arts Two Building	3503	2011	0.25		0.35	2.20	0.25	5.0	3	2.6	19%	942		2383	543	942	12246	5888	0	20851	29865	5888	4%	21367	103.63
Mile End	Student Union Building (Mile End) 5	3906	1979	0.25		0.50	3.50	0.25	2.0	3	2.6	14%	1362		1032	168	1362	7082	8513		12900	14700	8513	4%	43251	107.59
Mile End	People's Palace	4562	1937	2.50		2.00	4.80	1.50	4.0	3	2.6	4%	1843		2197	101	1163	12095	115188	0	109853	12080	43613	20%	58035	473.90
Mile End	G. E. Fogg Building	5454	1970	1.40	4.80	1.70	4.80	1.50	7.0	3	2.6	32%	1058	50	2734	1301	853	15525	37020	6000	116196	156137	31988	20%	74490	589.56
Mile End	Arts One Building	5492	1992	0.45	3.30	0.45	3.30	0.45	4.0	3	2.6	10%	1777	38	2643	287	1030	10715	19991	3135	29734	23678	11590	4%	51411	171.68
Mile End	G. O. Jones Building (Physics)	5580	1979	0.60		1.00	4.80	1.00	4.3	3	2.6	33%	1152		2624	1301	962	10839	17280	0	65591	156137	24050	4%	52005	390.70
Mile End	Joseph Priestley Building (New Chemistry)	5942	2003	0.16		0.35	2.00	0.25	4.0	3	2.6	21%	3187		2040	549	1647	17129	12748	0	17847	27432	10294	4%	44829	139.06
Mile End	Library (Mile End)	9203	1988	0.70		0.70	5.70	0.70	3.5	3	2.6	14%	3187		2636	413	3187	29002	55773	0	46134	58805	55773	4%	139155	437.16
Mile End	Queens' Building	13400	1890	2.50	4.80	2.00	4.80	1.50	4.6	3	2.6	16%	2592	107	5404	1001	3462	41180	162000	12840	270196	120158	129825	20%	197591	1237.94
Mile End	Francis Bancroft Building	14371	1990	0.70		0.70	5.70	0.70	3.5	3	2.6	20%	3189		3658	915	3189	29020	55808	0	64022	130331	55808	20%	139243	607.68
Mile End	Engineering Building	16015	1979	0.60		1.00	4.80	1.00	4.0	3	2.6	28%	2853		4922	1875	2853	29671	42795	0	123058	225000	71325	20%	142368	836.38
Mile End	Graduate Centre	6859	2016	0.25	2.20	0.35	2.20	0.25	7.5	3	2.6	12%	1127	13	3990	531	841	16400	7042	715	34913	29205	5256	4%	28614	130.60
Mile End	Arts Research Annexe	421	1840	0.12	1.20	0.15	1.00	0.10	3.0	3	2.6	6%	148		387	23	159	1239	443	0	1451	586	397	4%	5943	10.72
Mile End	Lock Keepers Cottage	236	1840	0.12	1.20	0.15	1.00	0.10	2.0	3	2.6	12%	167		270	38	167	867	500	0	1012	950	417	4%	5296	9.95
Mile End	The Nursery	423	2001	0.12	1.20	0.15	1.00	0.10	3.0	3	2.6	3%	155		1067	34	155	1207	464	0	4000	859	387	4%	5790	14.07
Mile End	Ifor Evans Place	2099	1996	0.12	1.20	0.15	1.00	0.10	4.0	3	2.6	9%	384		3461	351	228	2368	1153	0	12978	8768	569	4%	11362	42.92
Mile End	Lindop House	1406	1996	0.12	1.20	0.15	1.00	0.10	7.0	3	2.6	5%	330		2639	135	330	6003	990	0	9895	3370	825	4%	28804	53.38
Mile End	Hatton House Scheduled for demolition and redevelopment	1593	1990	0.10	1.20	0.15	1.00	0.10	3.0	3	2.6	20%	531	287	690	172	531	4141	1593	8620	2586	4310	1327	4%	19870	39.04
Mile End	Maynard House	2067	1992	0.12	1.20	0.15	1.00	0.10	6.0	3	2.6	40%	223		469	312	223	3475	668	0	1758	7804	557	4%	16675	33.47
Mile End	Varey House	2067	1992	0.12	1.20	0.15	1.00	0.10	6.0	3	2.6	40%	223		469	312	223	3475	668	0	1758	7804	557	4%	16675	33.47
Mile End	Stocks Court	3142	1992	0.12	1.20	0.15	1.00	0.10	3.5	3	2.6	24%	955		1381	433	955	8688	2864	0	5180	10822	2387	4%	41688	76.55
Mile End	Creed Court	2851	2005	0.12	1.20	0.15	1.00	0.10	4.0	3	2.6	17%	781		1643	347	781	8117	2342	0	6160	8670	1951	4%	14163	40.86
Mile End	Maurice Court	3835	2005						4.0	3	2.6	18%	1041		2153	460	1041	10822	4162	0	18839	25287	6504	4%	18882	91.04
Mile End	Beaumont Court	3887	2005						4.0	3	2.6	12%	1093		3487	487	1093	11363	4370	0	30514	26771	6829	4%	19826	109.26
Mile End	France House	4623	2005						6.0	3	2.6	15%	1823		2941	523	1823	28446	7294	0	25738	28783	11397	4%	49633	150.93
Mile End	Richard Feilden House	4857	2007	0.25		0.35	2.20	0.25	6.0	3	2.6	15%	1181		2430	418	1181	18430	7384	0	21265	22977	7384	4%	32156	112.23
Mile End	Pooley House	8333	2005						7.0	3	2.6	18%	1561		4943	1067	1561	28410	6244	0	43254	58704	9756	4%	49570	206.70
Mile End	Albert Stern House	1035	1913						3.5	3	2.6	9%	635		1685	166	685	6230	39666	0	84269	19922	25674	4%	29894	247.45
Mile End	Lynden House	526	2005						4.0	3	2.6	13%	136		470	71	136	1414	544	0	4113	3878	850	4%	2467	14.67
Mile End	404 Bancroft Road	142	1914						3.0	3	2.6	15%	54		161	28	54	423	3393	0	8065	3976	2036	4%	2031	24.24
Charterhouse Square	Old Anatomy Building (Rees)	1011	1894	2.50		2.00	4.80	1.50	5.0	3	2.6	12%	307		919	119	307	3991	19189	0	45935	14332	11514	20%	19151	153.98
Charterhouse Square	Joseph Rotblat Building	1496	1939	2.50	4.80	1.65	4.80	0.20	2.0	3	2.6	17%	500	32	326	68	532	2766	31250	3840	13439	8131	2660	20%	16894	105.69
Charterhouse Square	Wolfson Building	2042	1991	0.60		1.55	2.10	0.47	2.0	3	2.6	36%	920		732	416	920	4784	13800	0	28370	21834	10810	20%	29215	142.79
Charterhouse Square	William Harvey Heart Centre	3061	2000	0.25		0.35	2.00	0.12	3.0	3	2.6	38%	643		718	436	1312	10234	4019	0	6282	21807	3936	10%	46424	103.29
Charterhouse Square	John Vane Science Centre	11614	1996	0.25		0.45	3.30	0.45	7.0	3	2.6	22%	3482		5246	1498	1424	25917	21760	0	59020	123148	16020	10%	124353	439.55
Charterhouse Square	Lodge House	131	1874	2.50		2.00	4.80	1.50	3.0	3	2.6	4%	69		220	10	69	537	4306	0	11016	1234	2583	20%	2578	30.66
Charterhouse Square	Dawson Hall	8177	1979	0.60		1.56	5.80	0.24	9.0	3	2.6	19%	1592		4068	963	1592	37253	23880	0	158652	139635	9552	20%	227494	750.67
Whitechapel	Innovation Centre	6811	2009	0.30	2.20	0.35	2.20	0.25	4.0	3	2.6	80%	1703		634	2535	1703	17709	12773	0	5546	139441	10642	20%	30778	279.40
Whitechapel	Library (Whitechapel)	1468	1988	0.70	5.70	0.70	5.70	0.70	2.0	8.5	8.5	7%	1195		2249	165	1119	18942	20913	0	39350	23578	19580	20%	115676	287.74
Whitechapel	The Wingate Institute	1516	1999	0.25	3.30	0.45	3.30	0.45	3.0	3	2.6	15%	313		947	165	313	2438	1953	0	10654	13649	3516	20%	11697	56.91
Whitechapel	Yvonne Carter Building	1209	1999	0.25	3.30	0.45	3.30	0.45	3.0	3	2.6	15%	375		628	110	375	2925	2344	0	7065	9108	4219	20%	14035	49.58
Whitechapel	Whitechapel Students Union	1715	1979	0.60	5.70	1.00	5.70	1.00	4.0	3	2.6	20%	429	323	1034	258	429	4462	6430	46025	25839	36820	10716	20%	21390	172.39
Whitechapel	Abernethy Building	3068	1979	0.60	5.70	1.00	5.70	1.00	4.0	3	2.6	14%	890		1299	219	890	9251	13343	0	32472	31273	22238	20%	44389	196.30
Whitechapel	Garrod Building	5457	1979	0.60	5.70	1.00	5.70	1.00	4.0	3	2.6	18%	1164	276	2259	498	1440	14976	17464	39294	56477	71009	36000	20%	71858	403.38
Whitechapel	Blizard Building	8038	2005	0.16	2.20	0.35	2.20	0.25	4.0	3	2.6	100%	2992			3677	3572	37149	11967	0	0	202230	22325	20%	64817	418.37
Whitechapel	Floyer House	4681	1939	2.50	5.70	2.00	5.70	1.50	6.0	3	2.6	14%	1314	39	2022	339	1353	21107	82145	5515	101083	48343	50738	20%	101276	536.00
Whitechapel	64 Turner Street	181	1840	2.50	5.70	2.00	5.70	1.50	2.0	3	2.6	11%	58		127	14	48	249	3596	0	6347	1986	1799	20%	1523	21.60
Chislehurst	Athletics Ground (Chislehurst Sports Ground - Pavilion)	1539	1939	2.50	5.70	2.00	5.70	1.50	2.0	2	2.6	14%	342	8	450	71	342	1776	21349	1140	22510	10158	12809	20%	10847	110.89
Lincoln's Inn Fields	Lincoln's Inn Fields (Centre for Commercial Law)	2797	1939	2.50	5.70	2.00	5.70	1.50	6.8	3	2.6	20%	400		3046	762	400	7013	24976	0	152322	108529	14985	20%	33651	473.55
West Smithfield	Robin Brook Centre	3403	1840	2.50	5.70	2.00	5.70	1.50	5.0	3	2.6	20%	681		2975	595	681	8848	42538	0	148755	84790	25523	20%	42453	485.26

		Uplifted Heat Loads (W)							Total Heat Loads (kW)							
Campus	Name of Building	Roof	Roof Lights	External Wall	Windows	Floor	Thermal Bridges (%)	Air Infiltration	Uplifted Space Heating Load (kW)	Estimated Ventilation Heat Load (kW)	Uplifted Space + Estimated Ventilation Heat Load (kW)	DHW Fraction	Heating Fraction	Estimated DHW Load (kW)	Estimated Space Heating Load (kW)	Fabric Improvement (%)
Mile End	Informatics Teaching Labs	6030	0	13421	9130	2278	15%	20060	67	27	94	0.08	0.92	7.22	86.63	20%
Mile End	Geography Building	63671	0	93330	23851	38203	4%	38127	319	53	372	0.08	0.92	28.63	343.50	0%
Mile End	Laws Building	48125	4125	67542	56506	28875	4%	38424	302	57	359	0.08	0.92	27.63	331.54	0%
Mile End	Student Hub (Catering Building)	8516	0	20618	23458	8516	4%	43269	128	59	187	0.08	0.92	14.42	173.04	0%
Mile End	Computer Science Building	66285	0	21469	23485	21359	3%	25058	194	64	258	0.08	0.92	19.82	237.87	59%
Mile End	Mathematical Science Building	5339	0	44875	85610	2017	4%	35525	215	75	290	0.08	0.92	22.31	267.77	0%
Mile End	Arts Two Building	5888	0	20851	29865	5888	4%	21367	104	66	170	0.08	0.92	13.05	156.59	0%
Mile End	Student Union Building (Mile End)5	8513		12900	14700	8513	4%	43251	108	74	181	0.08	0.92	13.94	167.26	0%
Mile End	People's Palace	115188	0	109853	5537	43613	15%	58035	448	86	534	0.08	0.92	41.08	492.92	5%
Mile End	G. E. Fogg Building	37020	6000	116196	156137	31988	20%	74490	590	103	692	0.08	0.92	53.26	639.07	0%
Mile End	Arts One Building	19991	3135	29734	23678	11590	4%	51411	172	103	275	0.08	0.92	21.17	254.01	0%
Mile End	G. O. Jones Building (Physics)	17280	0	16398	71563	24050	3%	14183	177	105	282	0.08	0.92	21.69	260.28	55%
Mile End	Joseph Priestley Building (New Chemistry)	12748	0	17847	27432	10294	4%	44829	139	112	251	0.08	0.92	19.31	231.71	0%
Mile End	Library (Mile End)	55773	0	46134	58805	55773	4%	139155	437	173	611	0.08	0.92	46.97	563.62	0%
Mile End	Queens' Building	162000	12840	270196	55073	129825	15%	197591	1106	253	1359	0.08	0.92	104.53	1254.40	11%
Mile End	Francis Bancroft Building	55808	0	64022	130331	55808	20%	139243	608	271	878	0.08	0.92	67.58	810.91	0%
Mile End	Engineering Building	42795	0	30765	103125	71325	15%	38828	389	302	691	0.08	0.92	53.13	637.51	54%
Mile End	Graduate Centre	7042	715	34913	29205	5256	4%	28614	131	129	260	0.08	0.92	19.99	239.85	0%
Mile End	Arts Research Annexe	443	0	1451	586	397	4%	5943	11	8	19	0.08	0.92	1.44	17.22	0%
Mile End	Lock Keepers Cottage	500	0	1012	950	417	4%	5296	10	4	14	0.08	0.92	1.11	13.28	0%
Mile End	The Nursery	464	0	4000	859	387	4%	5790	14	8	22	0.08	0.92	1.70	20.35	0%
Mile End	Ifor Evans Place	1153	0	12978	8768	569	4%	11362	43	40	82	0.08	0.92	6.34	76.13	0%
Mile End	Lindop House	990	0	9895	3370	825	4%	28804	53	27	80	0.08	0.92	6.15	73.74	0%
Mile End	Hatton House Scheduled for demolition and redevelopment	1593	8620	2586	4310	1327	4%	19870				0.08	0.92	0.00	0.00	0%
Mile End	Maynard House	668	0	1758	7804	557	4%	16675	33	39	72	0.08	0.92	5.57	66.85	0%
Mile End	Varey House	668	0	1758	7804	557	4%	16675	33	39	72	0.08	0.92	5.57	66.85	0%
Mile End	Stocks Court	2864	0	5180	10822	2387	4%	41688	77	59	136	0.08	0.92	10.44	125.31	0%
Mile End	Creed Court	2342	0	6160	8670	1951	4%	14163	41	54	95	0.08	0.92	7.28	87.31	0%
Mile End	Maurice Court	4162	0	18839	25287	6504	4%	18882	91	72	163	0.08	0.92	12.56	150.74	0%
Mile End	Beaumont Court	4370	0	30514	26771	6829	4%	19826	109	73	182	0.08	0.92	14.04	168.46	0%
Mile End	France House	7294	0	25738	28783	11397	4%	49633	151	87	238	0.08	0.92	18.31	219.73	0%
Mile End	Richard Feilden House	7384	0	21265	22977	7384	4%	32156	112	92	204	0.08	0.92	15.67	188.08	0%
Mile End	Pooley House	6244	0	43254	58704	9756	4%	49570	207	157	364	0.08	0.92	27.98	335.74	0%
Mile End	Albert Stern House	39666	0	84269	9131	25674	3%	29894	232	19	252	0.08	0.92	19.35	232.22	6%
Mile End	Lynden House	544	0	4113	3878	850	4%	2467	15	10	25	0.08	0.92	1.89	22.69	0%
Mile End	404 Bancroft Road	3393	0	8065	3976	2036	4%	2031	24	3	27	0.08	0.92	2.07	24.85	0%
Charterhouse Square	Old Anatomy Building (Rees)	19189	0	45935	14332	11514	20%	19151	154	19	173	0.08	0.92	13.31	159.72	0%
Charterhouse Square	Joseph Rotblat Building	31250	3840	13439	8131	2660	20%	16894	106	28	134	0.08	0.92	10.30	123.59	0%
Charterhouse Square	Wolfson Building	13800	0	28370	21834	10810	20%	29215	143	38	181	0.08	0.92	13.94	167.33	0%
Charterhouse Square	William Harvey Heart Centre	4019	0	6282	21807	3936	10%	46424	103	58	161	0.08	0.92	12.38	148.58	0%
Charterhouse Square	John Vane Science Centre	21760	0	59020	123148	16020	10%	124353	440	219	658	0.08	0.92	50.65	607.76	0%
Charterhouse Square	Lodge House	4306	0	11016	1234	2583	20%	2578	31	2	33	0.08	0.92	2.55	30.57	0%
Charterhouse Square	Dawson Hall	23880	0	25425	52965	9552	15%	64998	232	154	386	0.08	0.92	29.72	356.68	69%
Whitechapel	Innovation Centre	12773	0	5546	139441	10644	20%	30778			870	0.08	0.92	66.92	803.08	0%
Whitechapel	Library (Whitechapel)	20913	0	39350	23578	19580	20%	115676	288	28	315	0.08	0.92	24.26	291.13	0%
Whitechapel	The Wingate Institute	1953	0	10654	13649	3516	20%	11697	57	29	85	0.08	0.92	6.58	78.90	0%
Whitechapel	Yvonne Carter Building	2344	0	7065	9108	4219	20%	14035	50	23	72	0.08	0.92	5.57	66.79	0%
Whitechapel	Whitechapel Students Union	6430	46025	25839	36820	10716	20%	21390			351	0.08	0.92	28.08	322.88	0%
Whitechapel	Abernethy Building	13343	0	32472	31273	22238	20%	44389	196	58	254	0.08	0.92	19.55	234.56	0%
Whitechapel	Garrod Building	17464	15166	56477	27407	36000	15%	71858	297	103	400	0.08	0.92	30.73	368.79	26%
Whitechapel	Blizard Building	11967	0	0	202230	22325	20%	64817	418	151	570	0.08	0.92	43.83	525.99	0%
Whitechapel	Floyer House	82145	5515	56859	67001	50738	15%	27621	395	88	483	0.08	0.92	37.17	446.09	26%
Whitechapel	64 Turner Street	3596	0	6347	1986	1799	20%	1523	22	3	25	0.08	0.92	1.92	23.08	0%
Chislehurst	Athletics Ground (Chislehurst Sports Ground- Pavilion)	21349	1140	22510	10158	12809	20%	10847	111	29	140	0.08	0.92	10.76	129.13	0%
Lincoln's Inn Fields	Lincoln's Inn Fields (Centre for Commercial Law)	24976	0	152322	108529	14985	20%	33651	474	53	526	0.08	0.92	40.48	485.78	0%
West Smithfield	Robin Brook Centre	42538	0	148755	84790	25523	20%	42453	485	64	549	0.08	0.92	42.26	507.12	0%

[5] See Student Hub. This building is an internal part of Student Hub.
[6] Scheduled for demolition and redevelopment.