Maiden Lane Estate – Heating Network

Low Carbon Heating Technology Feasibility Report

Issue 1

August 2020

MAX FORDHAM

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ISSUE HISTORY

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1.0 EXECUTIVE SUMMARY

Max Fordham have been commissioned by Camden Council to produce the Employer's Requirements for the heating network upgrade project at the Maiden Lane Estate in Camden, London. As part of these works Max Fordham are appraising various options for the central Low Temperature Hot Water (LTHW) plant and network configurations along with opportunities for low carbon technologies to provide a fully controllable and energy efficient heating network that supports Camden's plan in improving housing conditions.

The purpose of this report is to explore and describe the available low carbon heating technologies that are available to ultimately provide a lower carbon intensive source of heating to support the estates thermal demand. The feasibility pillars that have been considered when exploring the available technologies are; site integration and practicality, environmental and financial benefits, future proofing the heat source, site impacts and project risks.

The current position and direction on the energy sector indicates a shift from gas usage to electricity for the generation of heat and we have discovered that central electrical base load heat pumps best suit the existing residential estate. The proposals discussed in this report have been developed on a 750-1000kW thermal output large heat pump providing the annual base heating load of the whole estate, that includes the York Way development along with the existing old Maiden lane estate. Existing gas boilers will then provide the peak heating demand in a hybrid approach, which has been understood to best suit the existing infrastructure, available plant space and construction variety across the estate.

A desk top study approach has been used to investigate products on the market currently and within the next couple of years. Max Fordham have used their relationship with manufactures and specialists to collate performance and cost data for various technologies and complete systems.

The technologies that have been investigated are as follows:

- Bespoke air source heat pumps and dry air coolers (Type 1)
- 'Off the shelf' air source chiller heat pumps (Type 2)
- Closed loop ground source heat pump systems
- Open loop ground source heat pumps
- Waste water heat recovery heat pump system (Sharc)

A summary table of the findings is below (Table 1) and a brief description of the feasibility of each system has been discussed below.

The study has found that the Type 2 'off the shelf' air source heat pump systems are more cost effective in terms of capital expenditure when compared to a bespoke system, however the Seasonal Coefficient of Performance (SCoP) is less than 2.5. This ultimately effects the available carbon savings and price of heat production. Additionally, it is expected that future heat incentives will require a minimum SCoP of 2.8 in order to be eligible for tariff incentives or grants. This system configuration is not recommended for further consideration.

The open loop ground source heat pump system is restricted by the site layout in terms of abstraction and injection wells whereby there are limited orientation and configurations that would satisfy the minimum installation requirements to avoid ground temperature contamination and meet the demand. Test wells are required to be drilled in order to confirm the available yield and complete the well design. This essentially creates a high risk proposal that requires substantial up front works with no guarantee of meeting the desired output.

It has been discovered that due to the limited land area for the closed loop bore hole array, the site layout doesn't have available and practical space to accommodate a closed loop ground array. When operating ground source systems with large annual heat demands without the need for cooling, the ground depletes of temperature causing environmental issues.

From both above findings it isn't recommended that ground source heat pump systems are suitable to the estate.

A hydrocarbon bespoke heat pump with dry air coolers manufactured by Solid Energy provides excellent carbon savings and financial benefits in terms of heat production to the estate. Because of the nature of moving large amounts of air externally via external fans through heat exchangers, noise impacts to sensitive local receptors need to be assessed. The most suited location to position the external plant has been identified as the Community Centre roof which requires an existing structures survey to confirm the suitability along with a visual impact assessment. These further investigations are being carried out.

Comparably the waste water heat recovery heat pump system offers similar carbon savings and financial benefits to the cost of heat production. The system suits the layout of the estate with regards to plant space, waste water pipe work and location in terms of proximity to a sewer with source to meet the demand. Monitoring Heat recovery projects that rely on an external source of energy are not suited to every site in terms of proximity and transferring the energy along with commercial agreements. Thames Water have stated currently that an abstraction connection to the sewer would be considered under a standard connection agreement and are not currently motivated to seek commercial gain from the sale of heat. From the initial feasibility works it has been recognised that the suitability and benefits to the site should be considered further.

The conclusions of this initial feasibility study that the further investigation are being carried out to determine the suitability of the hydrocarbon bespoke air source heat pump which will then be compared against the waste water heat recovery system findings. A final report shall be issued to make a recommendation on the final technology and proposal with additional consideration to the following;

- Base load heat pump sizing model
- Development of a technical proposal
- Heat pump site integration proposal
- Cost of heat analysis
- Photovoltaic study findings
- Exposed floor insulation study findings
- Setting out key performance indicators

Manufacture		Heat Pump Technology	Capital Costs (£ million)	Maintenance Costs (£/yr)	SCoP	Carbon Savings (% reduction in CO2e/yr)	Price of Heat (p/kWh)	Future Proof	Project Risks
A	GEA	Air Source - Type 1	1.89	25,000	3.01	43%	6.51	✓✓✓	Noise, structural, visual
B	Solid Energy	Air Source - Type 1	1.77	9,360	3.38	46%	5.75	✓✓✓	Noise, structural, visual
C	Daikin	Air Source - Type 2	1.41	10,960	2.25	33%	7.81	✓✓	Noise, structural, visual
D	Mitsubishi	Air Source - Type 2	1.28	-	2.25	36%	7.46	✓✓	Noise, structural, visual
E	Gcore	Ground Source - Open	1.63	10,220	2.45	36%	7.3	✓✓	Achieving yields
E	Gcore	Ground Source - Closed	2.96	10,220	2.45	36%	7.3	✓✓	Space constraints
F	Sharc	Sewer heat recovery	1.63	18,875	3.31	45%	5.99	✓✓✓	Commercial agreement

Table 1 – Summary Table of the Feasibility Findings for Various Low Carbon Heating Technologies

2.0 INTRODUCTION

2.1 Project Background

Max Fordham have been commissioned by Camden Council to produce the Employer's Requirements for the heating network upgrade project at the Maiden Lane Estate in Camden, London. As part of these works Max Fordham are appraising various options for the central Low Temperature Hot Water (LTHW) plant and network configurations along with opportunities for low carbon technologies to provide a fully controllable and energy efficient heating network that supports Camden's plan in improving housing conditions.

The Maiden Lane Estate was constructed in three phases:

1. Maiden Lane West – Phase 1 1970s residential development
2. Maiden Lane East – Phase 2 of the 1970/80s residential development
3. York Way – later residential development with small commercial space constructed in 2015

Currently an existing LTHW heating network supplied by gas fired boilers serves both phase 1 and 2 of the 1970/80s Maiden Lane development. This network is due for an upgrade which will include new distribution pipe work, dwelling heat exchanger interfaces, dwelling heating controls and emitters along with the central plant. The thermal demand of the York Way development is supported by a new energy centre with gas fired boilers and a Combined Heat and Power machine (CHP) with a new separate heating network.

There is the opportunity to increase the capacity and extend the York Way heating network to serve both the Maiden Lane and York Way heating demands. However, there are some upfront works that are required in the York Way energy centre and distribution network to ensure that the heating network is operating to sufficient standards in order to be able to make this extension to efficiently support Maiden Lane.

The purpose of this report is to explore and describe the available low carbon heating technologies that are available to provide environmental and economic benefit to the central heating plant that would either serve only the Maiden Lane thermal demand or the demand of a combined network extended from York Way. The proposals based in this report have been developed on a 750kW thermal output heat pump providing the annual base heating load of the estate, including York Way. The thermal demand figures within the report are provisional and shall be confirmed within the final report.

The feasibility findings of this report shall make the basis for a further in-depth study of the most suitable technology to be incorporated into the estate, with a final report.

2.2 Technology Assessment Method

The criteria of the feasibility assessment for the available and suitable low carbon heating technologies has been developed from the Camden Council brief and knowledge from Max Fordham's industry experience.

Future proof
The low carbon heating plant and whole installation has a requirement to last for the next 20 years of operation to serve the estate. This means that components need to be economically replaceable with in maintenance agreements and in particular refrigerant gases (related to heat pump technologies) need to have minimal environmental impact to avoid future phase outs, which result in costly maintenance replacements.

The energy sector has been turbulent over the past years with a lot of emphasis on the decarbonisation of heat and so the heating fuel of the low carbon technologies needs to suit the direction of the sector.

Economic impacts
Capital costs (CAPEX) can be seen to be relatively high for low carbon heating technologies when compared to traditional gas boiler base cases due to a lower supply and demand. Certain configurations of low carbon heating technologies have been investigated to give an overview of the range of CAPEX that is seen across the technologies. Again, these technologies require quite complex control operation and bespoke components that can see an increase in ongoing maintenance costs.

Although environmental savings are important to control and reduce any impact to the climate, it is socially responsible that the most suitable technology provides a life cycle cost that doesn't inflate the cost of the production of heat to the end user and well planned operation of the technology and network.

The high level cost of heat production has been determined for the overall comparison of the low carbon heating technologies within this report. The costs have been based on direct fuel usage and the low carbon plant maintenance costs. Circulation pumping costs have not been directly included but allowed for in a margin. Costs shown are indicative as manufacture's COPs are calculated rather than measured and the price of energy fluctuates with time. The cost of heat analysis shall be determined in more detail within the final report that concludes on a developed proposal.

Operating efficiency and conditions
The eligibility of Government incentives and support of the production of low carbon heat is assessed through a seasonal efficiency target and it is therefore important for technologies to be selected to the required application at the qualifying efficiency.

Additionally, the operational efficiency will have a direct link to the fuel consumption and therefore the cost of heat produced.

The technologies need to be able to efficiently supply heat to the estates heating network at sufficient temperatures to allow for dwelling space heating and instantaneous hot water production. Further investigation will confirm the chosen network operating conditions, but at this stage Max Fordham envisage the network to operate in line with industry practice at 70/40ºC flow and return temperatures. This allows for the various construction types of buildings across the estate that have been built across the last 50 years, older with higher space heating losses than the more recent. Therefore. technologies have been considered that can operate at a flow and return temperature directly of 70/40ºC.

Environmental impact
The Camden Plan identifies that Camden's short term and ongoing goals are to provide a sustainable and clean environment to live and be in. By reducing operational carbon emissions from residential estates like Maiden Lane the local air quality improves along with the Borough's emissions.

Deploying low carbon heating technologies across Camden coupled with district heating networks has the potential to drastically reduce the Boroughs carbon emissions and so the selection of a potential technology needs to maximise environment savings. There is the opportunity for Camden to become a leader in the deployment of effective heat networks achieving large environmental savings.

Implications of installation to the estate
To achieve higher operating efficiencies and lower carbon emissions than gas fired boilers, low carbon heating technologies typically require large heat exchangers or components for the transfer/upgrade of thermal energy. With this comes visual aesthetic issues, an increase of plant noise and large structural loadings.

The assessment of available technologies includes mitigation methods to overcome the implications, and particularly where Maiden Lane is existing the disturbance to residents from installation must be minimised.

2.3 The UK Heat Sector

The greenhouse gas emissions from heat accounts for over a third of the UK's emissions. For the UK to meet the climate change targets, the heat to nearly all buildings and industry requires to be decarbonised. Recently the national electricity grid has seen a large uptake on renewable energy generation which has cleaned up the electricity supply to a lower carbon intensity than natural gas. As a result, it is apparent that the heat sector will see a transition from the use of traditional fossil fuel as a heating source to low carbon electricity.

The UK has recognised suitable low carbon heating sources that will contribute to the decarbonisation of the sector as, electrically driven heat pumps that can have efficiencies of 300% and decarbonised gas (hydrogen or bioenergy) suppling specific boiler systems. Heat networks will play a part in this transition to low carbon heat by connecting multiple buildings in dense areas to a central source where low carbon technologies become more financially viable [1].

Max Fordham understand that projects should be assessed on a project by project basis to determine the viability of low carbon heating technologies and heat network characterises. At the Maiden Lane estate there is the opportunity to extend the York Way energy centre which has gas fired boilers and a gas fired CHP, which offers reliability to the network. The CHP has the potential to supply electricity to a heat pump with the opportunity to further reduce network carbon emissions the costs of heat. This configuration would be classed as a 'hybrid' system and offers a degree of flexibility and reliability through a time of transition within the energy sector.

Currently the UK Government operates the Renewable Heat Incentive (RHI) to encourage the uptake of these low carbon heating technologies, that typically are more expensive to install when compared to traditional methods. The non-domestic RHI scheme finishes in 2021, which means the Maiden Lane installation would have to be installed and commissioned by 31st March 2021. The are other schemes that are currently being brought into consultation but no direct replacement for a non-domestic tariff has been suggested yet. The feasibility process in this study considers design parameters for eligibility with a future scheme. The RHI tariff figures, carbon fuel factors and energy prices used in this study are identified in Chapter 9.

The Heat Network Investment Program (HNIP) has been set up by the Committee on Climate Change which offers grants and loans supporting the uptake of good quality heating networks. A pre-application can be submitted for the scheme and discussion will be had with Camden regarding this. It appears to be aimed at larger networks serving multiple developments.

2.4 Heat Pump Technologies

Background
From the direction of the UK and global heat sector it becomes apparent to see that large scale electrically driven heat pumps can be seen as an appropriate low carbon technology to support heating networks that supply residential developments. They have been considered as the most appropriate technology for Maiden Lane and have been pursued in this study.

Heat pumps work by absorbing heat from an external medium and increasing the temperature to produce usable heat through the operation of a vapour compression cycle.

In the case of an air source heat pump, the process uses electrical energy into usable thermal energy which is distributed via the hot water produced within the process. The four stages of a typical air source heat pump cycle are shown in figure 1.

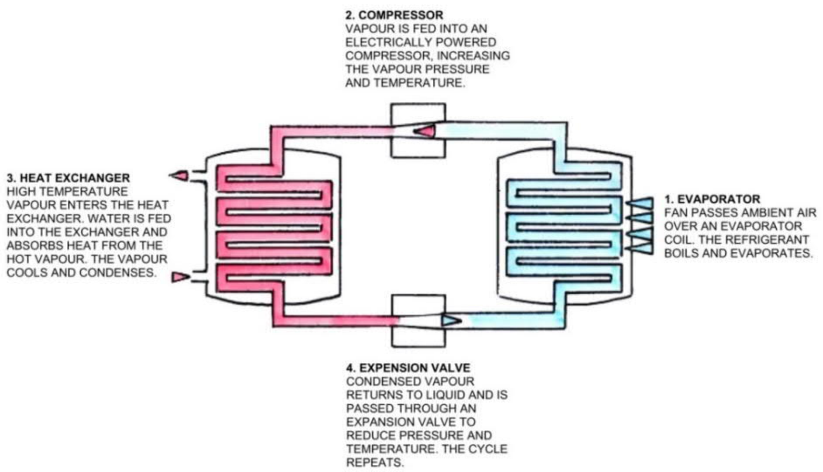

Figure 1 – Vapour compression cycle for an air source heat pump.

The source of heat can be supplied from many different sources including from the air, ground, from a water source, as waste heat from nearby processes and industry and from waste water and sewage to name but a few. Each technology works in a similar way to produce hot water through the vapour compression cycle irrespective of the heat source; however the added complexity and infrastructure/plant equipment requirements associated with each source does vary.

Refrigerants
Regardless of the heat source, all heat pumps rely on a refrigerant vapour compression cycle in order to raise the outgoing water temperature. The refrigerant used is dependent on the available heat source and the required output water temperature. If used within the heat pump, some refrigerants may require additional design consideration and complexity. A summary for three common refrigerants used within air source heat pump systems is given below in Table 2. All refrigerant heat pumps systems must be designed, installed and operated in accordance with BS EN 378:2016.

Refrigerant	Source / Output Medium	Max Output Temperature	Notes
R32	Air / Water	45°C	- Lower flammability - Lower toxicity - Safety classification A2L
R513A	Air / Water	70°C (maximum)	- Non-flammable - Lower toxicity - Safety classification A1
R134a	Water / Water	70°C (maximum)	- Non-flammable - Lower toxicity - Safety classification A1
R-1234ze (HFO)	Water / Water	> 70°C	- Lower flammability - Lower toxicity - Safety Classification A2L - Ensure work area is well ventilated and free of sources of ignition - Leak detection required
R717 (Ammonia)	Water / Water	> 70°C	- Lower flammability - Higher toxicity - Safety classification B2L - Ensure work area is well ventilated and free of sources of ignition - Leak detection required
R290 (Propane)	Water / Water	60°C	- Higher flammability - Lower toxicity - Safety classification A3 - Ensure work area is well ventilated and free of sources of ignition - Leak detection required
R600a (Isobutane)	Water / Water	> 70°C	- Higher flammability - Lower toxicity - Safety classification A3

Table 2 – Available refrigerants

Heat Pump Technologies
Type 1 - A two stage integrated natural or hydrocarbon refrigerant unit is capable of generating LTHW to 80°C directly from an air source. Within the unit, an initial stage air/ water refrigeration cycle is used to supply hot refrigerant to a second stage refrigeration cycle which uses ammonia or isobutane as the refrigerant. The benefit of this system is that all parts of the overall heat pump system are contained within a single unit footprint which can be located within a roof plant enclosure or plant room. Figure 2 shows a simple process diagram showing the inputs and outputs from the ammonia heat pump system.

The operating efficiency of a heat pump system is determined by its coefficient of performance (CoP), this is the ratio of the thermal energy out over the electricity energy put in. A high CoP value indicates that the heat pump is more efficient; thereby reducing the electricity input required delivering a specific quantity of heat and, by association, a reduced fuel cost. The CoP of the heat pump system is also dependent on the operating conditions of the equipment; a higher external air temperature and a lower output LTHW temperature will both result in higher CoP performance.

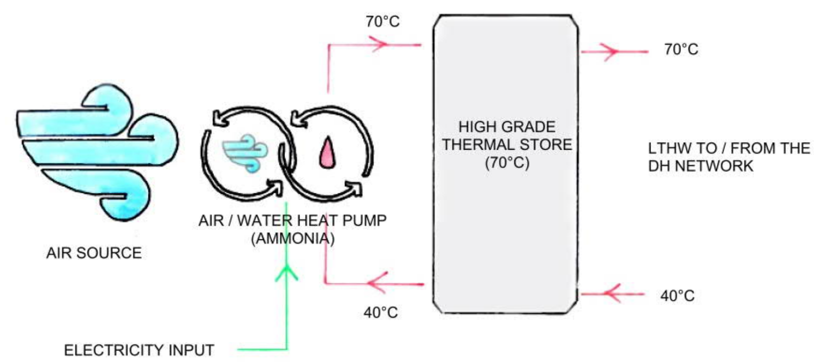

Figure 2 – Simplified process diagram of package Ammonia air source heat pump

Type 2 – a two stage split approach that generates LTHW to 70°C by using two separate units; one to generate low grade LTHW using an ASHP and a second water/ water heat pump to increase this up to 70°C. This approach utilises two commonly adopted technologies but has the significant drawback of an appreciably lower overall CoP when compared to type 1 systems. Figure 3 shows a simple process diagram showing the inputs and outputs from the two stage heat pump system.

It is important to note that this system would require an intermediate buffer vessel at which to store the low grade LTHW prior to the second stage heat pump operation.

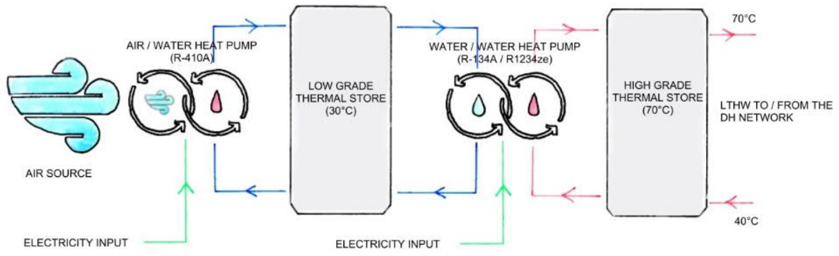

Figure 3 – Simplified process diagram of a two stage split air source heat pump

2.5 Site Electrical Power Requirements

Low carbon heating technologies that are supplied by electricity rather than natural gas typically require larger electrical power supplies than what was originally installed, in particular when considering retrofit projects.

On the Maiden Lane estate there are two electrical substations.

Maiden Lane Substation 20650 which is 500kVA transformer supporting the east and west side of the existing estate dwellings. The earthing system is expected to be a PME or TN-C-S. It has been confirmed by UKPN that the Maiden Lane substation enclosure is not big enough to allow a transformer upgrade or the installation of a new transformer alongside the existing and the existing transformer has no additional spare capacity.

York Way Substation 45555 which houses two 1000kVA transformers which serve the new York Way development. These substations are IDNO operated by ESP Electricity, with one transformer having 60kVA spare capacity and the other 180kVA.

To provide a 750-1000kW electrically driven heat pump that supports the estates base heating load of the heating network 600kVA of electrical capacity is required. This allows for auxiliary equipment such as pumps and fans at a design power factor of 0.8

As a result of reviewing the available electrical capacity on the estate, it has been determined that a new substation is required. A quotation has been provided by UKPN to supply and install a new 800kVA transformer with an agreed import of 600kVA from the local network.

The proposed substation design to support the heat pump has been located to the east of Block 10 (156-188 St. Pauls Crescent) which allows access to substation with a flat bed truck and other special requirements as per UKPNs specification. UKPN provide the transformer, cabling and connections however a brick enclosure is to be provided by the Main Contractor and 4No. 125mm ducts between the substation and St. Pauls Crescent for UKPN to make the connections.

Typically, a brick enclosure would be contrasted to house the transformer to the UKPN substation specification, Figure 4 below shows an example of this.

Figure 4 – UKPN standard brick substation enclosure

The UKPN quotation reference 8500146627 provides an installation cost of £100,951 excluding the brick enclosure. It is anticipated that the brick enclosure, low voltage connection from the transformer to plant room including a MCCB panel that would serve the heat pump would be a further £60,000. The estimate cost for the electrical power upgrade requirements to allow the installation of 750-1000kW heat pump is c.£160,000.

The UKPN quotation for the works can be found in Appendix 3 of this report and on the following page a diagrammatic figure shows the substations on a site layout.

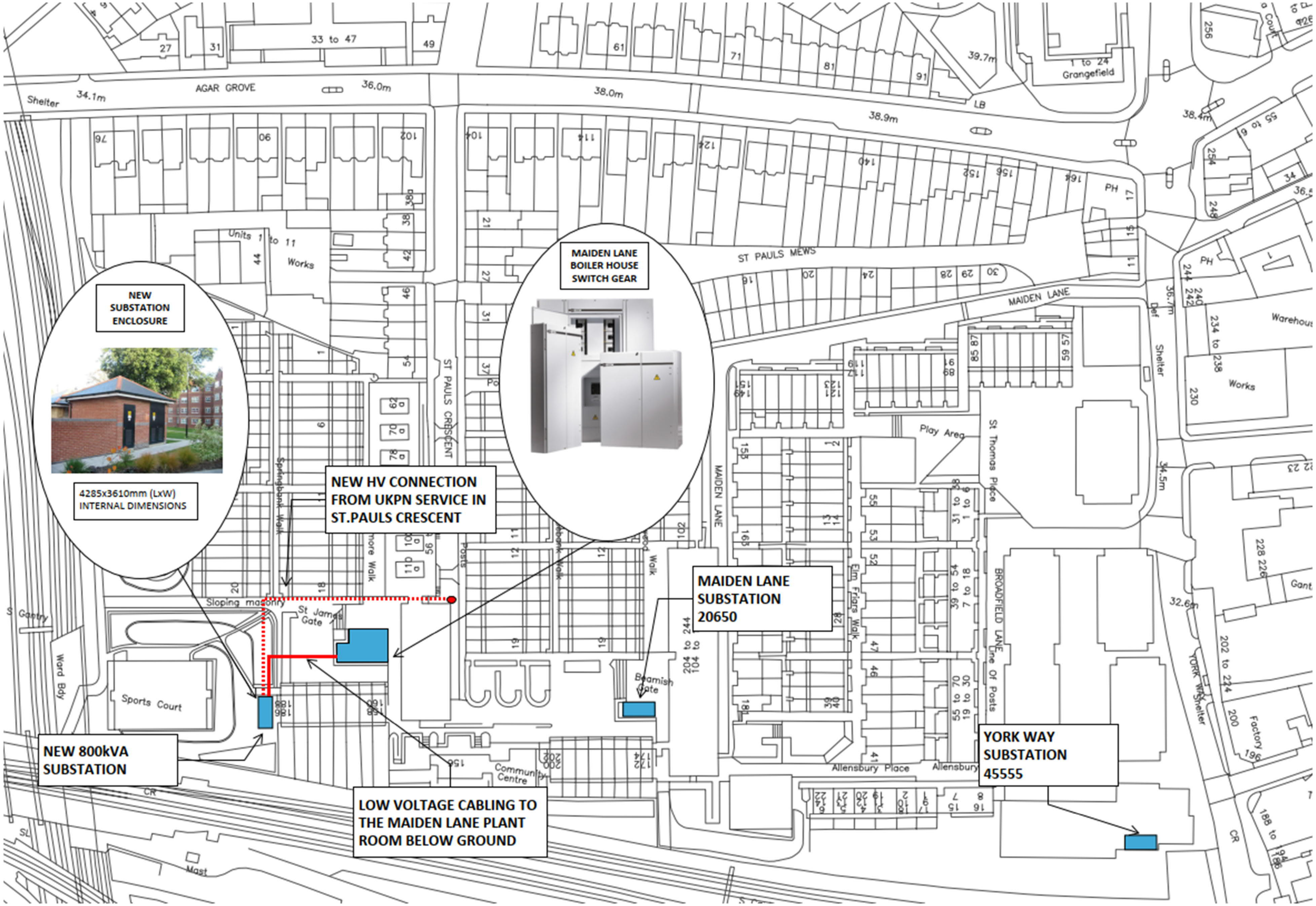

Figure 5 – Electrical Power Requirement Works Site Diagram

3.0 TYPE 1 AIR SOURCE HEAT PUMP

3.1 System Description and Characteristics

Max Fordham have developed detailed correspondence with bespoke refrigeration equipment manufactures GEA Refrigeration (Manufacture A) and Solid Energy (Manufacture B), both manufacture large scale high temperature heat pumps suitable for the application of heating networks. GEA Refrigeration have extensive global refrigeration experience in a wide range of industries such as food, beverage, oil and gas. All of which require precise temperature control at high temperatures. There extensive experience is now being applied in the district heating industry. Solid Energy are refrigeration experts and manufactures based in Denmark, leading the path for district heating supplied by heat pumps in Danish cities.

Heat Pump type
Manufacture A - Type 1 two stage (dual compressor) Ammonia based bespoke heat pump with an air source heat exchanger.

Manufacture B – Type 1 two stage (dual heat pump) Hydrocarbon based bespoke heat pump with an air source heat exchanger.

Components and how it fits together
Both Manufacture A & B heat pumps are configured in a very similar way and the following arrangement applies to both heat pumps. Figure 6 on the following page shows a diagrammatic schematic of how the heat pump components connect together.

The heat pump themselves have two water to water shell and tube heat exchangers for the evaporation and condensation stages of the vapour refrigeration cycle.

The arrangement of Manufacture A heat pump has work applied in the form of electricity on two compressors that are arranged in a two-stage configuration. Along with the shell and tube condenser, a desuper-heater provides multiple passes of the LTHW heating flow water which allows the production of LTHW at 70ºC from one heat pump at high efficiencies.

The configuration of the heat pump from Manufacture B is slightly different where multiple heat pump units are arranged in series that allows a staged temperature lift of the LTHW at 70ºC at high efficiencies. First is a Propane heat pump followed by an Isobutane heat pump that operates at the higher temperature.

The two-stage compressor or multi-stage heat pump unit configuration allows the thermal energy absorbed from the ambient air to be as low as -5ºC at design conditions at worthwhile efficiencies.

Both manufactures attain the thermal energy source through the ambient air harnessed with a Dry Air Cooler (DAC) that consists of finned heat exchangers with fans that absorb the thermal energy and transfers it to a water/glycol mixture that is pumped to the heat pump. The advantages of using a DAC allow a minimum charge of refrigerant gas to be contained within the heat pumps which allows the heat pump to be remote from the DAC.

Typically, the evaporation temperatures shall operate 10ºC below the ambient air with a temperature increase seen across the DAC of 5ºC. Due to the large volumes of air moved at potentially low temperatures, consideration needs to be given to cold air plumes forming around the DAC along with defrost cycle methods. To maximise the running hours and mitigate short cycling of the compressors a thermal storage vessel would be installed on the network side of the heat pump.

Site Integration
The Type 1 staged air source heat pumps would supply heat to a self-balancing thermal storage vessel at times of low thermal demand and directly into the common network return under times of higher demand, as shown in Figure 6.

It is anticipated that the most suitable location for the DAC would be on the community centre roof, with ambient temperature connecting pipe work to the heat pump/s that could be installed within the existing Maiden Lane boiler house, along with the thermal store. The heating flow from the thermal store needs to be piped directly to the common flow header in the York Way energy centre to enable the maximum contribution to the network, the heating return to the heat pumps thermal store would be also taken from energy centre. Figure 7 shows how this equipment integrates with the site layout.

Both heat pumps from Manufacture A & B can support the heating network flow and return temperatures directly at 70/40ºC flow and return. Manufacture A has the potentially to increase the supply temperature to 80ºC if required, however a c.20% drop in efficiency (CoP) will be experienced. The second stage Isobutane heat pump from Manufacture B can also support a heating flow temperature of 80ºC, but again efficiency will drop off by c.20%.

The additional electrical power supply requirements to support the heat pump installation have been estimated at c.600kVA and would require either a transformer upgrade of the Maiden Lane substation or a new substation to supply the heat pump equipment.

Refrigerants
Both heat pump manufactures operate on natural refrigerants which are the best available for the natural environment, however both have associated safety hazards that need to be considered. The tables adjacent identifies the properties and complexities of both.

Manufacture A	
Type	Ammonia (NH_3) is a natural refrigerant gas (R717) produced from natural elements hydrogen and nitrogen.
Environment	Because of Ammonia's natural properties it has a very low environmental impact, Global Warming Potential (GWP) equal to 0 and Ozone Depletion Potential (ODP) equal to 0.
Efficiency	Ammonia has good heat transfer properties and thermal characteristics that suit the application range from low to high temperatures achieving good efficiency.
Safety	Ammonia is toxic and a flammable gas at certain concentrations and therefore requires design methods to mitigate risks such as ventilation systems and leak detection. (B2L safety class)
Price	Ammonia has been around for a long time and with its low GWP and ODP the cost of the refrigerant gas is unlikely to rise in the future as a result of refrigerant gas phase downs, it is considered as a low cost refrigerant however safety measures and training procedures of maintenance do increase ongoing prices. c.£5/kg.

Table 3 – Manufacture A refrigerant review

Manufacture B	
Type	Propane (R290) and Isobutane (R600a) are both natural refrigerants under the Hydrocarbon category.
Environment	Because of their natural properties both have very low environmental impact. Propane GWP 3 and ODP 0, Isobutane GWP 3 and ODP 0.
Efficiency	The thermal dynamic properties are not as good as Ammonia which is why Propane and Isobutane operate well in a cascade configuration which all low high efficiency from low to high temperatures.
Safety	Both refrigerants are classed with highly flammable properties and therefore require design methods to mitigate risks such as ventilation systems and leak detection. (A3 safety class)
Price	Propane is a mixed-use gas and cost effective to buy as a refrigerant (c.£13/kg) [1]. Isobutane is generally more expensive but at a comparable price to HFO's (c.£28/kg) [1]. As the GWP and ODP of Isobutane is very low there should be no apparent reason for the price to increase as a result of future F-Gas phase downs and is seen a secure refrigerant choice.

Table 4 – Manufacture B refrigerant review

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3.2 Future Proof

The natural refrigerant gas and Hydrocarbons offer future security due to their low environmental impact that avoids future phase outs which would result in increased refrigerant costs and restrictions.

With the correct maintenance procedures in plan, the life expectancy of the refrigeration equipment is expected to span over 20 years which would qualify for the heating network life expectancy.

3.3 Efficiency

The CoP of a heat pump is the measure of efficiency at specified source and sink temperatures. As the temperature of the air source heat pumps changes across the year Seasonal Coefficient of Performance (SCoP) is used to determine the annual efficiency of the heat pump. The SCoP of the heat pumps have been calculated in accordance with BS EN 14825, taking into consideration the summer hot water demand in addition to the winter peak space heating and hot water demand along with the DAC fan power. An example SCoP calculation is attached within Appendix 4.

Manufacture A – 3.01 SCoP

Manufacture A – 3.38 SCoP

It is expected that the latest version of the GLA London Plan and any updates to the RHI will require a minimum SCoP for heat pumps of 2.8.

3.4 Environmental and Economic Factors

The capital costs for both Manufacture A & B of the heat pumps and DACs have been provided from the manufactures. All-in installation costs have been determined from Spon's Mechanical and Electrical Services Price book. Costs are an estimate for comparison and feasibility purposes.

Manufacture A	
Preliminaries	£12,800
Dry Air Cooler installation, inc. connecting pipework, structural works, acoustic/visual enclosure	£457,750
Heat Pump and plant room installation	£1,138,403
Additional items buried pipework and control and power wiring to York Way energy centre, new power supply and substation etc.	£246,100
Estimated grand total Ex.VAT	*£1,855,053*

Table 5 – Manufacture A capital costs

Manufacture B	
Preliminaries	£12,800
Dry Air Cooler installation, inc. connecting pipework, structural works, acoustic/visual enclosure	£430,477
Heat Pump and plant room installation	£1,046,272
Additional items buried pipework and control and power wiring to York Way energy centre, new power supply and substation etc.	£246,100
Estimated grand total Ex.VAT	*£1,735,649*

Table 6 – Manufacture B capital costs

The capital and installation costs of both the Ammonia heat pump and hydrocarbon heat pumps are comparable with one another. The bespoke heat pump manufacturing incurs greater capital costs than standard production line chillers from manufactures such as Daikin Applied of Mitsubishi/Climaveneta, which are compared against within this study. The ongoing maintenance costs have also been provided by both manufactures and are as below. The costs of maintaining an ammonia system are substantially higher than the hydrocarbon.

Manufacture A – £25,200/year

Manufacture B – £9,360/year

The operational costs (fuel use) of the heat pumps is directly linked to efficiency, and so to compare the anticipated annual fuel costs the SCoP of the heat pumps have been used. A Key Performance Indicator (KPI) for the heating network upgrade project will inevitable be controlling the cost of heat to end users. With the higher cost of electricity, high efficiency heat pumps need to be supplied in order to control this cost.

A gas boiler base case has been used to compare the annual economic and environmental performance of the heat pumps. The energy prices and carbon factors used for this estimation can be found in Chapter 9. When determining the cost of heat production, the ongoing maintenance costs have been included, although it is recognised that these costs could be included in a separate service charge arrangement. The cost of heat calculated doesn't include circulation pump utility costs. The current RHI agreement runs till 2021, and there has been no reports of this being renewed or replaced. The cost of heat has been shown with the current RHI tariff for the production of low carbon heat and also without.

Boiler Base Case	
Annual operational carbon equivalent emissions	1,701tonnesCO_2e/year
Anticipated cost of heat	3.7p/kWh

Table 7 – Manufacture A capital costs

Manufacture A	
Annual operational carbon equivalent emissions	974tonnesCO_2e/year *(43% reduction)*
Anticipated cost of heat	6.51p/kWh
Anticipated cost of heat (with RHI)	3.95p/kWh

Table 8 – Manufacture A capital costs

Manufacture B	
Annual operational carbon equivalent emissions	923tonnesCO_2e/year *(46% reduction)*
Anticipated cost of heat	5.75p/kWh
Anticipated cost of heat (with RHI)	3.19p/kWh

Table 9 – Manufacture A capital costs

Both the operational cost and environmental benefits from the systems provided by Manufacture A & B are very similar due to the SCoP of both being high. The lower annual maintenance costs of Manufacture B's system slightly reduce the production of heat cost. It is anticipated that the CHP machine at York Way Energy Centre has the opportunity to reduce the cost of heat when generating electricity that supplies the heat pump by c.0.5p, this is being explored further and shall be reported.

3.5 Complexities

The roof of the existing community centre seems the most suitable location for the DACs, however being an existing structure, a structural survey is required to develop calculation checks to prove whether the existing structure can support the additional loadings.

The following loads of both Manufacture A & Bs DAC and associated roof top plant has been estimated as follows.

Manufacture A – 37,000kg

Manufacture B – 35,000kg

With the community centre situated in the middle of a residential development it is important that the noise levels emitted from the DAC fans do not increase the local background noise levels and become a nuisance to local residents. The DAC can increase in heat exchanger size to allow slower fan speeds to be used along with fan attenuation and attenuated louvred screens. An acoustic survey is required to set noise level limits from the DAC at the same time as confirming the footprint to enable the structural development.

The physical size of the heat pumps themselves need to suit the installation of the Maiden Lane boiler house to limit the amount of building works by making use of the existing estate. The heat pump proposed by Manufacture A is required to be manufacture and delivered in two sections due to the length. Manufacture B's heat pump comprises of two separate heat pump units.

Manufacture A – 7,500 x 2,400 x 3,000mm (LxWxH)

Manufacture B – 2,742 x 2,093 x 2,290mm x3No. (LxWxH)

From the review of existing drawings, both manufactures heat pumps fit within the existing boiler house. A measured site survey is required to confirm this.

By locating the DACs on the roof of the community centre remote from the heat pumps interconnecting pipe work needs to be trenched between the two. A route needs to be confirmed down from the community centre and into the existing distribution trench which will require coordination with existing below ground services and structure coordination.

The visual aspect of installation plant and equipment on a low rise roof will raise aesthetic concerns. A screen would be installed to screen the equipment however it could end up increasing the height of the visual elevation as seen in an example in Figure 7.

The electrical power requirements determine that either a transformer upgrade is required at the Maiden Lane substation or a new substation suppling the heat pump. UKPN shall determine the viable option with an installation cost.

3.6 Further Investigations Required

The complexities identified as part of this study leads to further investigations required to determine the feasibility for the Maiden Lane estate. Some of which are being carried out now as they apply to all of the technologies and proposals within this report, and others will be looked at in more detail if necessary. The following areas are the methods used to further explore the complexities.

Structural – a structural survey is being carried out to determine whether the existing community roof structure is safe to take the additional plant loads or if a steel grillage system is required to distribute and spread the load.

Acoustics – a acoustic survey is being carried out to determine the background noise levels on the estate and set noise level targets that any additional plant must be designed to not exceed. Measures may have to be included such as fan attenuation or acoustic louvre/screen design to mitigate increased noise break out.

Cold plumes and condensation – by using the air as the source for a heat pump it involves removing heat from large volumes of air that could potentially cause a hazard or nuisance for the surrounding areas. An assessment on the volume of cold air at various ambient conditions is required to determine that the DAC will not cool the air further than required (via recirculation). Condensation drainage from the DAC also needs to be reviewed to avoid hazards around the equipment.

Defrost cycle integration – as a result of cooling large volumes of air at low ambient temperatures across the DAC there will be times where the surface temperature of the coils is below 0ºC and therefor frost and ice will form. The piping arrangement from the heat pump needs to include for an automatic defrost cycle that diverts hot water from the heat pump to the coil. This defrost method needs to be agreed and designed with the manufacture's recommendations.

Access for installation – a discussion with a mobile crane company needs to be had to determine a suitable crane that can be manoeuvred into the location and raise the external DAC onto the roof of the community centre.

Electrical substation – the viability of upgrading the Maiden Lane substation transformer needs to be assessed by UKPN and if this is not a possible solution then UKPN will proceed with the design of a new substation to serve the heat pump. UKPN have been instructed to proceed on this basis.

Refrigerant safety – mitigation and safety measures need to be explored in the handling and storing of the B2L and A3 refrigerants. This applies to both Manufactures A & B. Such measures will include ventilation system design and leak detection.

Pipe work trenching – a buried services and site survey is required to confirm the routes possible to connect the DAC from the community centre roof to the Maiden Lane boiler house and also the heat pump to the common district heating flow and return.

3.7 Precedent Installations

Manufacture A – GEA Refrigeration have a two-stage compressor bespoke Ammonia 1.5MW capacity heat pump installed at the Bunhill 2 energy centre in Islington, London. The heat pump is connected to an air heat exchanger that is installed within a ventilation shaft connecting an underground railway with the atmosphere. Air temperatures from the ventilation shaft are higher than the ambient air, however the heat pump achieves an 80ºC LTHW flow at with a CoP between 3 and 5.

Figure 6 – Bunhill 2 energy centre GEA ammonia heat pump

Manufacture B – Solid Energy has extensive involvement with heat pumps supporting district heating networks in Danish Cities. Solid Energy have no installed air source heat pumps installed in the UK connected to heat networks, however in Denmark a 3.5MW system is installed support a city-wide network. Solid Energy state that they currently have multiple systems in the planning/design stage connecting to UK networks.

Figure 7 – 3MW air source heat exchanger with an acoustic screen

3.8 Feasibility

In order to determine the initial feasibility of the Type 1 air source heat pumps from both Manufactures A & B the strengths and weakness have been listed. These findings are collated in a feasibility matrix at the rear of this report.

Type 1 Air Source Heat Pump - Manufacture A

Strengths

- Seasonal efficiency is high
- Future proof low carbon heating solution
- Opportunity to provide low carbon heat for a controllable price
- Precedent installations and experience with district heating in the UK

Weaknesses

- B2L safety class safety measures required
- On-going maintenance costs are higher than Manufacture B
- Structural assessment required for location of DAC
- Acoustic measures likely required to control noise break out
- Heat pump will need to be manufacture in two parts to allow installation to boiler house. This could increase installation costs
- Unknown pipe work trenching detail between community centre roof and boiler house

Type 1 Air Source Heat Pump - Manufacture B

Strengths

- Seasonal efficiency is high
- Future proof low carbon heating solution
- Opportunity to provide low carbon heat for a controllable price
- Maintenance costs are lower than Manufacture A

- Precedent installations and experience with district heating

Weaknesses

- A3 safety class safety measures required
- Structural assessment required for location of DAC
- Acoustic measures likely required to control noise break out
- Unknown pipe work trenching detail between community centre roof and boiler house
- Aesthetics of locating plant and equipment on a low rise roof

Conclusion
Both Manufacture A & B offer installations with rewarding CoPs that have the opportunity to be marketed as highly efficient large scale heat pumps that will result in the maximum environmental and financials savings from the investment.

The ammonia heat pump from Manufacture A has its benefits of a precedent installation in London with performance data. Although Manufacture B does have extensive experience with heat pumps connected to district heating networks overseas.

The vastly lower maintenance cost of the HFO heat pumps is attractive from Manufacture B, however both refrigerants required safety measures in place.

It is anticipated that the acoustic and structural risks that are imposed by the DACs can be designed out within further study work.

Both heat pump proposals area seen as suitable low carbon investments to continue further investigations in determining feasibility to the Maiden Lane estate.

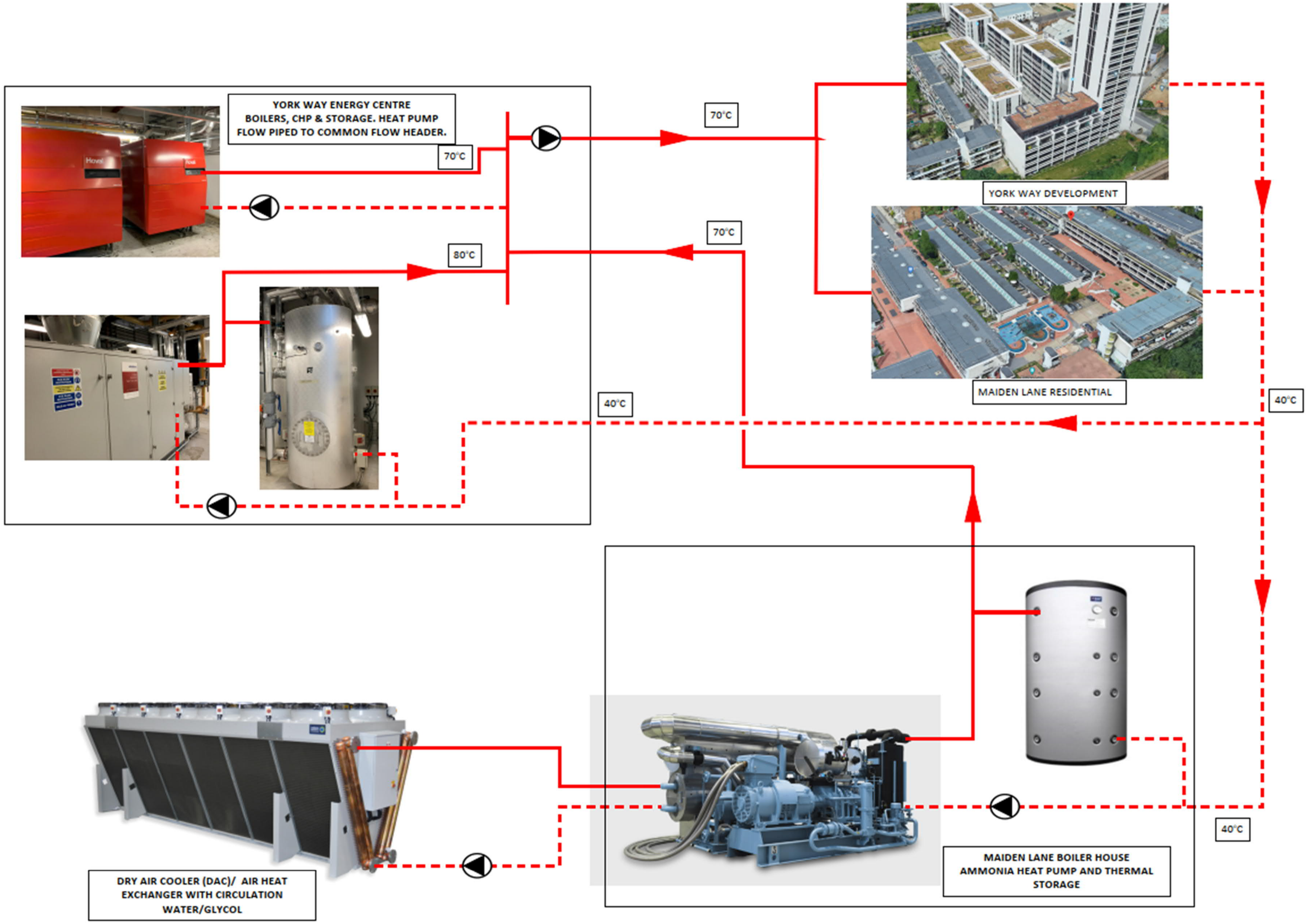

Figure 8 - Natural Refrigerant Air Source Heat Pump Principle Schematic

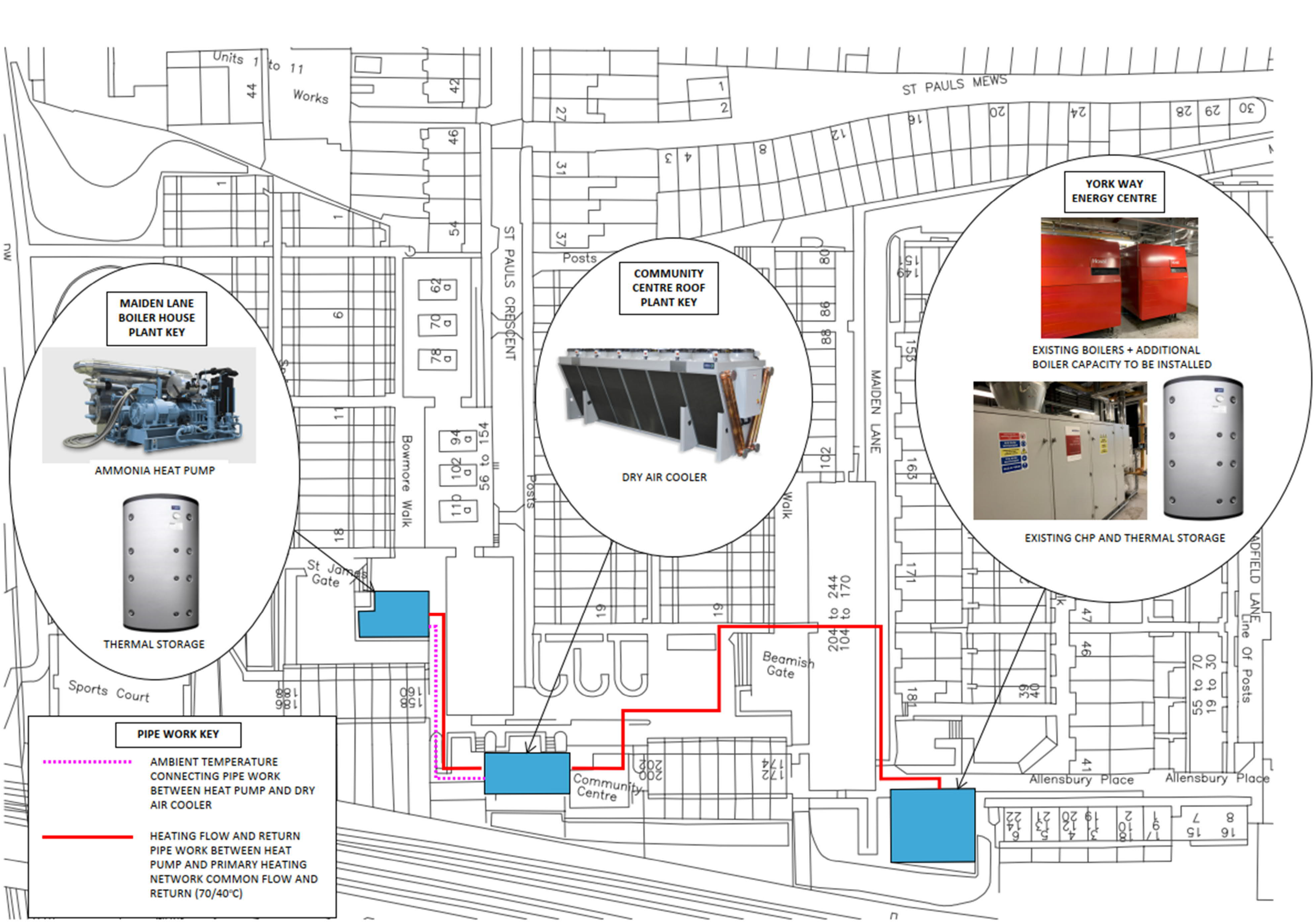

Figure 9 - Natural Refrigerant Air Source Heat Pump Site Integration Layout

4.0 TYPE 2 AIR SOURCE HEAT PUMP

4.1 System Description and Characteristics

The other current approach to air source heat pump systems is a Type 2 configuration with a closed circuit air source chiller connected to a water to water heat pump via a water/glycol low grade temperature loop. Many Air Conditioning and Refrigeration manufactures offer solutions of this configuration and we have looked at the Daikin Applied and Mitsubishi/Climaveneta proposals as part of this study.

This configuration typically requires more connecting components when compared to the Type 1 configuration and proposals are generally more 'off the shelf', rather than bespoke refrigeration equipment.

Heat Pump type
Manufacture C – Type 2 two stage air source chiller and water to water heat pump from Daikin Applied

Manufacture D – Type 2 two stage air source chiller and water to water heat pump from Mitsubishi/Climaveneta

Components and how it fits together
Both manufactures C & D heat pump proposals are configured in a similar way and the following arrangement applies to both heat pumps. Figure 8 on the following pages shows a diagrammatic schematic of how the heat pump components connect together.

The air source chillers from Manufacture C for this proposal are arranged in a modular configuration with 3No. chillers, as the heating demand increases the chillers will modulate on. The low-grade heating flow and returns from the chillers are fixed throughout the year at 20/15ºC to allow a reasonable efficiency from the air source chillers. 1No. large water to water heat pump upgrades the heat to a usable temperature of 70ºC.

Manufacture D proposes 2No. modular air source chillers that provide low-grade heating flow and return temperatures of 45/40ºC fixed throughout the year. 3No. water to water heat pumps modulate and upgrade the heat to a usable temperature of 70ºC.

Both configurations require a buffer vessel between the air source chillers and the water source heat pumps to allow a minimum system water volume to mitigate the risk of compressor short cycling. The packaged air source chillers have the benefit of having propriety inbuilt controls that means defrost cycle control is simpler to perform.

Site Integration
The Type 2 two stage staged air source heat pump configurations would supply heat to a self-balancing thermal storage vessel at times of low thermal demand and directly into the common network return under times of higher demand in the same manner as the Type 1 system would, as shown in Figure 8.

Again, it is anticipated that the most suitable location for the air source chillers would be on the community centre roof, with low-grade temperature connecting pipe work to the heat pump/s that could be installed within the existing Maiden Lane boiler house, along with the thermal store. The low-grade heat buffer vessels would be best located within the Maiden Lane boiler house, because if they were also located on the community centre roof it would be additional plant loading that would have to be distributed onto the existing structure.

The main heating flow from the thermal store needs to be piped directly to the common flow header in the York Way energy centre to enable the maximum contribution to the network, the return back to the heat pumps thermal store would be also taken from energy centre. Figure 9 shows how this equipment integrates with the site layout. Both heat pumps from Manufacture C & D can support the heating network flow and return temperatures directly at 70/40ºC flow and return. Neither of the water source heat pumps are able to provide heating flow above 70ºC.

The additional electrical power supply requirements to support the heat pump installation have been estimated at c.600kVA and would require either a transformer upgrade of the Maiden Lane substation or a new substation to supply the heat pump equipment.

Refrigerants
Both manufactures operate on different refrigerants which are the best available for the natural environment, however both come with safety hazards that need to be considered. The tables adjacent identifies the properties and complexities of both.

Manufacture C	
Type	R32 is a HFC refrigerant which is used in the air source chiller and R1234ze is a HFO that the water to water heat pump operates on.
Environment	The properties of most HFCs are generally harmful to the environment and risk future F-Gas phase downs. The chemical composition of HFO refrigerants are much more environmentally friendly than HFCs however impose further safety measures. R32 – GWP 675 & ODP 0 R1234ze – GWP 7 & ODP 0
Efficiency	The thermodynamic properties of both refrigerants on their own are unable to provide temperature lifts from ambient temperatures to 70ºC efficiently, which is why the Type 2 stage configuration is used.
Safety	Both refrigerants are safety class A2L mildly flammable and therefore require design methods to mitigate risks such as ventilation systems and lead detection.
Price	Currently R32 is one of the cheaper refrigerants on the market at c.£16.45/kg however due to its GDP its likely to risk future F-gas phase downs. R1234ze is a relatively new refrigerant with quite a high cost at c.£27.53.

Table 10 – Manufacture C refrigerant review

Manufacture D	
Type	R513a is a blend refrigerant of R1234yf (HFO) and R134a, where R134a is a HFC.
Environment	Because of the blended properties R513a is a lot more environmentally friendly than R134a that certainly risks future F-Gas phase downs. R513a – GWP 631 & ODP 0 R134a – GWP 1430 & ODP 0 HFO blends still risk future F-Gas phase downs, and it is expected that future phase downs could limit the use of refrigerants with a GWP greater than 500.
Efficiency	R134a has good thermal dynamic properties, not as good as ammonia however, which is why the two-stage configuration is used with R513a.
Safety	R134a is generally a safe refrigerant to use and handle, and when blended with HFOs it reduces the safety category of the HFO. R513a A1 safety class would require design methods to mitigate risks such as ventilation systems and leak detection.
Price	R134a was regarded as a cheaper refrigerant however recent price increases have been seen due to the current F-Gas phase down restrictions and is now c.£26.51/kg. R513a is c.£29.88/kg as a result of the blended properties.

Table 11 – Manufacture D refrigerant review

4.2 Future Proof

Manufacture C's air source chillers operating on R32 refrigerant do risk future F-gas phase down restrictions, however it is expected to only limit the refrigerant use. Because of this, the price of R32 may increase more than expected throughout the 20- year life span.

Manufacture D does not offer a HFO water to water heat pump, and therefore is not considered as future proof when compared to Manufacture C.

4.3 Efficiency

The SCoP of the heat pumps have been calculated in accordance with BS EN 14825, taking into consideration the summer hot water demand in addition to the winter peak space heating and hot water demand.

Manufacture C – 2.25 SCoP

Manufacture D – 2.39 SCoP

It is expected that the latest version of the GLA London Plan and any updates to the RHI will require a minimum SCoP for heat pumps of 2.8.

4.4 Environmental and Economic Factors

The capital costs for both Manufacture C & D of the air source chillers and water to water heat pumps have been provided from the manufactures. All-in installation costs have been determined from Spon's Mechanical and Electrical Services Price book. Costs are an estimate for comparison and feasibility purposes.

Manufacture C	
Preliminaries	£12,800
Air source chiller installation, inc. connecting pipework, structural works, acoustic/visual enclosure	£516,250
Heat Pump and plant room installation	£614,004
Additional items buried pipework and control and power wiring to York Way energy centre, new power supply and substation etc.	£256,100
Estimated grand total Ex.VAT	*£1,399,153*

Table 12 – Manufacture C capital costs

Manufacture D	
Preliminaries	£12,800
Air source chiller installation, inc. connecting pipework, structural works, acoustic/visual enclosure	£489,250
Heat Pump and plant room installation	£510,503
Additional items buried pipework and control and power wiring to York Way energy centre, new power supply and substation etc.	£246,100
Estimated grand total Ex.VAT	*£1,268,653*

Table 13 – Manufacture D capital costs

The capital and installation cost of the Manufacture D is c.£500,000 cheaper than the Ammonia or hydrocarbon proposal. This is mainly down the R134a water to water heat pump which is fairly old compressor technology with production costs a lot less than the more environmentally friendly solutions.

The ongoing maintenance costs have also been provided by both manufactures and are as below. The costs of maintaining the 'off the shelf' chillers are comparable to the HFO proposal.

Manufacture C – £10,960/year

Manufacture D – not provided

A gas boiler base case has been used to compare the annual economic and environmental performance of the heat pump proposals from Manufacture C and D. The energy prices and carbon factors used for this estimation can be found in Chapter 7. When determining the cost of heat production, the ongoing maintenance costs have been including, although it is recognised that these costs could be included in a separate service charge. The cost of heat calculated doesn't include circulation pump utility costs. The cost of heat has been shown with the current RHI tariff for the production of low carbon heat and also without.

Boiler Base Case	
Annual operational carbon equivalent emissions	1,701tonnesCO_2e/year
Anticipated cost of heat	3.7p/kWh

Table 14 – Boiler base case environmental and financial estimated performance

Manufacture C	
Annual operational carbon equivalent emissions	1,133tonnesCO_2e/year *(33% reduction)*
Anticipated cost of heat	7.81p/kWh
Anticipated cost of heat (with RHI)	Ineligible

Table 15 – Manufacture C environmental and financial estimated performance

Manufacture D	
Annual operational carbon equivalent emissions	1,096tonnesCO_2e/year *(36% reduction)*
Anticipated cost of heat	7.46p/kWh
Anticipated cost of heat (with RHI)	Ineligible

Table 16 – Manufacture D environmental and financial estimated performance

Both the operational cost and environmental benefits from the systems provided by Manufacture C & D are much reduced when compared to the Type 1 air source heat pumps as a result of the reduced efficiency. It is apparent that the higher efficiency heat pump systems have a greater capital cost but provide further environmental savings and lower cost heat production.

4.5 Complexities

As with the Type 1 air source heat pump proposals, the Type 2 air source chillers also require external space to accommodate the air heat exchange.

The following loads of both Manufacture C & Ds air source chillers and associated roof top plant has been estimated as follows.

Manufacture C – 31,458kg

Manufacture D – 32,756kg

As previously mentioned, the Type 2 air source chiller and heat pump proposals require a buffer vessel between the chillers and water to water heat pumps. This requires additional plant space, which is best suited to be located in the existing Maiden Lane boiler house. Unfortunately, this would reduce the amount of plant space for high grade thermal storage which in turn will potentially reduce the annual run hours of the heat pumps.

From review of the available record drawings and the manufactures data, the physical sizes of both water source heat pumps fit within the existing Maiden Lane boiler room.

Manufacture C – 3,822 x 1,287 x 2,430mm (LxWxH)

Manufacture D – 1,223 x 877 x 1,496mm x3No. (LxWxH)

Again, by locating the air source chillers on the roof the community centre, the connecting pipe work routes needs to confirmed and verified with an existing pipe work tracing survey and a site investigation survey.

The electrical power requirement to supply the heat pump configurations from both manufactures will also require a transformer upgrade or new substation.

4.6 Further Investigations Required

The complexities identified as part of this study leads to further investigations required to determine the feasibility for the Maiden Lane estate. Some of which are being carried out now as they apply to all of the technologies and proposals within this report, and others will be looked at in more detail if necessary. The following area are the methods used to further explore the complexities.

Structural – a structural survey is being carried out to determine whether the existing community roof structure is safe to take the additional plant loads or if a steel grillage system is required to distribute and spread the load.

Acoustics – a acoustic survey is being carried out to determine the background noise levels on the estate and set noise level targets that any additional plant must be designed to not exceed. Measures may have to be included such as fan attenuation or acoustic louvre/screen design to mitigate increased noise break out.

Cold plumes and condensation – by using the air as the source for a heat pump it involves removing heat from large volumes of air that could potentially cause a hazard or nuisance for the surrounding areas. An assessment of the volume of cold air at various ambient conditions is required to determine that the air source chillers will not cool the air further than required (via recirculation). Condensation drainage from the air source chillers also needs to be reviewed to avoid hazards around the equipment.

Access for installation – a discussion with a mobile crane company needs to be had to determine a suitable crane that can be manoeuvred into the location and raise the air source chillers onto the roof of the community centre.

Electrical substation – the viability of upgrading the Maiden Lane substation transformer needs to be assessed by UKPN and if this is not a possible solution then UKPN will proceed with the design of a new substation to serve the heat pump. UKPN have been instructed to proceed on this basis.

Refrigerant safety – mitigation and safety measures need to be explored in the handling and storing of the A2L refrigerant that applies to Manufacture C. Such measures will include ventilation system design and leak detection.

Pipe work trenching – a buried services and site survey is required to confirm the routes possible to connect the DAC from the community centre roof to the Maiden Lane boiler house and also the heat pump to the common district heating flow and return.

4.7 Precedent Installations

Manufacture C – Daikin are currently in the process of launching their HFO water to water heat pump, however, do have precedent projects where HFC water to water heat pumps are installed coupled with ground source low grade heat supplies. Daikin have no precedent projects with the air source chiller supplying low grade to large scale water to water heat pumps serving district heating networking currently.

Manufacture D – Mitsubishi do not offer a HFO water to water heat pump, only with a HFC refrigerant. Again, Mitsubishi also do not have any precedent projects with the proposed air source chillers supplying low grade heat to large scale water to water heating pumps serving district heating networks.

4.8 Feasibility

In order to determine the initial feasibility of the Type 2 air source heat pumps from both Manufactures C & D the strengths and weakness have been listed. These findings are collated in a feasibility matrix at the rear of this report.

Type 2 Air Source Heat Pump - Manufacture C

Strengths

- Packaged system with built-in defrost cycle control
- Lower capital cost
- Less structural loading from air source chillers when compared to DACs

Weaknesses

- Additional storage required between air source chillers and water source heat pumps i.e. further plant space, structural implications and potential to limit space for thermal storage vessels
- R32 refrigerant risks price increases with future F-Gas phase down restrictions
- Seasonal efficiency is not as high as a natural refrigerant heat pump which results in greater costs of heat and smaller environmental savings
- No precedent installations connected to heating networks

Type 2 Air Source Heat Pump - Manufacture D

Strengths

- Packaged system with built-in defrost cycle control
- Lower capital cost
- Less structural loading from air source chillers when compared to DACs

Weaknesses

- Additional storage required between air source chillers and water source heat pumps i.e. further plant space, structural implications and potential to limit space for thermal storage vessels
- R134a refrigerant doesn’t carry environmentally friendly properties and certainly risks future price increases via F-Gas phase downs, not future proof
- Seasonal efficiency is not as high as a natural refrigerant heat pump which results in greater costs of heat and smaller environmental savings
- No precedent installations connected to heating networks

Conclusion
By using two refrigeration technologies in a two stage configuration the overall CoP is considerably below the high temperature Type 1 air source heat pumps. This is due to the increased electrical work on the compressors operating at a lower efficiency on the refrigerants available.

Without precedent installations of this size serving district heating networks in the Type 2 configuration opens up risk to a project. The risk could be seen particularly with commissioning of the systems, and ongoing operation and actual performance. Although the capital costs are less than the natural refrigerant or hydrocarbon proposals, the ongoing performance risks and reduction in environmental and financials savings would limit the overall performance of the investment.

Manufacture C (Daikin) would be the proposal to put forward if the Type 2 configuration was to be taken further, this is due to the future proof refrigerant selections available with their technology.

The installation of a heat pump system that risks not being eligible for future government incentives such as the RHI or compliance with the London Plan, does not present itself well as an innovative low carbon investment for Camden.

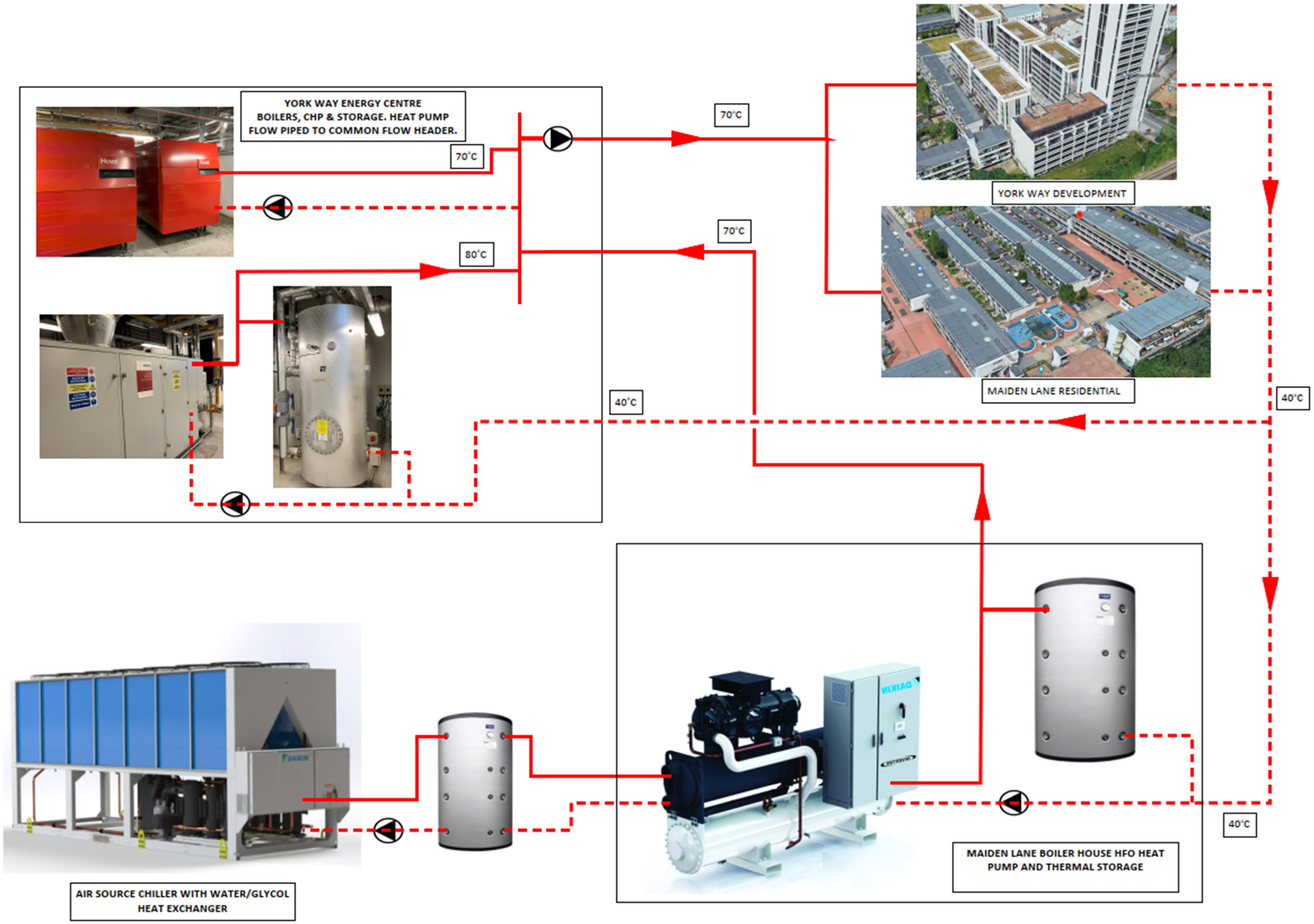

Figure 10 - HFO Refrigerant Air Source Chiller and Water Source Heat Pump Principle Schematic

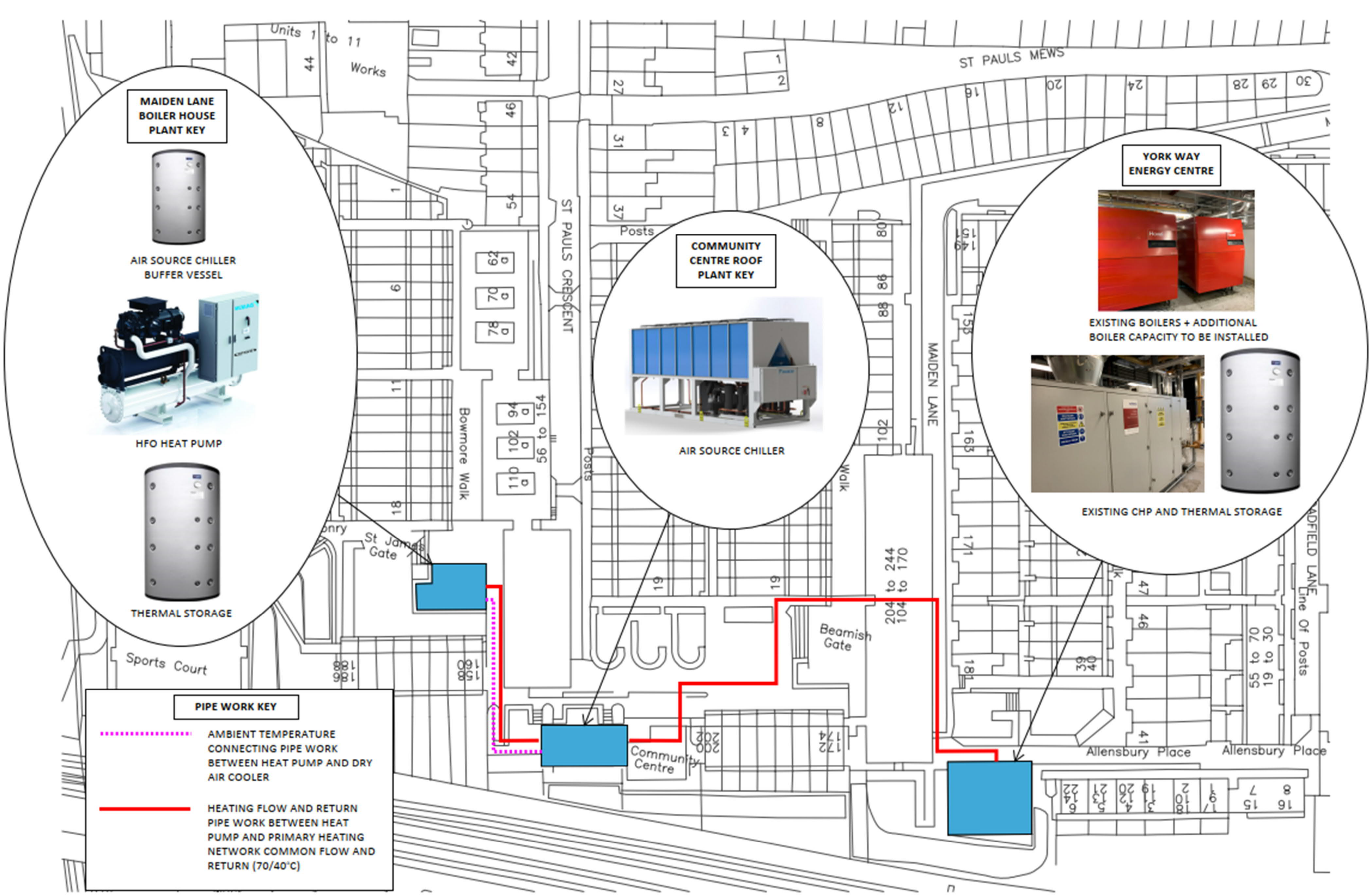

Figure 11 - HFO Refrigerant Air Source Chiller and Water Source Heat Pump Site Integration Layout

5.0 GROUND SOURCE HEAT PUMP

5.1 System Description and Characteristics

Max Fordham have developed two initial ground source heat pump proposals with the specialist supplier and installer GCore Limited, who have a wide range of ground source installations ranging from 5kW to 2.5MW across the UK.

Two types of ground source heat pump systems have been looked at that are known as open loop and closed loop.

System type
Manufacture E – Open loop ground water source system connected to modular HFO heat pumps

Manufacture E – Closed loop ground water source system connected to modular HFO heat pumps

Components and how it fits together
Both the open loop and closed loop ground source systems operate with the same modular HFO heat pumps that allow heating water production at 70ºC.

The open loop system utilises 2No. abstraction wells and 2No. injection wells that are drilled deep enough to allow the abstraction of ground water from the aquifer. A submersible pump is installed within the abstraction wells and the ground water is pumped and filtered to a heat exchanger where a certain amount of thermal energy is transferred to a refrigeration heat pump system. The water is returned to the ground via the injection wells. Figure 11 on the following page shows a diagrammatic schematic of the system. The wells need to be drilled to around 300m to allow enough ground water exposure and the abstraction and injection wells are required to be a minimum of 80-100m apart.

A closed loop system requires a densely packed array of bore holes drilled to 150m where flow and return pipe work is passed down each borehole. A water/glycol mix is circulated down each borehole in a header arrangement that absorbs heat from the ground allowing the transfer of thermal energy from the ground to the heat pump as the heat source. Figure 13 on the following page shows a diagrammatic schematic of the system. The land area required to provide a borehole array has been estimated at 2,025m2, which would support the thermal output of a 750kW heat pump.

Site integration
The modular HFO heat pumps would supply heat to a self-balancing thermal storage vessel in the same configuration as the other heat pump proposals, enabling storage at times of low demand and heat injection directly into the common network return under times of higher demand, as shown in both Figure 12 and 14.

The largest land area on the site available for the installation of ground source wells or bore holes, is at the very west of the site. This land area has a dense covering of trees and shrubbery and additionally buried services such as water drainage pipes and electrical cables that would require coordination with or diversions of.

This area of land initially looks large enough for an open loop well ground source system, however the space available is very limited to a certain positioning of the wells as shown in Figure 12. If the land area is proven suitable, borehole water would be pumped to the existing Maiden Lane boiler room via buried pipework where a backwash filter system and plate heat exchanger would allow the transfer of thermal energy to the heat pumps.

For a closed loop borehole array, the available land area is extremely pushed for space. Figure 14 demonstrates the space required for the borehole array to support the heat pump. It is quite quickly seen that this perhaps doesn't suit the estates space constraints. If for a reason a closed loop system was persisted then via the common header pipework arrangement, flow and return pipe work is passed down the boreholes with the water/glycol heat transfer medium circulating back to Maiden Lane boiler house heat pumps.

Refrigerant
Both the open loop and closed loop systems are configured with the same heat pumps operating on a HFO refrigerant, the table below identifies the properties and complexities of the refrigerant.

Manufacture D	
Type	R1234ze is a HFO refrigerant
Environment	The chemical composition of HFO refrigerants are much more environmentally friendly than HFCs however do impose further safety measures. R1234ze – GWP 7 & ODP 0
Efficiency	The thermodynamic properties of R1234ze is similar to R134a, however a slight drop in CoP is seen. For a heating output 70ºC with ground source temperatures between 10-15oC, a relatively CoP can be achieved.
Safety	The refrigerant safety class of R1234ze is A2L mildly flammable and therefore requires design methods to mitigate risks such as ventilation systems and lead detection.
Price	R1234ze is a relatively new refrigerant with quite a high cost at c.£27.53.

Table 17 – Manufacture D refrigerant review

5.2 Future Proof

The HFO refrigerant offers future security due to its low environmental impact that avoids future phase outs which would result in increased refrigerant costs and restrictions.

With the correct maintenance procedures in plan, the life expectancy of the refrigeration equipment is expected to span over 20 years which would qualify for the heating network life expectancy.

The boreholes and wells if designed and constructed to correct standards shall last and be operational for the life expectancy of the heating network. The open wells have the opportunity to have a longer life expectancy with less pipe work in situ.

5.3 Efficiency

The CoP of a ground source heat pump is dependent upon the temperature of the water that is approaching the heat pump from the ground. Typically, in the London Basin hydrogeology and geology, from experience the following steady state temperatures can be expected to be seen.

Open loop 14 - 14.5ºC
Closed loop 13 - 14.6ºC

Although the temperature of the ground water is received higher in an open loop system, a temperature drop is experienced over the heat exchanger before the heat pump which typically results in both configurations providing a similar water source temperature. For this reason, both CoPs have been considered the same with an average approach temperature of 13ºC.

The SCoP of the heat pump has been calculated in accordance with BS EN 14825, taking into consideration the summer hot water demand in addition to the winter peak space heating and hot water demand.

Manufacture E – 2.45 SCoP

It is expected that the latest version of the GLA London Plan and any updates to the RHI will require a minimum SCoP for heat pumps of 2.8.

5.4 Environmental and Economic Factors

The capital costs for both the open loop and closed loop systems and heat pumps have been provided from GCore. All-in installation costs have been determined from Spon's Mechanical and Electrical Services Price book. Costs are an estimate for comparison and feasibility purposes.

Manufacture E Open Loop	
Preliminaries inc. well design, test pumping, Environment Agency	£73,375
Well drilling and development	£522,962
Heat Pump and plant room installation	£767,628
Additional items buried pipework and control and power wiring to York Way energy centre, new power supply and substation etc.	£241,100
Estimated grand total Ex.VAT	*£1,604,065*

Table 18 – Manufacture C capital costs

Manufacture E Closed Loop	
Preliminaries	£17,375
Borehole installation	£1,806,250
Pipework header installation	£522,962
Heat Pump and plant room installation	£668,252
Additional items buried pipework and control and power wiring to York Way energy centre, new power supply and substation etc.	£241,100
Estimated grand total Ex.VAT	*£2,959,701*

Table 19 – Manufacture C capital costs

The capital and installation cost of the closed loop system is drastically more expensive than open loop arrangement. This is due to the quantity of boreholes and associated drilling required to make up the thermal source to the heat pump.

The ongoing maintenance costs of the HFO heat pumps are the same as the previously provided figures, and borehole pumping maintenance would be captured within the annual maintenance contracts the same way DAC circulation pumps would. However, an allowance has been recognised and made for the maintenance of the filtration system that serves the open loop configuration.

Manufacture E – £10,220/year

A gas boiler base case has been used to compare the annual economic and environmental performance of the heat pump proposals from Manufacture C and D. The energy prices and carbon factors used for this estimation can be found in Chapter 7. When determining the cost of heat production, the ongoing maintenance costs have been including, although it is recognised that these costs could be included in a separate service charge. The cost of heat calculated doesn't include circulation pump utility costs. The cost of heat has been shown with the current RHI tariff for the production of low carbon heat and also without.

As the SCoP of both the open loop and ground loop have been considered the same for the purpose of this study, the cost of heat production and carbon savings are also considered the same.

Boiler Base Case	
Annual operational carbon equivalent emissions	1,701tonnesCO_2e/year
Anticipated cost of heat	3.7p/kWh

Table 20 – Boiler base case environmental and financial estimated performance

Manufacture E	
Annual operational carbon equivalent emissions	1081tonnesCO_2e/year *(36% reduction)*
Anticipated cost of heat	7.3p/kWh
Anticipated cost of heat (with RHI)	Ineligible

Table 21 – Manufacture C environmental and financial estimated performance

The available carbon savings are slightly improved upon when compared to the Type 2 air source heat pump systems, however not as rewarding as the Type 1 air source system. The cost of heat increases and without the eligibility for the RHI, there is no financial incentive available to help reduce the cost.

5.5 Complexities

Both ground source heat pump configurations bring complexities to the design and installation of the systems within the estate.

When using the ground as a heat source for heating and cooling loads, there are legal requirements that need to be met to reduce the risk of any environmental harm that could be caused. The Environment Agency govern these requirements [3], as discussed below.

For closed loop systems the environmental requirements are less, however approval is still required. For the Maiden Lane estate, a large area of closed loop boreholes in a densely packed area has the potential to alter the local ground temperature, as a result over time the efficiency of the heat pump system will degrade due to the lower source temperature. If ground source systems are used for both heating and cooling throughout the year, the ground temperature becomes balanced which reduces any changes in efficiency and the effect to the local ground and water environment.

The available land for a closed loop ground source system is very limited and currently has young and older trees planted, residential path ways and out buildings. This land area would have to be completely cleared with all trees removed and buried services such as electrical cables which would require diversion works to allow the borehole drilling.

Due to the limited land area for the closed loop bore hole array and potential effect to the local ground and water environment from temperature changes, the closed loop borehole ground source heat pump system is not considered suitable for the estate.

The Environment Agency requires early engagement for open loop systems where wells are used to abstract ground water [3]. To obtain approval from the Environment Agency, the local land needs to not be in a ground water source protection zone and the abstraction rates within their guidelines. The risk falls at Maiden Lane with the restricted land area and potential locations to position wells. The orientation of the injection wells relative to the abstraction is a key consideration to allow for the ground water flow direction and thermal breakthrough. With the limited land area, it is clear to see that there are only a few orientations available. If the Environment Agency give approval of the scheme, then a test well would be drilled, and the possible water abstraction rates confirmed. GCore have provided a provision cost for this investigation and approval works at £73,375.

By providing continuous heating all year from the wells there is still the possibility of depleting the local ground water, even if the Environment Agency approve the scheme. This can degrade the performance of the heat pump system when compared to such scheme that can utilise a cooling load during summer and provide heat back into the ground.

As a result of the upfront work to again approval along with the limited land space for the well design to actually work, the open loop ground heat scheme is being considered as a high risk scheme to apply to Maiden Lane estate.

5.6 Further Investigations Required

The complexities identified as part of this study leads to further investigations required to determine the suitability of open loop ground source heat pump system. The risk of the scheme wouldn't be de-risked until after the further works are carried out, which does come with the upfront cost from specialist analysis.

The following areas are the methods used to further explore the complexities, as mentioned above to further the feasibility of the well development an upfront cost is required.

Ground temperature depletion assessment – the well design needs to be carried out to determine the optimum configuration with the ground water flow and the land area available. From this the temperature depletion assessment can be carried out to determine on going performance of the heat pump system, and ultimately the effect if any on the ground environment.

Abstraction and injection well approval – initial approval of abstraction of ground water from the below land needs to be approved by the Environment Agency, and then once a firm proposal for the well design is determined, the approval of this abstraction and injection would be given in accordance with the impact on the ground environment.

Test wells – once approval is given a test well would be drilled to confirm the possible abstraction yield. Only once this has been drilled and confirmed is it known that the ground source heat pump system will be able to perform as expected and able to meet thermal demand required.

Access for installation – a discussion with a ground drill company needs to be had to determine the size of the drilling equipment and ensure it can access the land area for the test well drilling.

Electrical substation – the viability of upgrading the Maiden Lane substation transformer needs to be assessed by UKPN and if this is not a possible solution then UKPN will proceed with the design of a new substation to serve the heat pump. UKPN have been instructed to proceed on this basis.

Refrigerant safety – mitigation and safety measures need to be explored in the handling and storing of the A2L refrigerant that applies to Manufacture E. Such measures will include ventilation system design and leak detection.

Pipe work trenching – a buried services and site survey is required to confirm the routes possible to connect the pipe work from the abstraction wells to the Maiden Lane boiler house and back to the injection wells, along with from the heat pump district heating network flow and return.

5.7 Precedent Installations

GCore Limited have provided a case study of an open loop ground source system with a 500kW heating load and 750kW cooling load via 2No. 100m wells. The system serves a commercial building in the city of London. The benefits of the heating and cooling demand meant that the geological and hydrogeological conditions underlying the site were not impacted with temperature changes and dissipation. The proposal was engaged as feasible early on in the project.

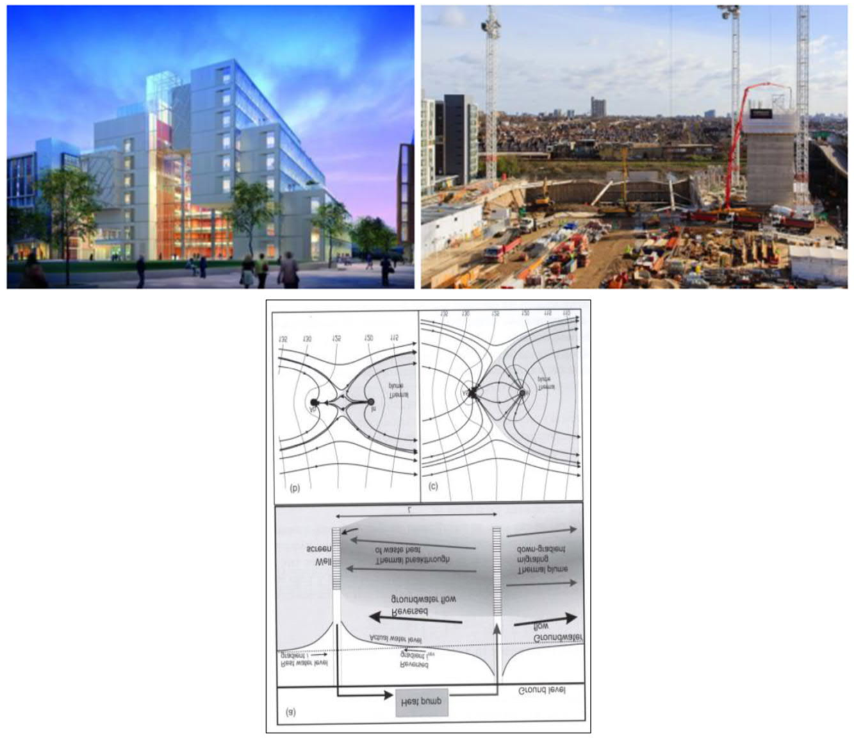

Figure 12 – GCore Limited White City Open Loop Ground Source Heat Pump

5.8 Feasibility

The strengths and weaknesses have been summarised below for both ground source heat pump options. These findings are collated in a feasibility matrix at the rear of this report.

Open Loop Ground Water Source Heat Pump System - Manufacture E

Strengths

- Lower capital cost than a closed loop ground source system
- Reasonable controllability of the price of heat production
- Future proof installation

Weaknesses

- Initial SCoP efficiency analysis indicates the system wouldn't qualify for future incentives or London Plan recognition
- Extensive further investigations required with up front costs, considered as high-risk scheme
- Potential for diminishing efficiency due to no summer cooling load that would balance out ground temperature dissipation
- Limited land area available to configure abstraction and injection wells

Closed Loop Ground Water Source Heat Pump System - Manufacture E

Strengths

- Future proof installation

Weaknesses

- Initial SCoP efficiency analysis indicates the system wouldn't qualify for future incentives or London Plan recognition
- Large land area required for borehole ground heat exchanger array
- Potential for diminishing efficiency due to no summer cooling load that would balancing out temperature dissipation, this would also lead to potential environmental harm to the local ground
- High capital costs

Conclusion
The open loop ground source solution utilising ground water wells creates high risks at the initial preliminary design stages of the project, where further investigation and design work may not prove successful. The land area where the wells could be position is limited and orientations of the wells may not suit the ground water flow direction.

Both systems risk temperature ground dissipation causing environmental harm and diminishing heat pump performance due to the continuous heating demand without any cooling load.

The spatial area required to fulfil the bore hole array of the closed loop system doesn't lend itself to the estate, with extensive clearing and ground works required the closed loop isn't considered practical. Along with the environmental concerns to the ground environment, the closed loop ground source heat pump system is considered as not a feasible low carbon heating solution for the Maiden Lane estate.

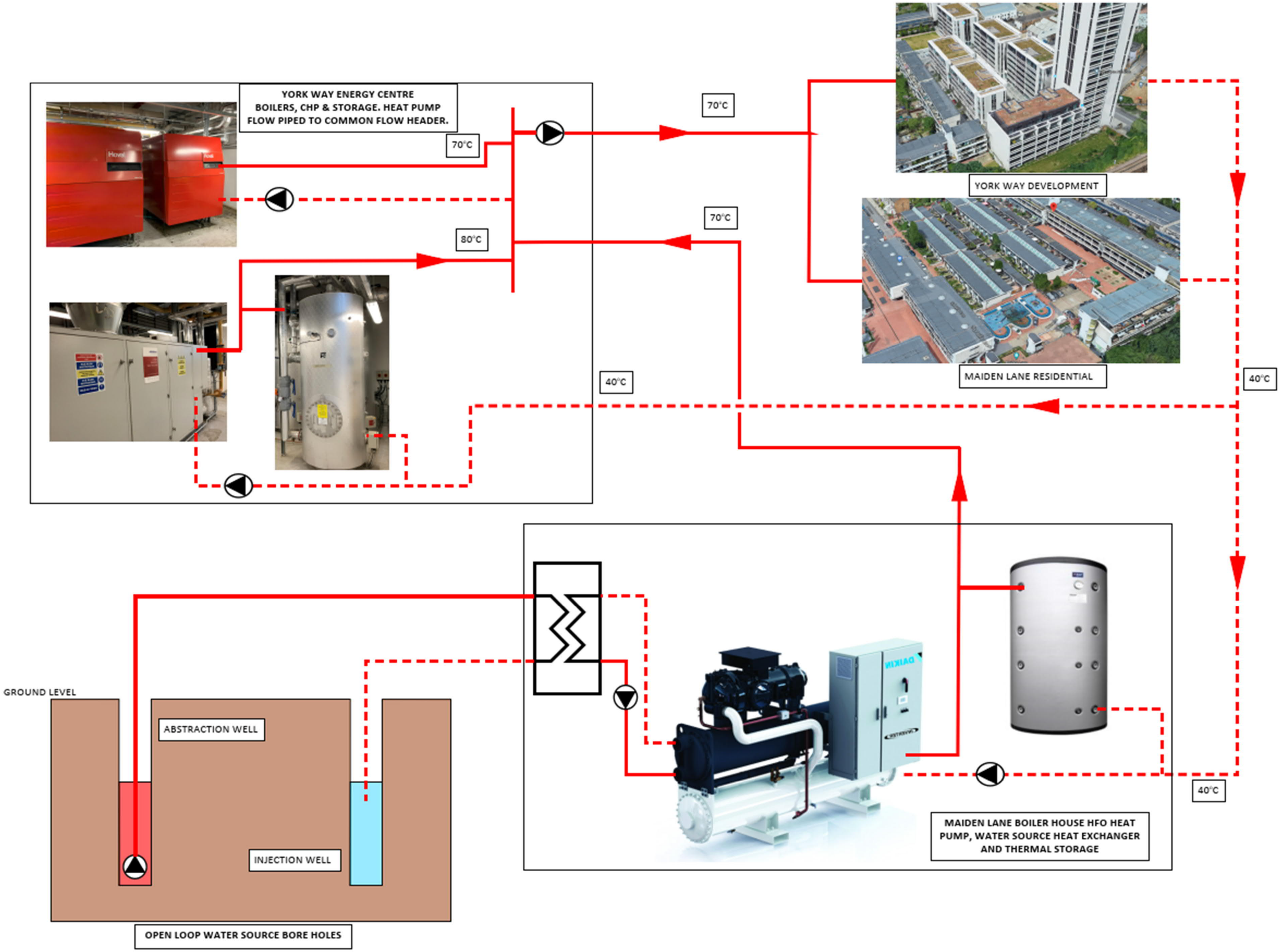

Figure 13 - HFO Refrigerant Open Loop Ground Water Source Heat Pump Site Integration Schematic

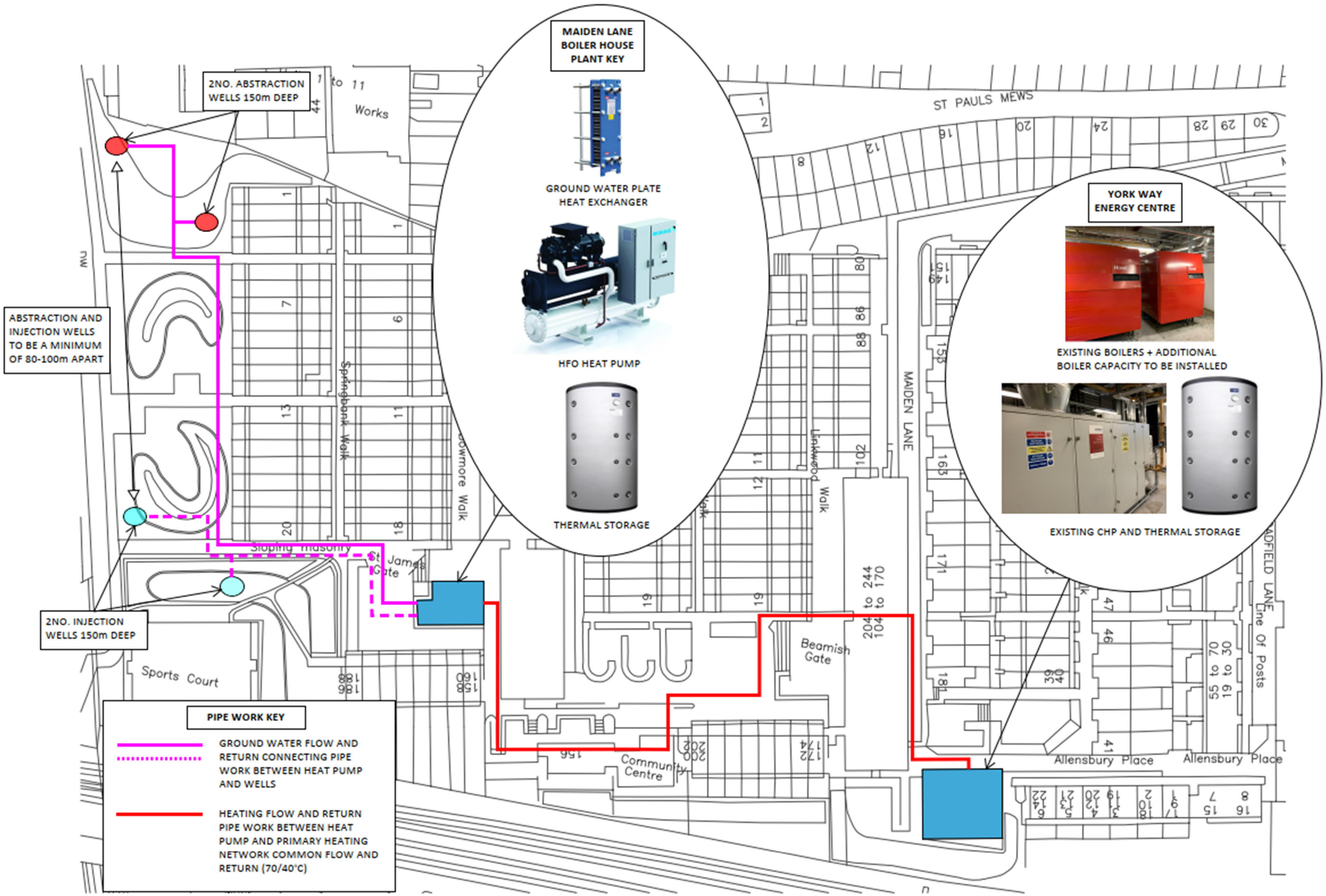

Figure 14 - HFO Refrigerant Open Loop Ground Water Source Heat Pump Site Integration Layout

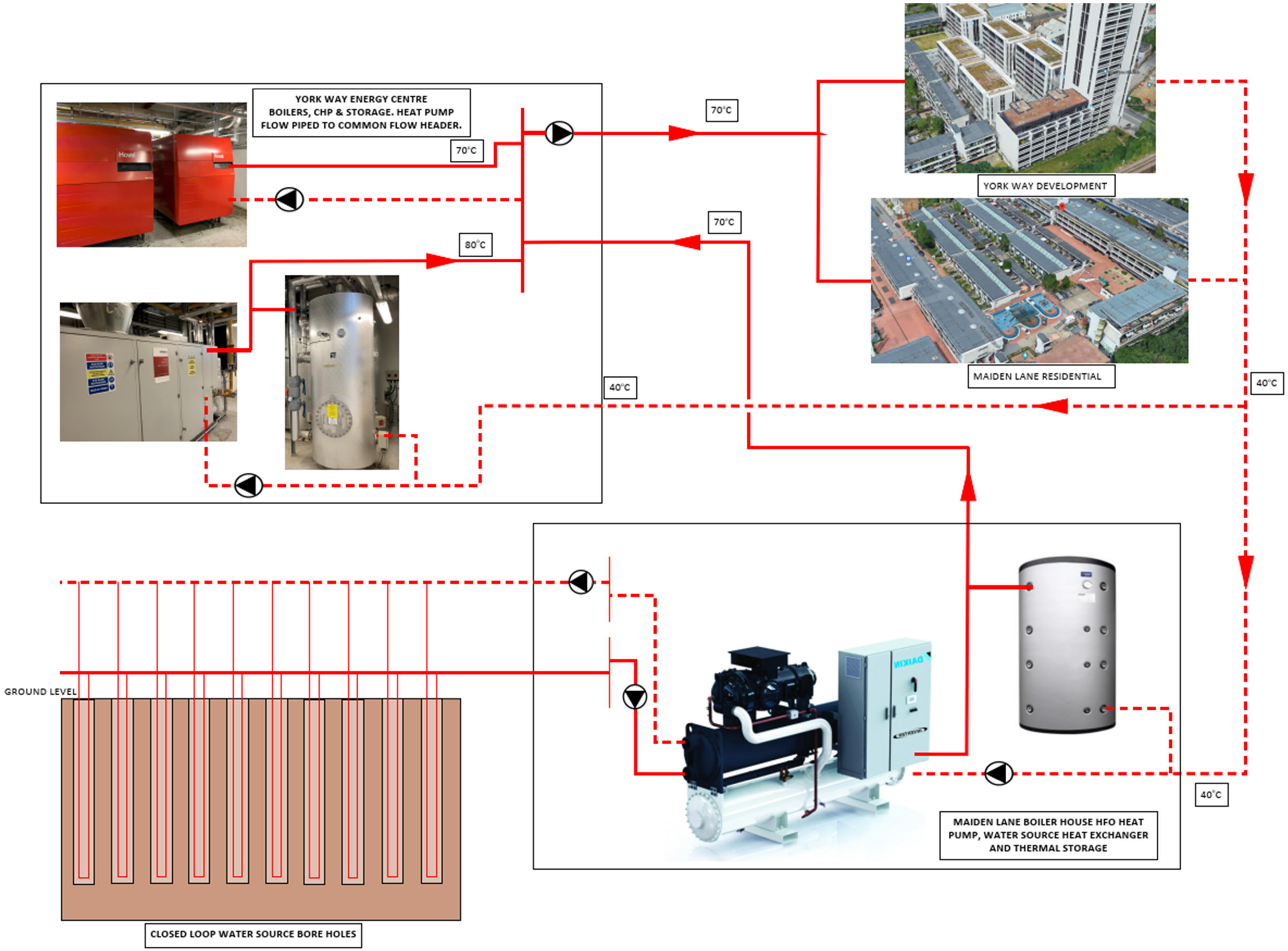

Figure 15 - HFO Refrigerant Close Loop Ground Source Heat Pump Site Integration Schematic

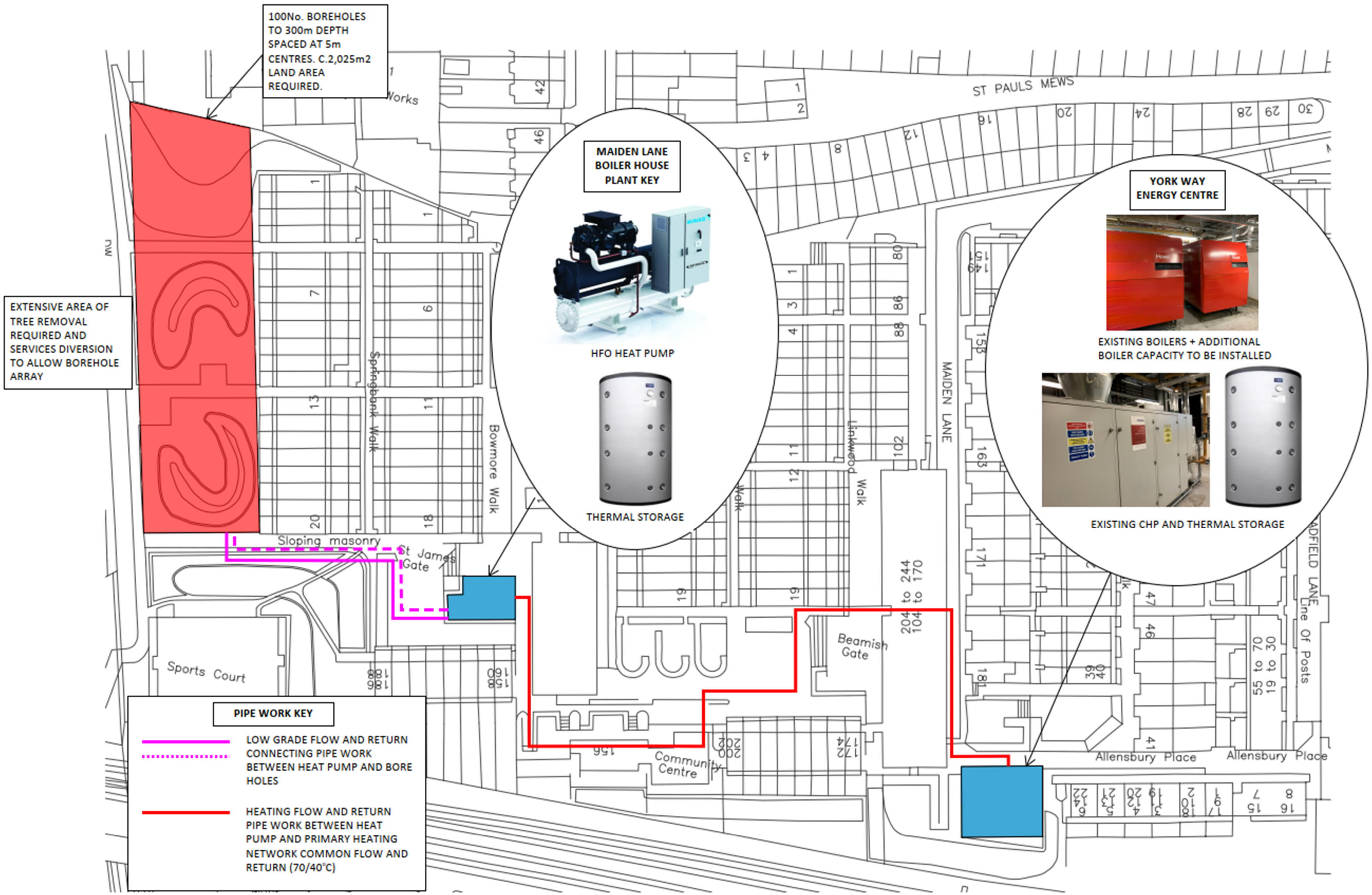

Figure 16 - HFO Refrigerant Close Loop Ground Source Heat Pump Site Integration Layout

6.0 WASTE WATER HEAT RECOVERY HEAT PUMP SYSTEM

6.1 System Description and Characteristics

Max Fordham commissioned Recirc Energy to carry out an initial feasibility study on the opportunity of recovering waste energy from the local waste water sewers that run along the boundaries of the Maiden Lane estate. Recirc Energy have extensive experience in waste water energy recovery and have enhanced the level of detail brought to this study with their knowledge of connections to sewer drains, the characteristics of the waste water within the sewers and additionally the operation of such energy recovery schemes.

The main parts of the system that make up a waste water heat recovery system are waste water collection chamber and connection to a sewer, a pumped filtration and heat exchanger arrangement and a water to water heat pump to increase the low grade temperature waste water to more usable temperatures for the use of space heating and domestic hot water.

The full waste water heat recovery feasibility report produced by Recirc Energy is attached in Appendix 1 of this report. Some of the diagrams produced in the report have been lifted from the Recirc report for the use of visual clarity in this report.

System type
As part of this study a Sharc filtration and heat recovery unit has been explored, due to the previous experience Recirc Energy have with a precedent project that they now operate. HFO heat pumps have been put forward by Recric in a cascaded series configuration.

The HFO heat pumps are manufacture by Trane and referred to in this study as Manufacture F.

There is other waste water filtration and heat exchanger equipment on the market, however with Recirc Energy's experience with operating a Sharc system it was decided that basing the study on this system would be the most beneficial for this study.

Components and how it fits together
To connect the Sharc heat recovery heat exchanger to the waste water sewer, a pumped below ground waste water service is connected into a local sewer. Holes are drilled into the main sewer pipe and by gravity sewer water and waste fall into a purpose-built collection chamber below ground. From here the sewer waste is pumped to a pre-screen buffer tank below ground that provides filtration of solids such a wipes etc. Another set of pumps pass the sewer water to a plant room where the Sharc heat recovery heat exchanger and filtration system are located. Once the waste water has passed through the Sharc system, the cooled waste water is passed back to the pre-buffer chamber which acts as a volumetric and thermal buffer. Depending on the volume and temperature of the waste water in the pre-buffer chamber, waste water is either returned to the sewer or mixed and recirculated through the heat recovery system.

The Sharc heat exchanger equipment is piped to the evaporator of a heat pump, which allows the transfer of thermal energy from the evaporator and into the refrigeration circuit. Through the vapour compression cycle the temperature of the energy recovery is increased and utilised from the condenser of the heat pump.

Site integration
The modular HFO heat pumps would supply heat to a self-balancing thermal storage vessel in the same configuration as the other heat pump proposals, enabling storage at times of low demand and heat injection directly into the common network return under times of higher demand, as shown in both Figure 17 and 18.

The preferred sewer connection point has been identified to the north of the Maiden Lane estate, which is a large combined sewer that flows from east to west along Agar Grove. The connection point is at a confluence of two large trunk sewers where high flow rates are expected with the opportunity for higher heat outputs. The connection point also initially appears to best fit the site layout constraints, with a corridor of land which is within the Maiden Lane estate boundary that connects the existing Maiden Lane boiler house to Agar Grove. This provides an accessible route for access and installation, along with a low risk area for coordination of existing services within soft dig.

Given the location of the sewer along Agar Grove in a busy road and near a bus stop, a road closure would be required. The connection to the sewer will require local excavation where 300-400mm tap in points are drilled into the sewer pipe. An option has been identified by Recirc Energy that allows a smaller diameter collection chamber to be constructed, which would minimise excavation. It appears this would be the preferred option to explore further. See page 15 of the Recirc Energy report in Appendix 1.

The sewer connection and pumping of waste water would only temporarily affect the local site and area through construction works. The pumping chambers and pre-screen buffer are proposed to be located within the corridor to Agar Grove which provide non-disruptive access for maintenance.

The Maiden Lane boiler house provides a suitable location to accommodate the heat pumps, Sharc heat recovery equipment and thermal storage. However, this is based on the opportunity of increasing the capacity and extending the York Way heating network to serve the old Maiden Lane blocks.

Availability
Recirc Energy have estimated that the minimum expected seasonal sewer flow rates from the confluence sewer are between 250l/s in winter to 150l/s in summer. Under these conditions a minimum waste water flow rate of around 45l/s is required to provide an output of 936kW from the heat pumps.

This shows that there is expected to be sufficient sewer flow with an otherwise wasted resource of energy that could be harnessed to provide the required output from a low carbon heat pump system.

Refrigerant
The water to water heat pumps proposed operate on a HFO refrigerant, the table below identifies the properties and complexities of the refrigerant.

Manufacture F	
Type	R1234ze is a HFO refrigerant
Environment	The chemical composition of HFO refrigerants are much more environmentally friendly than HFCs however do impose further safety measures. R1234ze – GWP 7 & ODP 0
Efficiency	The thermodynamic properties of R1234ze is similar to R134a, however a slight drop in CoP is seen. For a heating output 70ºC with ground source temperatures between 10-15oC, a relatively CoP can be achieved.
Safety	The refrigerant safety class of R1234ze is A2L mildly flammable and therefore requires design methods to mitigate risks such as ventilation systems and lead detection.
Price	R1234ze is a relatively new refrigerant with quite a high cost at c.£27.53.

Table 22 – Manufacture D refrigerant review

6.2 Future Proof

The HFO refrigerant offers future security due to its low environmental impact that avoids future phase outs which would result in increased refrigerant costs and restrictions.

With the correct maintenance procedures in plan, the life expectancy of the refrigeration equipment is expected to span over 20 years which would qualify for the heating network life expectancy.

From Recircs experience with operating a precedent Sharc heat recovery system they can confirm the quality of filtration and heat exchanger system which shows no sign of failure with the correct maintenance procedures in place. With the following annual maintenance procedures below in place a 20 year life span is expected of the system.

- Annual routine maintenance
- Annual clean down
- Heat exchanger cleaning 8 times per year

6.3 Efficiency

The CoP of a waste water source heat pump is dependent upon the temperature of the water that is approaching the heat pump from the sewers. Recirc Energy from their experience and provided the following expected temperatures that are to be expected from a London based combined trunk sewer.

Winter	12ºC
Spring	13ºC
Summer	19ºC
Autumn	17ºC

The SCoP of the waster water source heat pump system has been calculated in accordance with BS EN 14825, taking into consideration the summer hot water demand in addition to the winter peak space heating and hot water demand. Additionally, the configuration of series heat pumps have been considered by Recirc Energy when providing the CoPs, and the waste water pumping and heat exchanger ancillaries have also be captured in the SCoP calculation.

Manufacture F – 3.31 SCoP

It is expected that the latest version of the GLA London Plan and any updates to the RHI will require a minimum SCoP for heat pumps of 2.8.

6.4 Environmental and Economic Factors

The capital costs for heat pumps, Sharc heat recovery equipment and ground works have been estimated by Recirc Energy. There is a 15% + or – contingency on the cost of the ground works and Sharc equipment. This is due to the amount of excavation carried out during the connection works to the sewer and also Sharc equipment being manufacture in Canada so shipping costs can vary.

All-in installation costs have been determined from Spon's Mechanical and Electrical Services Price book. Costs are an estimate for comparison and feasibility purposes.

Manufacture F Sharc Waste Water Heat Recovery System	
Preliminaries	£65,418
Heat recovery system inc. civil works	£610,783 (+/- 15%)
Heat Pump and plant room installation	£681,267
Heat Pump and plant room installation	£668,252
Additional items buried pipework and control and power wiring to York Way energy centre, new power supply and substation etc.	£272,100
Estimated grand total Ex.VAT	*£1,629,567*

Table 23 – Boiler base case environmental and financial estimated performance

It can be seen that utilising the HFO heat pumps the capital cost of the overall water source heat recovery system has been controlled. There was a concern that the anticipated civil works would increase the cost above a bespoke air source heat pump system, however the costs are comparable.

The annual maintenance costs for this type of system and the heat pump are more than an air source heat pump system, but less annually than the Ammonia heat pump. This is due to the challenges faced when handling Ammonia. Typical expected maintenance costs are as below.

• Annual routine maintenance	£2,000/yr
• Annual clean down	£3,500/yr
• Heat exchanger cleaning 8 times per year	£6,875/yr
• Heat pump service	£6,500/yr
	£18,875/yr

A gas boiler base case has been used to compare the annual economic and environmental performance of the heat pump proposals from Manufacture F. The energy prices and carbon factors used for this estimation can be found in Chapter 7. When determining the cost of heat production, the ongoing maintenance costs have been including, although it is recognised that these costs could be included in a separate service charge. The cost of heat calculated doesn't include circulation pump utility costs. The cost of heat has been shown with the current RHI tariff for the production of low carbon heat and also without.

Boiler Base Case	
Annual operational carbon equivalent emissions	1,701tonnesCO_2e/year
Anticipated cost of heat	3.7p/kWh

Table 24 – Boiler base case environmental and financial estimated performance

Manufacture F	
Annual operational carbon equivalent emissions	931tonnesCO_2e/year *(45% reduction)*
Anticipated cost of heat	5.99p/kWh
Anticipated cost of heat (with RHI)	3.43p/kWh

Table 25 – Manufacture F environmental and financial estimated performance

The environmental and financial benefits from the water source heat recovery system are rewarding and again comparable to the bespoke air source system. The lower maintenance cost than the Ammonia heat pump system is a benefit.

6.5 Complexities

Due to the nature of the system there are various complexities that would be faced when planning and constructing the waste water heat recovery system to a below ground sewer. These initially have been identified below.

The quantity of excavation and location around the sewer on Agar Grove road will require a road closure. This will require agreement with the Council during the planning stage. A logistics plan is required to indicate the amount o excavation, where the excavated earth will be stored, and how long the excavation will be open to allow the connections to the sewers before being reinstated.

Along with this, excavation will be required along the Maiden Lane soft dig foot path corridor that runs down the west site of the estate. It appears this corridor could also be used for emergency vehicle access and also for the care takers deliveries of equipment. A plan will be required to enable access to still be provided or via a different route.

Recirc Energy have started a dialog with Thames Water with regards to the most likely terms of a sewer connection agreement and the process required. Thames Water's current position on the commercial considerations for sewer heat recovery at Maiden Lane would be that a use of sewer agreement to abstract the waste water would be similar in nature to a standard connection agreement. Thames Water expressed no usage charge rate from the abstraction but showed interest in sharing such carbon savings obtained for the heat recovery system.

Recirc Energy have also identified that the proposal includes works that may impact (are within 10m) of the existing operational railway. This will require a BAPA (Basic Asset Protection Agreement) between the developer and Network Rail

6.6 Further Investigations Required

The complexities identified as part of this study leads to further investigations required to develop the proposal further. This mainly comes down to agreements with the sewer connection and excavation. The information provided by Recirc Energy to date identifies the proposal is suited to the estate layout in terms of land ownership, layout, available plant space and in proximity to a suitable sewer.

In order to progress the feasibility further the awaiting Thames Water modelled sewer data and further detailed sewer maps will verify the assumptions made by Recirc Energy within the initial feasibility study.

The next steps would then be to actually carry out recorded monitored sewer flow and temperature measurements. This would validate the expected heat pump SCoP and overall system efficiency along with thermal output.

Along with this, a sewer connection application would be submitted and a commercial discussion with regards to abstraction between Thames Water and Camden. To confirm the installation costs soft market testing on the system as a whole can be tendered along with various waste water heat exchanger and filter systems explored within a tender.

Specialist design would be carried out on the basis of a successful tender and basis that the above steps where satisfied. The preliminary cost for the above has been estimate by Recirc Energy as £65,418.00 +VAT.

6.7 Precedent Installations

Recirc Energy own and operate a waste water heat recovery system including a Sharc heat exchanger and filtration system with heat pumps providing 800kW of thermal energy to the Borders College in Scotland. The heat pumps deliver heat at 60oC and achieve a peak COP of 4.8. The scheme has been running since 2015 and provides a saving of 170tonnesCO_2e/year.

Recirc Energy commented on the operation and maintenance of the heat recovery equipment at the Borders project, to which they were impressed with quality of. They have not had to replace and major waste water components due to wear and tear in the 5 years of operation.

The Borders project shows that the waste water system has been tried and tested and the involvement that Recirc have had with this brings confidence in terms of procurement, installation and operation. See Appendix 2 for a detailed write up on the Borders project

Figure 16 – Borden College Sharc Heat Exchanger and Filtration System

6.8 Feasibility

The strengths and weaknesses have been summarised below for waste water heat recovery system and these findings are collated in a feasibility matrix at the rear of this report.

Waste Water Hear Recovery Heat Pump System - Manufacture F

Strengths

- Comparable capital cost to bespoke air source heat pumps
- Good controllability of the price of heat production
- Future proof installation
- The estate is in close proximity to a sewer of suitable size in terms of flow and temperatures
- Land ownership and plant room space suits the application and equipment
- High SCoP is achievable through the use of HFO heat pumps and waste water approach temperatures

Weaknesses

- Extensive excavation with a predicated 15% +/- contingency cost
- Road closure would be required during the connection to the sewer
- Commercial agreement required for the use of waste heat
- Preliminary costs to validate sewer flows and temperatures

Conclusion
Due to the nature of the system relying on the location of local sewers in close proximity to the demand, the system doesn't suit every application. However, at the Maiden Lane site the initial feasibility study indicates that the site layout suits the waste water heat recovery system in terms on site integration and suitability to demand.

The estimated efficiency of the system provides large carbon savings the estates heating demand, along with opportunity to provide controlled low cost heat.

The HFO heat pumps are future proof and with the correct maintenance procedures in place the precedent installation indicates the quality of a future proof system.

The proposal is seen to be suitable as a low carbon investment to continue with further development in terms of returns to the estate and shall be explored further.

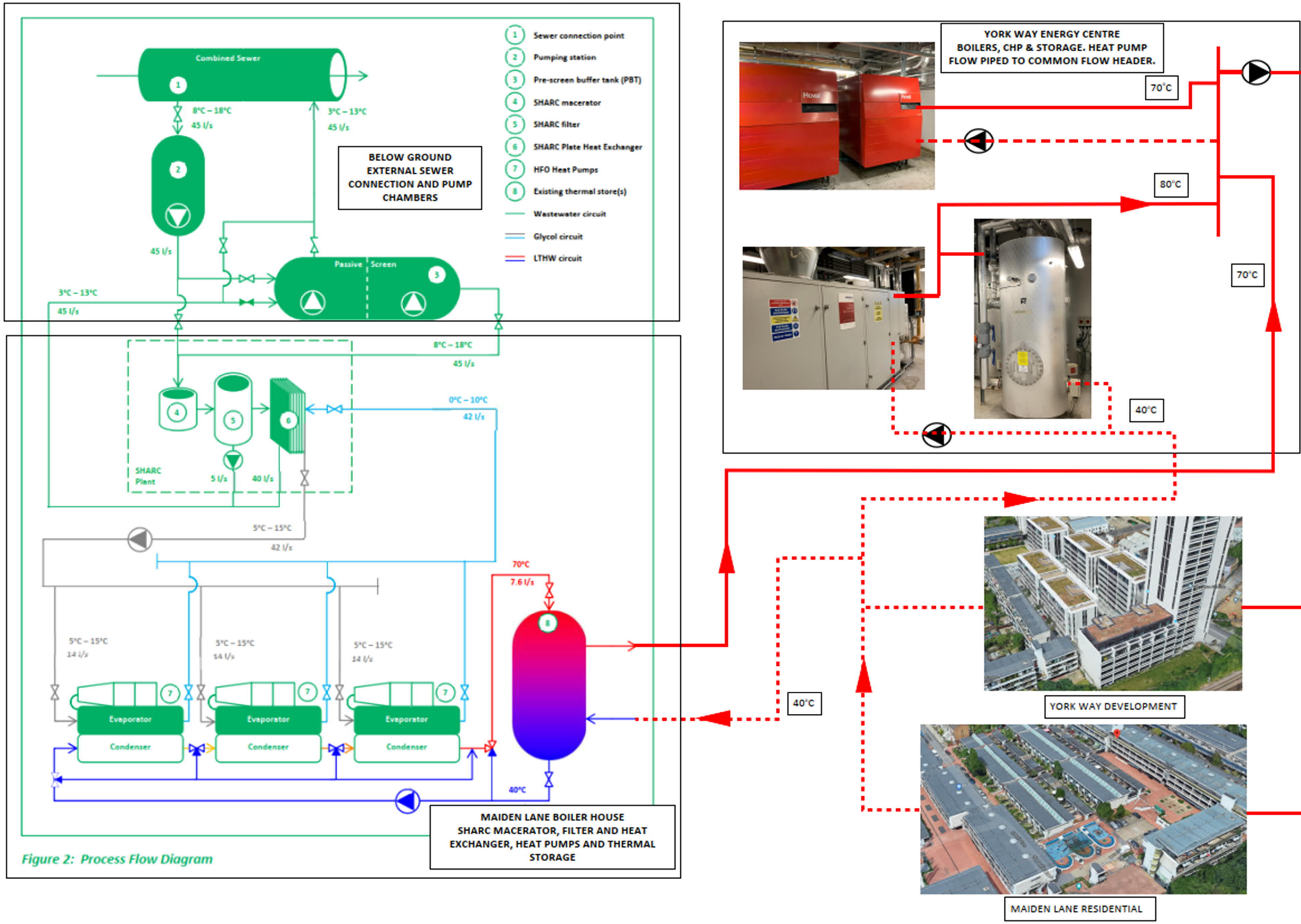

Figure 17 - HFO Refrigerant Sharc Waste Water Heat Recovery Heat Pump Site Integration Schematic

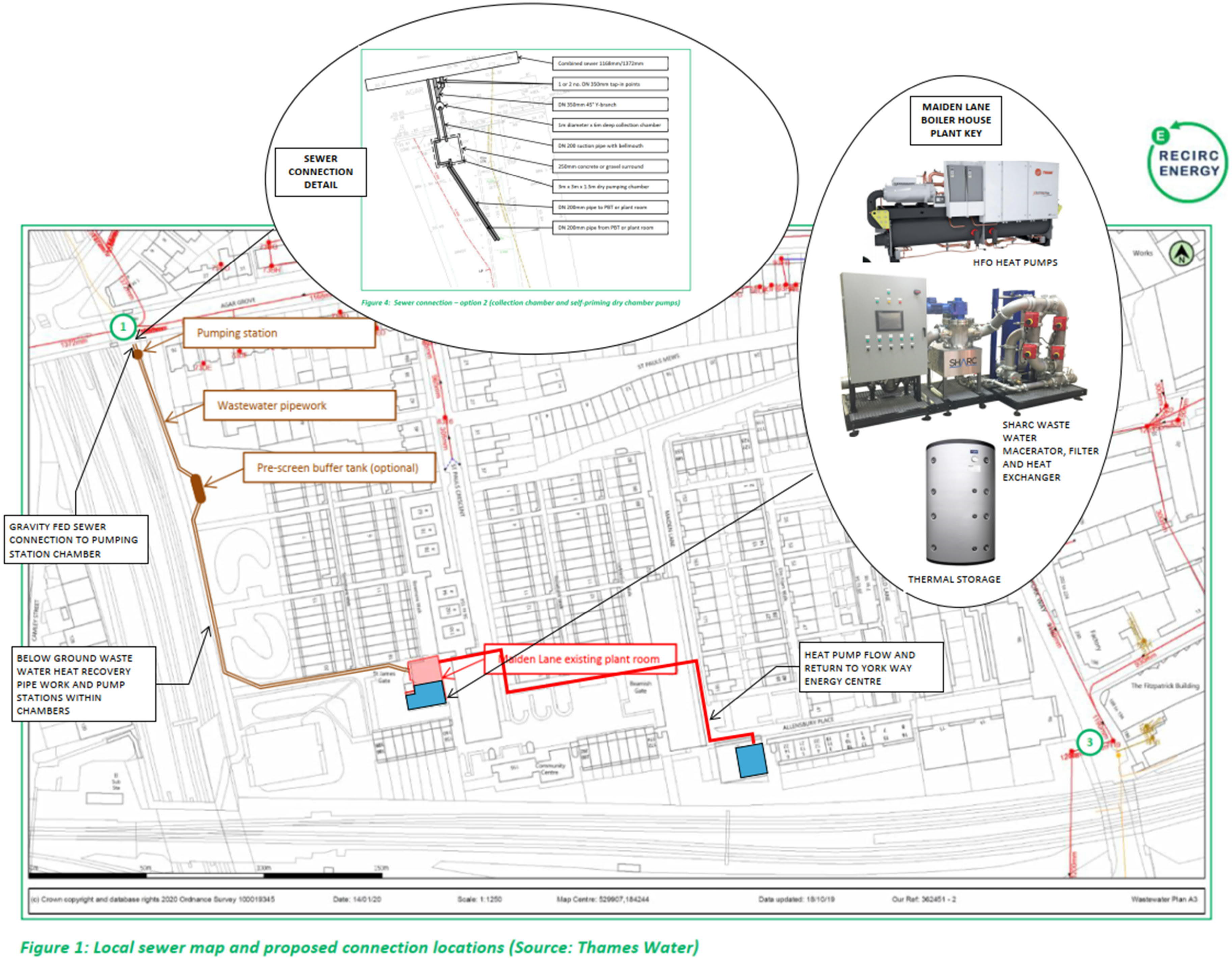

Figure 18 - HFO Refrigerant Sharc Waste Water Heat Recovery Heat Pump Site Integration Schematic

7.0 FEASIBILITY CONCLUSION

7.1 Low Carbon Heating Technology Matrix

A summary of the practical and technical viability findings has been outlined below with a visual representation of the project feasibility through a weighted matrix.

The Type 1 air source heat pumps utilising either a natural or hydrocarbon refrigerant coupled with a DAC have been seen to provide a low carbon heating solution for the Maiden Lane estate. The future proof characteristics of the equipment and refrigerant, along with the rewarding seasonal efficiency out-perform the other air source heat pump configurations and types.

The Type 2 air source heat pump systems configured with air source chillers and water to water heat pumps have their limitations with efficiency and lack of precedent installations on large heating networks. The refrigerant that Manufacture D operates on doesn't offer future protection, unlike natural, hydrocarbons or HFO refrigerants.

The weakness of the Type 1 air source system is the acoustic, visual and structural impact the external plant could have on the existing site, which needs to be investigated further.

The available land area at the Maiden Lane estate restricts the opportunity of a closed loop ground source heat pump system. With the densely packed array that is required to meet the heating load creates problems with the ground environment, particularly without a cooling load to help balance the annual ground temperature dissipation.

The waste water heat recovery heat pump system suits the site layout and provides rewarding carbon and financial benefits to the use of heat on the estate. It is seen as a technology to explored further in relation to the Type 1 air source heat pump systems.

The following feasibility matrix in Table 12 represents the above and provides a weighted feasibility ranking.

7.2 Feasibility Going Forward

The feasibility matrix identifies in terms of a scored weighting that the Hydrocarbon type 1 air source heat pump and waste water source heat pump system are the most suited low carbon heating technologies to the Maiden Lane estate.

A final feasibility report shall be produced that investigates the type 1 air source heat pump further to understand the intricacies and detail of locating external plant on the community centre roof in terms of noise, structure and aesthetics. The findings from these further investigations will be looked at against the waste water heat recovery scheme, the most suitable proposal will be recommended with further detailed explored on the cost of heat, life cycle cost and site engineering integration.

			System Cost			Cost of Heat (without RHI)			Maintenance Cost			Seasonal Efficiency SCoPnet			Spatial Requirements (heat source heat exchanger, req.d plant space)		Future Proof (Components and refrigerant)		Environmental Impact (carbon savings and local environment)		Overall Practicality		
Manufacture		**Heat Pump Technology**	*£m.*	Weight	Score	*p/kWh*	Weight	Score	*£k./yr*	Weight	Score	*SCoP*	Weight	Score	Weight	Score	Weight	Score	Weight	Score	Weight	Score	**Total**
A	GEA	Air Source - Type 1	*1.89*	5	**3**	*6.51*	5	**4**	*25.2*	3	**1**	*3.01*	5	**4**	4	**3**	4	**4**	4	**4**	4	**2**	110
B	Solid Energy	Air Source - Type 1	*1.77*	5	**4**	*5.75*	5	**5**	*9.4*	3	**3**	*3.38*	5	**5**	4	**3**	4	**4**	4	**4**	4	**2**	131
C	Daikin	Air Source - Type 2	*1.41*	5	**5**	*7.81*	5	**2**	*11.0*	3	**2**	*2.25*	5	**2**	4	**3**	4	**3**	4	**3**	4	**2**	95
D	Mitsubishi	Air Source - Type 2	*1.28*	5	**5**	*7.46*	5	**2**	*11.0*	3	**2**	*2.25*	5	**2**	4	**3**	4	**1**	4	**3**	4	**2**	87
E	Gcore	Ground Source - Open	*1.63*	5	**4**	*7.3*	5	**3**	*10.2*	3	**2**	*2.45*	5	**3**	4	**2**	4	**4**	4	**2**	4	**2**	96
E	Gcore	Ground Source - Closed	*2.96*	5	**2**	*7.3*	5	**3**	*10.2*	3	**2**	*2.45*	5	**3**	4	**1**	4	**3**	4	**2**	4	**1**	74
F	Sharc	Sewer heat recovery	*1.63*	5	**4**	*5.99*	5	**4**	*18.8*	3	**1**	*3.31*	5	**5**	4	**4**	4	**4**	4	**4**	4	**3**	128

Score Scale	
Worst weighting	1
Best weighting	5
Max score	148

Table 14 – Low carbon heating technology feasibility matrix

8.0 REFERENCES

[1] BEIS, “Clean Growth - Transforming Heating,” The Department for Business, Energy & Industrial Strategy, London, 2018.

[2] FSW Refrigeration , *Refrigerant Price List,* Reading, 2020.

[3] Environment Agency, “Environmental good practice guide for ground source heating and cooling,” Environment Agency, Bristol, 2011.

[4] Environmental Agency, “Open-loop heat pump systems: permits, consents and licences,” 3 April 2018. [Online]. Available: https://www.gov.uk/guidance/open-loop-heat-pump-systems-permits-consents-and-licences.

[5] BEIS, “Future support for low carbon heat,” The Department for Business, Energy & Industrial Strategy, London, 2020.

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9.0 ASSUMPTIONS USED

The following assumptions have been used to generate the environmental and financial performance factors each technologies feasibility within this study.

Natural gas and grid supplied electricity utility cost, 2020 estimated prices.

Natural Gas	3p/kWh
Electricity	15p/kWh

Natural gas and grid supplied electricity fuel carbon intensity factors.

Natural Gas	0.184kgCO_2/kWh (UK Gov. 2019 Emission Factor Tables)
Electricity	0.256kgCO_2/kWh (UK Gov. 2019 Emission Factor Tables)

The current (Q2 2020) non-domestic Renewable Heat Incentive (RHI) tariffs.

Air source heat pumps	2.79p/kWh for 20-years (Minimum SCoP 2.5)
Ground source heat pumps	2.89p/kWh for 20-years (Minimum SCoP 2.5)

The current RHI scheme is being axed and a cut off date for commissioned systems to receive the incentive is the 31st March 2021. The program for the heating network upgrade at Maiden Lane falls outside the RHI cut-off date which means that a scheme at Maiden Lane won't be eligible for the current RHI incentive.

There are currently consultations being undertaken on the future of the NDRHI subsidy (for which applications will be closed in 2021 but payments will be guaranteed until 2041) and the Future Support for Low Carbon Heat, which includes a Clean Heat Grant scheme, meant as a follow on from the RHI, as well as a £270 million Green Heat Network scheme [5].

The Clean Heat Grant scheme is anticipated to begin to provide subsidies between April 2022 and March 2024. It is aimed at households and small non-domestic buildings, however, and only funds installations up to 45kW, providing a £4000 flat rate for all technologies: meaning the Maiden Lane heat pump will not be eligible for this subsidy as the current proposal is based on a 750kW output installation [5].

The consultation contains limited information about the proposed Green Heat Network scheme. The scheme will be able to provide £270 million of funding, and will be accessible from 2022-2025, the aim of it being to bridge the gap between the NDRHI and the Heat Network Investment Project (HNIP), essentially £90 million/year of funding for all projects [5]. There is uncertainty over how much funding the scheme will provide and what installations would be applicable; whether it would only apply to the network capital/improvement costs or whether it would also apply to larger heat pump installations over 45kW, which are not anticipated to be covered under the new Clean Heat Grant proposal.

Future incentives are expected to support the uptake on heat pumps and further information shall be consulted with Camden upon earliest receipt.

10.0 APPENDIX 1 – WASTE WATER HEAT RECOVERY SHARC FEASIBILITY REPORT

MAX FORDHAM

Maiden Lane and York Way Wastewater Heat Recovery System

Project	Maiden Lane Energy Centre: Wastewater Heat Recovery System		
Client	Max Fordham LLP		
Contact	James Bowman		
Project Reference	MAX001		
Report type	Feasibility Report		
File name	MAX001 Max Fordham Maiden Lane Energy Centre 2020 07 12		
Revision	Author	Reviewer	Date Approved
Draft	Joe Short	Stewart McDonald	09/07/2020
Final	Joe Short	James Bowman	12/07/2020

Contents

Introduction

Max Fordham are evaluating the potential of using wastewater heat recovery (WHR) technology in combination with water-source heat pumps at the Maiden Lane Estate in The London Borough of Camden (“Camden”) to capitalise on this inexhaustible and very efficient renewable heat source.

Heat will be supplied in the form of low temperature hot water (LTHW) via an existing district heat network (DHW) to a nearby housing development for space heating and domestic hot water.

The report below comprises a preliminary conceptual design and costing to support Max Fordham in the development of a business case and project plans.

Key benefits of WHR

Affordable

WHR combines tried-and-tested components in innovative ways to provide affordable technology solutions. WHR combines water-source heat pumps, a highly reliable and efficient way to produce low-carbon heat, with an innovative heat source in the form of wastewater from sewers and industrial sources. WHR uses off-the-shelf, tried and tested components, to provide a heat source buffering, filtration and heat exchange which is easy to install and low cost to repair and maintain. High levels of system efficiency and availability are further achieved by using carefully selected instruments, control and automation to run and operate the system.

Reliable and robust

Wastewater is an abundant and inexhaustible source of heat. WHR technology is simple, reliable and robust. Screening is achieved in one or two stages depending upon the application: 1) a coarse pre-screen in an underground wastewater buffer tank where there are high levels of solids to be removed such as non-dispersible wipes, and 2) a fine SHARC filter in the energy centre to remove a large proportion of any remaining solids. The filtered wastewater is then ready to be fed into a traditional plate heat exchanger technology.

Efficient, low carbon heat

The SHARC fine filtering system enables the use of plate heat exchangers. These are the most compact, efficient and low-cost heat exchangers for heat recovery.

Wastewater is a warm heat source providing high heat pump efficiency. WHR heat pump systems save over 50% on carbon emissions compared to boilers using fossil fuels. WHR heat pump systems only use about 0.25 to 0.3 kWh of electrical power to produce 1 kWh of heat, whereas boilers (depending on type and age) consume about 1.1 to 1.2 kWh of combustible fuel.

Heat pumps will continue to provide further carbon savings as electricity production is decarbonised. Since 2002, grid electricity generation carbon emissions have decreased by 43% from 0.45 to 0.26kg/kWh and this is expected to continue.

Heat pumps can be retrofitted into an existing building to achieve a level of energy efficiency greater than that of many new buildings. WHR is also suited to buildings that are Listed and/or in Conservation Areas where other renewable energy or energy efficiency options are limited.

Project brief

Introduction

Recirc Energy (Recirc) have been commissioned by Max Fordham (and Camden Borough Council) to carry out a feasibility study into the use of a wastewater heat recovery (WHR) system to provide heat to the heating network that serves the Maiden Lane Estate as part of a low carbon heat generation plant study.

The goal of the low carbon heat generation is to supply the base heating demand of the Estate from a Heat Pump system providing a reduction in carbon emission whilst controlling the price of heat generation.

The heating network upgrade plan that Max Fordham are investigating is based upon the following:

- Combine the heating loads of the York Way and Maiden Lane development and create an Estate wide heating network
- Utilise the York Way energy centre boilers and CHP
- Add a gas fired boiler(s) to allow some redundancy
- Add a heat pump to provide the base heat load with circa 15m^3 of thermal storage
- Lay new district heating pipework and with new HIUs, radiators and controls supplying the 1970/80s Maiden Lane development
- Retain the York Way district heating pipework

Max Fordham has asked Recirc to provide a costs and basic technical information for a SHARC-based WHR solution. The heat pump system is expected to have a heat output capacity in the region of 750kW to 1000kW delivering low temperature hot water (LTHW) at flow/return temperatures of 70/40°C.

The costs and technical information provided is based on using HFO refrigerant charged heat pumps as a lower-capex alternative to NH_3 refrigerant based heat pumps.

High levels of efficiency and availability are also achieved using carefully selected instruments, control and automation to optimise how the heating system is operated.

Key objectives of this study

Max Fordham has asked the following aspects to be covered in the writing of this report:

- Heat recovery and interface equipment required
    - A schedule of plant and equipment as well as underground structures (sewer connection and pumping station) required for the project is provided
    - Dimensions, including the footprint required by the whole wastewater heat recovery system including and heat pumps is provided
    - Estimated electrical power supply required for WHR equipment
- Equipment interface with the site (considerations for piping routes and plant location)
- Sewer flow review - potential for heat recovery
    - The likelihood of there being sufficient flows based on previous project experience

- Thames Water to obtain modelled flow data where possible
    - Amount of extractable energy from the modelled flow rate
    - Average temperatures for spring/summer/autumn/winter for COP calculations
- Understanding the sewer interface and civil works
    - Sewer connection options (final design subject to Thames Water approval)
    - Advantages and disadvantages of the different connection options
- Thames Water
    - Liaise with Thames Water to establish a dialogue regarding a potential sewer connection and abstraction point.
    - Discuss high-level outline/heads of terms of a sewer connection agreement
    - Discuss process required by Thames Water to establish the above sewer connection and connection agreement
- Heat pump evaluation
    - We will suggest potential heat pump options and configurations
- Understanding of CAPEX and OPEX
    - Provide indicative CAPEX with an indication of certainty/risk at this stage (±%)
    - Provide indicative OPEX with an indication of certainty/risk at this stage (±%)
- Required maintenance procedure for SHARC heat recovery system
    - Routine/preventative maintenance activities required and costs

Project Description

Project Location

The project is located at the Maiden Lane Estate in the London Borough of Camden, south of Agar Grove and west of York Way (A5200).

Maiden Lane Estate comprises of the 1970/80s Maiden Lane development and the more recent York Way development that was constructed in 2015. The Maiden Lane development consists of 443 no. dwellings ranging from bedsits to four-bedroom maisonettes along with a community centre. The York Way development is 273 no. flats across several blocks.

The Maiden Lane development is currently supplied by old gas fired boilers and the York Way development is supplied by a new energy centre with gas fired boilers and a gas-fired combined heat and power (CHP) plant with 10m^3 of thermal storage.

After assessing the options of locating the SHARC WHR system and heat pumps at either Maiden Lane plant room or York Way energy centre, it was decided the existing plant room at Maiden Lane was the best location for the following reasons:

- Large amount of space available allowing the colocation of SHARC equipment and heat pumps
- The use existing building will reduce capital costs and planning consent requirements
- Maiden Lane has a larger existing power supply that can be upgraded more easily to that required by the SHARC equipment and heat pumps
- It is relatively simple to run a cable to take the power from the CHP in York Way to Maiden Lane to directly use the power from the CHP to power the heat pumps

Heat Demand

Heat demand data was provided by Max Fordham (see Table 1 below). This shows heat loads for the two heating network options under consideration: option 1) providing space heating and domestic hot water (DHW) for both Maiden Lane and York Way dwellings, or option 2) providing space heating and domestic hot water (DHW) for Maiden Lane dwellings alone. The peak heat loads of 4.0MW have been estimated with heat pumps providing a baseload capacity of 500 to 750kW, providing 3.4 to 5.5GWh of heat per year (70% of the total annual heat load).

Table 1: Heat loads (Source: Max Fordham)

Option 1 - Maiden Lane & York Way	Value	Units
Estimated Peak Heat Demand	4.0	MW
Annual Heat Demand	7864	MWh
Annual Heat from Heat Pump	5533	MWh
Annual Heat from Boilers	2331	MWh
Anticipated Heat Pump Power	750	kW
Percentage of Heat Demand from Heat Pump	70.4	%
Heat Pump Run Hours	7728	hours
Option 2 - Maiden Lane	**Value**	**Units**
Estimated Peak Heat Demand	2.25	MW
Annual Heat Demand	4866	MWh
Annual Heat from Heat Pump	3423	MWh
Annual Heat from Boilers	1442	MWh
Anticipated Heat Pump Power	500	kW
Percentage of Heat Demand from Heat Pump	70.4	%
Heat Pump Run Hours	7728	hours

Sewer Connection Location

Please see Figure 1 for a map of the potential sewer connection points onto the sewer network operated by Thames Water.

The preferred sewer connection point identified (see no. 1, Figure 1) is a confluence where a large (1168mm) combined (surface and foul water) sewer flowing east to west along Agar Grove feeds into another larger (1372mm) trunk sewer running north to south across St Augustine's Road. This location was chosen as the preferred sewer connection point for the following reasons:

- Connection point is at the confluence of two large trunk sewers
  - High flow rates expected to be far in excess of what is required
  - Opportunity for higher heat outputs and financial returns
- Corridor of land (confirmed by Max Fordham to be owned by Camden Borough Council) leads from the sewer connection point to the energy centre, providing
  - Space available for off-road pumping station
  - A lower cost route for wastewater pipework with

- Low number of underground utilities (confirmed by drawings supplied by Max Fordham: GS8110931 Sheet 1 of 10 and GS8110931 Sheet 7 of 10)
- Portions of soft dig and block paving to reduce trenching costs

  - Safer route in terms of CDM
  - Less disruption to car users and reduced need for lane closures during construction
  - Minimising apparatus in the highway for easier permitting under The New Roads and Street Works Act

- There are some considerations that will need to be addressed when using this route
  - Permission to use the land from Camden Borough Council
  - Emergency vehicle access will need to be maintained during construction
  - As the proposal includes works which may impact (are within 10m of) the existing operational railway, a BAPA (Basic Asset Protection Agreement) will need to be agreed between the developer and Network Rail

Sewer Resource

Recirc has provided conservative estimates (based on previous project experience) of sewer flows and temperatures for the different seasons of the year in Table 2. It is important to note that these are estimates only and sewer flows and temperatures will need to be confirmed by undertaking full sewer monitoring. Dry weather (foul only) sewer temperatures and flows vary from location to location based on the number of types of building connected to the branch of the sewer network and the average distance between these buildings to the sewer connection point. Wet weather sewer temperatures and flows vary due to amount of surface water captured by the branch of the sewer network and prevailing ambient temperatures. The temperatures shown where used to calculate COP/SCOP of the heat pumps later in the report.

Table 2: wastewater flows and temperatures (Source: Recirc Energy Ltd)

Season	Months	Flow rates (l/s) Average (typical range)	Temperatures (°C) Average (typical range)
Winter	Dec, Jan, Feb	500 (250 – 630)	12 (8 – 14)
Spring	Mar, Apr, May	400 (200 – 530)	13 (9 – 17)
Summer	Jun, Jul, Aug	300 (150 – 400)	19 (16 – 24)
Autumn	Sep, Oct, Nov	500 (250 – 630)	17 (12 – 20)

Table 2 shows average seasonal flow rates ranging from around 300 l/s in summer to 500 l/s in autumn and winter months. Minimum expected flow rates are estimated to be 250 l/s in winter; 160 l/s in spring; 150 l/s in summer; and 250 l/s in autumn.

The actual flow of wastewater required for the 936kW proposed WHR solution is around 45l/s. Table 3 shows the percentage of the seasonal wastewater flows that would be required to meet to meet the 936kW peak heat output required for the WHR solution. It is clear there is excess wastewater flow available. The largest proportion of wastewater flow that would need to be captured is 30%, which will be very straightforward to abstract using a simple teed sewer connection.

Table 3: wastewater flows and heat outputs

Season	Flow rates (l/s) Average (minimum)	% of sewer flows required Average (maximum)
Winter	500 (250)	9% (18%)
Spring	400 (200)	11% (23%)
Summer	300 (150)	15% (30%)
Autumn	500 (250)	9% (18%)

Modelled Flow Rates

Through its connections with Thames Water, Recirc has requested modelled flow data for the planned connection point on Agar Grove. This information has been obtained at no additional cost. At the time of writing, the modelled flow data was outstanding from Thames. It is hoped the data will be available around the middle of July.

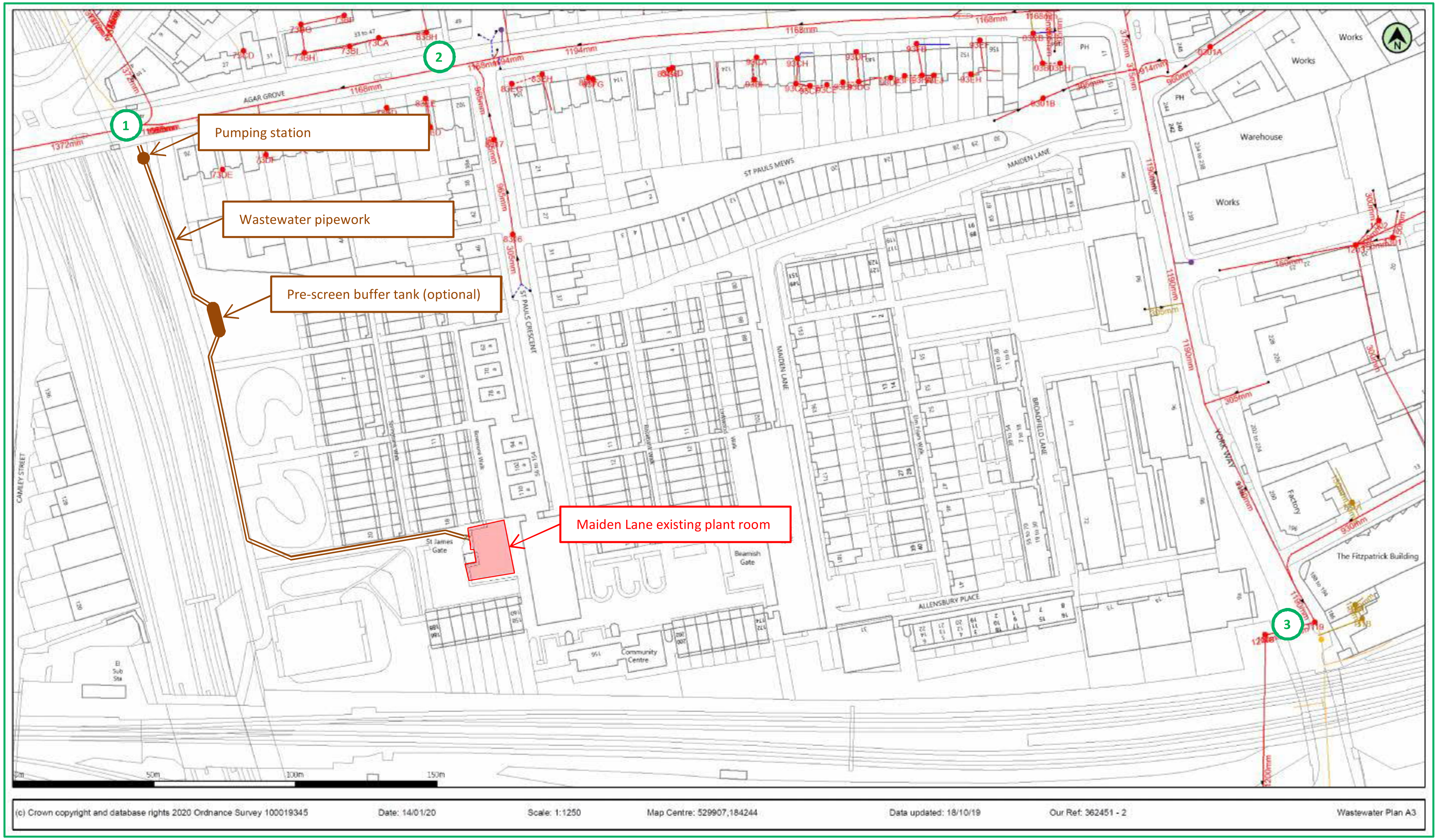


Figure 1: Local sewer map and proposed connection locations (Source: Thames Water)

Use of Sewer Agreement

Recirc has liaised with Thames Water (Thames) and established a dialogue regarding a potential sewer connection and abstraction point. Discussions have included obtaining further sewer maps, modelled flow data (as discussed above) and any other asset intelligence. At the time of writing this report, this information was not yet forthcoming. Further information is expected to be received around the middle of July.

Recirc has also commenced discussions with Thames Water regarding the most likely terms of a sewer connection agreement and the process required by Thames Water to progress such a sewer connection and connection agreement.

Thames' current position on the commercial considerations for sewer heat recovery at Maiden Lane is that any 'use of sewer' agreement to abstract the wastewater would be very similar in nature to a standard connection agreement.

Thames are not currently motivated to seek commercial gain from the sale of the heat. They would however, very much like to explore the possibility of linking a 'use of sewer' agreement to a 'sharing' of any carbon savings achieved by the scheme.

There is no fixed formula for such an agreement, but Recirc view is that one could be very easily arrived at. It is worth noting that carbon savings are a strong motivation for Thames. They, along with other UK water authorities, have signed up to a joint commitment to achieve net-zero carbon by 2030.

Though discussions regarding Thame final position on wastewater heat recovery (WHR) is still in development, they are very supportive of their network being used for this technology and are exploring several WHR projects in the Greater London area.

Thames' stance is very positive in comparison to some other UK Water Authorities, who are yet to fully recognise the carbon saving opportunities of WHR.

In our opinion, there are no significant obstacles to a 'use of sewer' agreement being put in place by Camden Council for the Maiden Lane Estate.

Recirc will continue its discussions with Thames to further clarify the technical, commercial and legal requirements to secure a 'use of sewer' agreement at Maiden Lane; any updates will be passed onto Max Fordham.

Proposed WHR Solution

Summary

The technology proposed is comprised of the following key components:

1) Pumping station
2) Pre-screen buffer tank (PBT) – optional
3) SHARC Plant assembly comprising macerator, filter, heat exchanger, and local control panel
4) Heat pumps
5) Thermal stores – existing
6) Instrumentation, Control and Automation (ICA) panel

The following design parameters have been considered when developing the WHR solution:

1) Heat loads
    a. Peak capacity 936kW (3 no. 312 kW water-to-water HFO heat pumps in series)
    b. LTHW flow/return temperatures 70/40°C (ΔT 30°C): heat pump 1 50/40°C; heat pump 2 60/50°C; and heat pump 3 70/60°C
    c. Minimum evaporator flow/return temperatures 0/5°C (ΔT 0°C)
2) Wastewater flows from sewer
    a. Minimum wastewater flow/return temperatures 8/3°C (ΔT 5°C)
    b. Peak wastewater flow rate required 45 l/s

The Process Flow Diagram below shows an overview or out proposed WHR solution conceptual design (Figure 2). Each key component is described in more detail below.

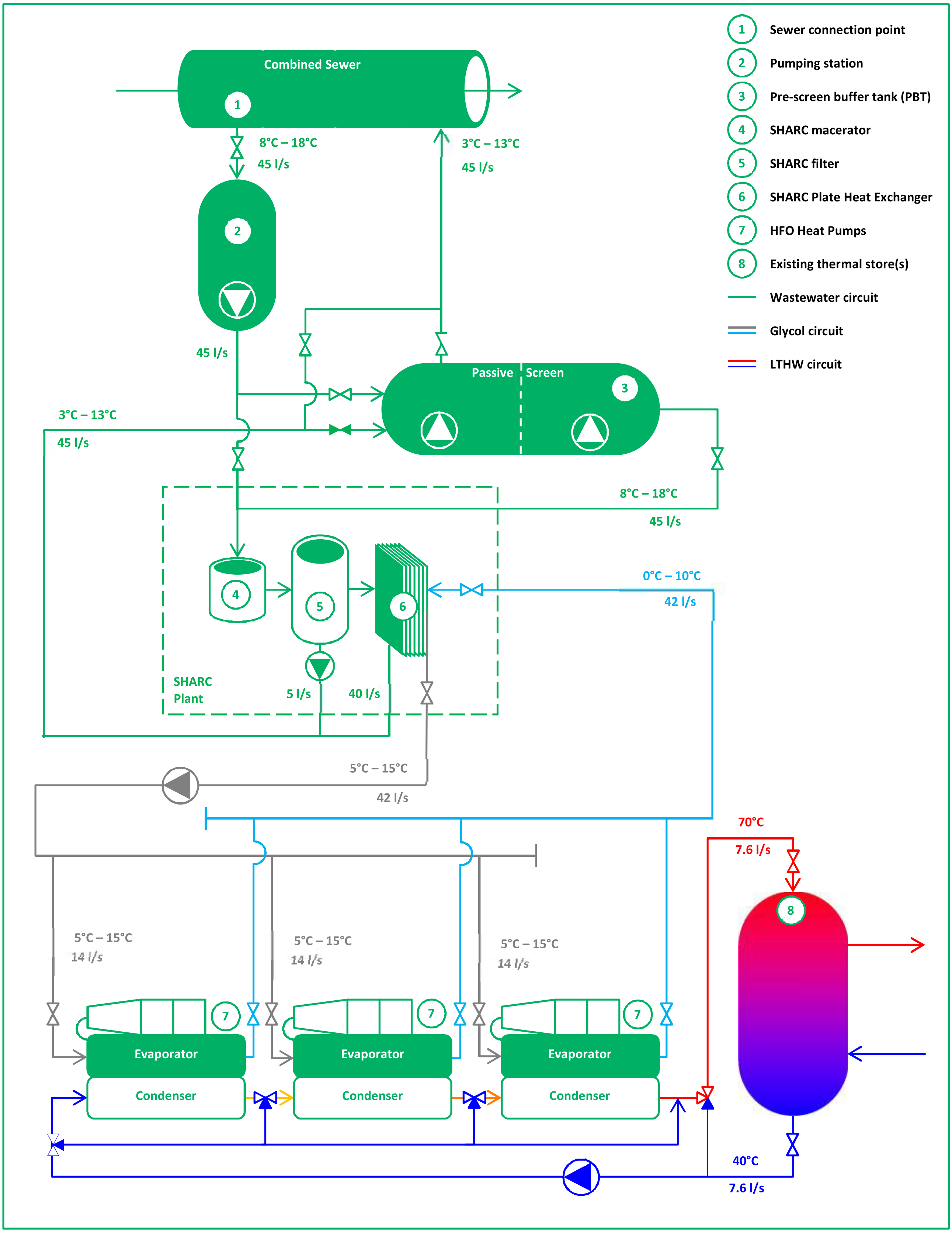


Figure 2: Process Flow Diagram

Sewer Connection and Pumping Station

A critical part of any WHR system is the connection to the sewer. Careful design and execution of this is key to capturing the required wastewater flow rates to provide the source heat required. Potential connection approaches are described below. Exact design details will be subject to invert levels and flow rates obtained during sewer flow and temperature monitoring.

Given the location of the sewer (in a busy road constrained by parking and bus stops) the best connection approach is a simple tap-in approach placing 1 no. or 2 no. cores into the wall of the main sewer into which abstraction pipework would be placed.

Whether 1 no. or 2 no. cores are required will be subject to subject to wastewater flow data obtained during monitoring. Two options to achieve this have been provided: option 1) using a standard pumping station equipped with submersible pumps, and 2) using a much shallower dry pumping station equipped with suction-end self-priming pumps.

Whichever option/approach is taken, a lane closure will be required while construction works are taking place in/under the carriageway.

Option 1 (Figure 3) shows 2 no. cores into the sewer to connect DN 350mm pipework combining a single DN 350mm pipe, which will feed, under gravity, a standard pumping station. The standard pumping station comprises a 2m diameter and 6m deep vertical cylindrical chamber fitted with submersible wastewater pumps. Pumping stations can be prefabricated offsite from fibre reinforced polymer (FRP/GRP), placed into an excavation and surrounded with concrete or pea gravel. They can also be constructed using precast concrete sections, or cast in-situ. Wastewater pumps are installed in full duty/standby arrangement and driven by VFDs with automatic cleaning routines.

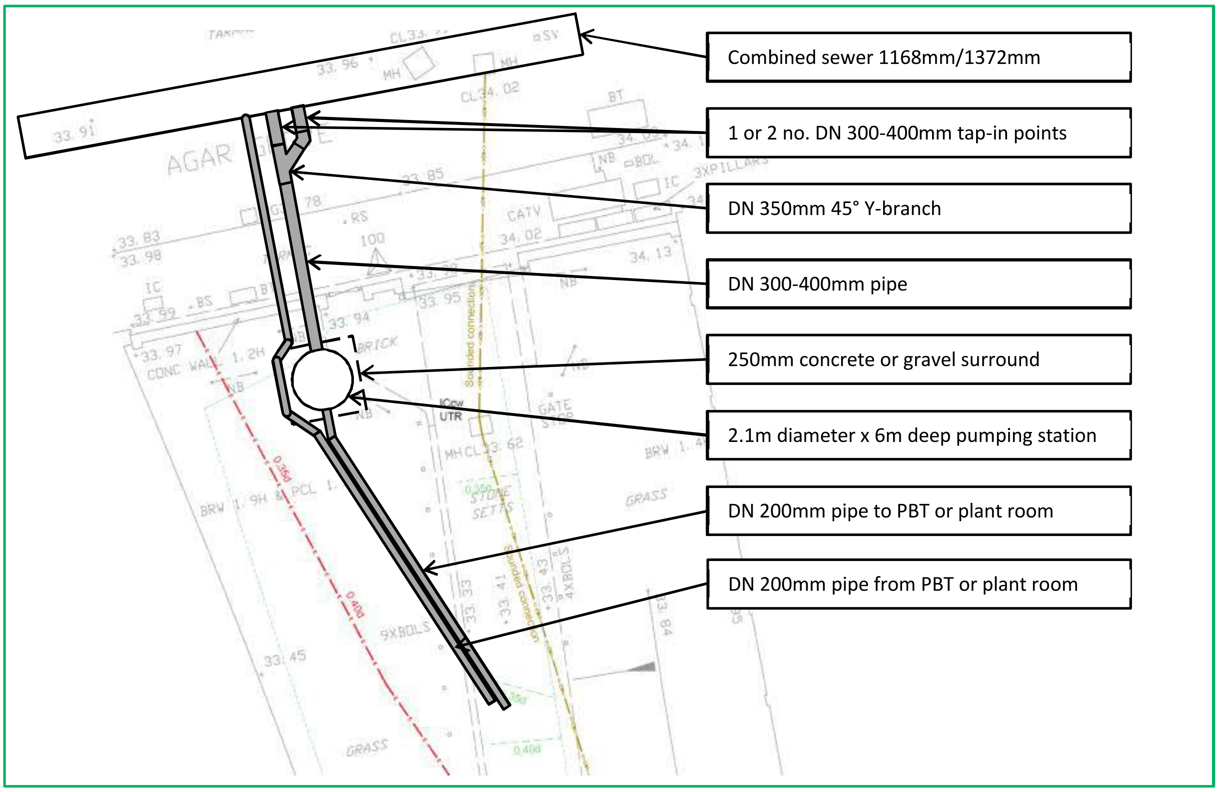


Figure 3: Sewer connection – option 1 (standard pumping station with submersible pumps)

Option 2 (Figure 4) again shows 2 no. cores into the sewer to connect DN 350mm pipework combining a single DN 350mm pipe, which will feed, under gravity, a standard 1.2m diameter and 6m deep vertical cylindrical chamber fitted with suction pipework leading to a dry chamber pumping station. The dry chamber pumping station comprises a 3m x 3m and 6m deep square chamber fitted with self-priming suction-end wastewater pumps.

The potential benefit of option 2 is that the excavation for the pumping station is much shallower and easier to construct, requiring smaller excavation machinery and presenting a lower risk of disturbance to the nearby railway infrastructure. The extent of excavations in the road remain largely similar to option 1.

The disbenefits of option 2 are: 1) annual or possibly biannual maintenance will be required to the collection chamber in the road and 2) self-priming suction-end pumps are slightly less efficient than submersible pumps.

More detailed cost/benefit analysis can be conducted during the detailed feasibility and/or detailed design stages of the project.

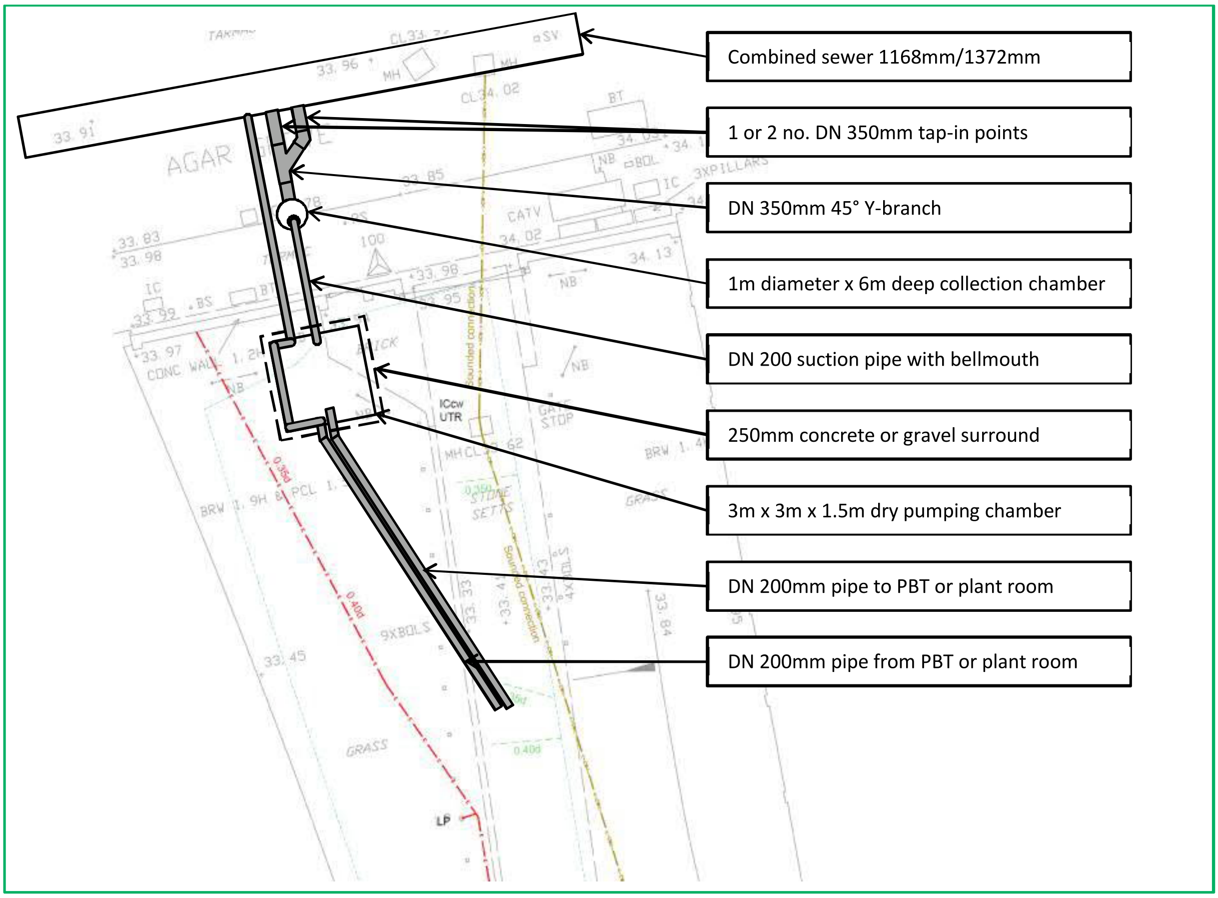


Figure 4: Sewer connection – option 2 (collection chamber and self-priming dry chamber pumps)

Pre-screen buffer tank (optional)

Wastewater can be pumped from the pumping station to an underground pre-screen buffer tank (PBT). The PBT is divided into two sections by a passive screen: 1) a screened wastewater section, and 2) an unscreened wastewater section. The passive screen (no moving parts) captures wipes and rags, which by far the biggest cause of maintenance issues. These are then simply pumped back to the sewer unmodified.

Within the screened and unscreened wastewater sections are housed standard submersible wastewater pumps which pump screened wastewater to the SHARC filtration and heat exchange assemblies (housed in the plant room) and unscreened wastewater (containing wipes and rags) back to the sewer (downstream of the abstraction point). Wastewater pumps are installed in full duty/standby arrangement and powered by inverter drives programme with automatic self-cleaning and anti/de-ragging routines.

The PBT provides a number of benefits including:

- Provides a volumetric buffer when/if sewer flows are lower than the required flow rate
- Provide a thermal buffer by using a multi-pass operation whereby wastewater can be recirculated through the heat exchanger multiple times when wastewater temperatures are high and sewer flows are low
- Removes wipes and rags, negating the need for wastewater maceration[1]
- Facilitates the commissioning and maintenance of the WHR system using clean water

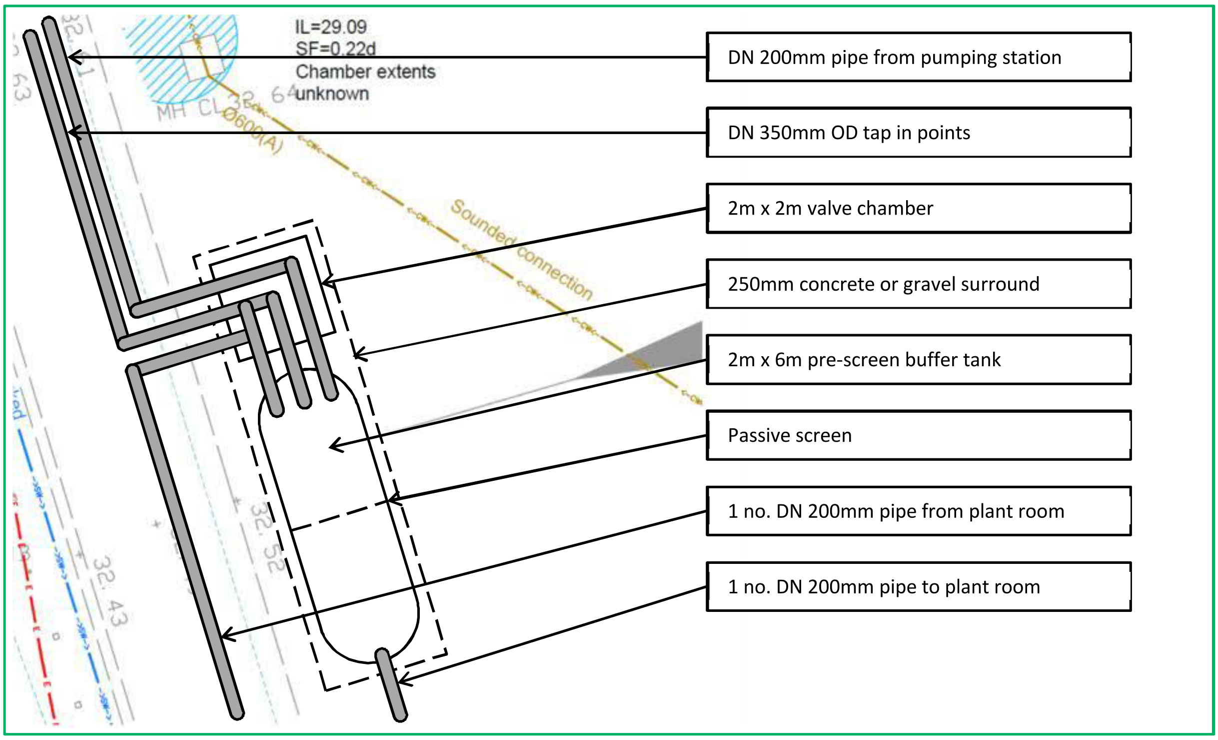


Figure 5: Sewer connection – option 2 (collection chamber and self-priming dry chamber pumps)

[1] Some water authorities may prohibit/restrict maceration; maceration can cause increased bypass of inlet screen at sewage treatment works reducing the quality of the final treated effluent.

SHARC Plant

The SHARC plant comprises a macerator, filter and heat exchanger assembly for filtering and extracting heat from the wastewater. The SHARC plant undertakes the following process steps:

1. Wastewater is pumped to the SHARC plant from the pumping station or PBT
2. Wastewater is macerated to reduce large particles and wipes to a more manageable size
3. Macerated wastewater passes into a self-cleaning filter that removes solids >3mm
4. Filtered wastewater passes through a plate heat exchanger where heat is extracted by the glycol solution circuit pumped through the heat pump evaporators
5. Filtered solids are simply pumped back into return pipework and recombined with filtered wastewater after it has passed through the plate heat exchanger
6. Recombined wastewater flows back to the PBT (multi-pass operation) or directly back to the sewer (single-pass operation) downstream of the abstraction point

The SHARC macerator is specially designed and selected to deal with the wipes, the biggest cause of potential maintenances issues.

The SHARC filter uses self-cleaning technology that has been tried and tested across a number of projects in the UK and North America.

The heat exchanger is a specially selected plate heat exchanger with designed specifically to handle solids and fibre without fouling or blocking. Plate heat exchangers create highly turbulent flows between the heat transfer plates, which results in efficient heat transfer and allows for more heat to be extracted per unit volume of wastewater. The SHARC heat exchangers provide circa 1000kW of source heat per 50 litres per second of wastewater flow.

Highly turbulent flows between the heat exchanger plates achieve high levels of self-cleaning by creating high shear forces that continuously remove biofouling and fats, oils and greases (FOGs) from the plates surface. However, the gradual build-up of biofouling and FOGs on heat exchange surfaces is unavoidable, reducing heat transfer efficiency and heat production. The heat exchangers are deliberately oversized to allow some fouling without reducing the heat capacity or efficiency of the system and to reduce cleaning frequency.

When cleaning is required, the SHARC heat exchangers are very easily cleaned using a simple, fast and effective cleaning in place (CIP) methodology; with no need to disassemble or open the heat exchanger.

Heat Pumps

Heat is extracted from the wastewater using glycol solution is circulated through clean side of the wastewater heat exchanger to/from the heat pump evaporator. Heat is extracted from the glycol solution by the heat pump and upgraded by the heat pump using a refrigerant compression and expansion cycle.

The glycol solution flows through the evaporator heat exchanger and is cooled as cold refrigerant is heated. The heated refrigerant expands and enters the heat pump compressor where it is compressed to a high pressure and temperature. The hot compressed refrigerant flows into the condenser heat exchanger of the heat pump. LTHW flows through the condenser heat exchanger and is heated as the hot refrigerant is cooled. The cooled refrigerant, still under high pressure, then flows through the expansion valve where is expands and cools rapidly. The cold refrigerant then flows back into the evaporator of the heat pump where it is heated by the glycol solution.

Any heat pump can be used with the SHARC technology using a range of refrigerants. Different refrigerants offer different benefits depending on the specific requirements of the project. Most heat pumps we have used have operated on HFO refrigerants.

The heat pumps chosen for this project are HFO refrigerant based heat pumps, which are capable of relatively high temperatures and large ΔT at relatively low LTHW flow rates. The 70°C LTHW condenser leaving temperatures required by the Maiden Lane heat network are well within the operating map of the proposed heat pumps (see Figure 6).

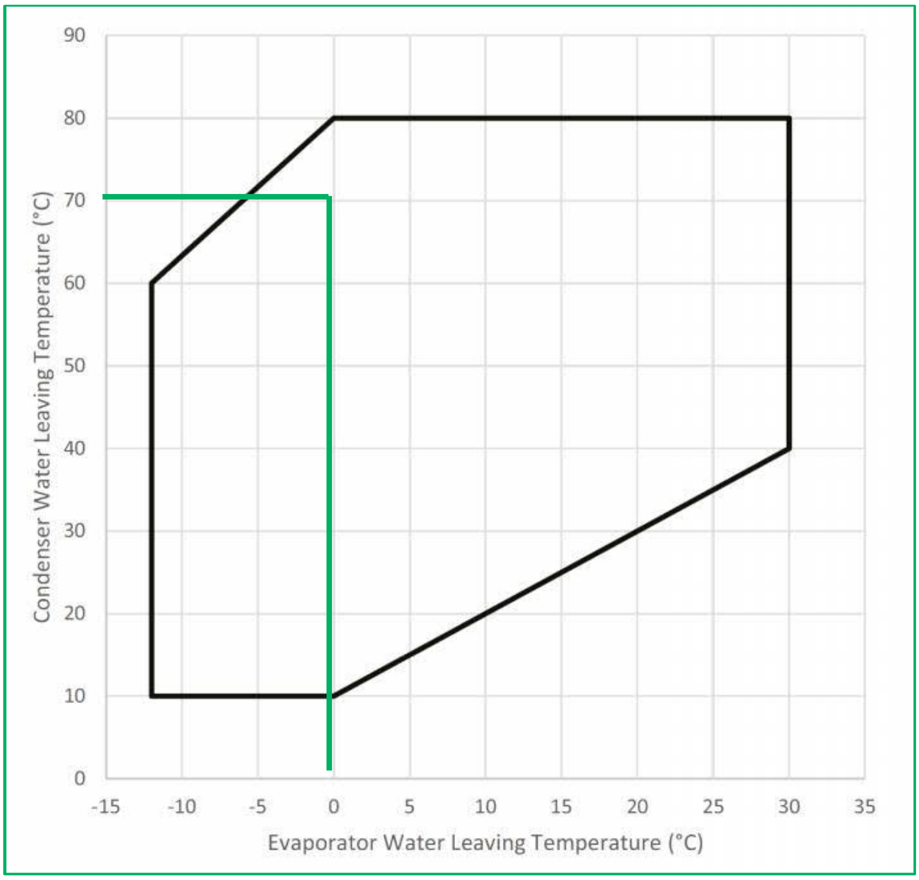


Figure 6: Heat pump operating map

Various heat pump configurations were assessed to achieve the meet base heat load and flow and return temperatures, whilst at worst case lowest sewer temperatures.

Table 4, below, shows the various heat pump configurations and associated coefficient of performance (COP) and capital expenditure (CAPEX) for supply only.

Worst case (sewer at lowest temperatures) COPs of between 2.52 and 2.84 were calculated for the configurations assessed. The best configuration in terms of COP and CAPEX was "Series B" for 3 no. heat pumps where all 3 no condensers operate in series, whilst all three evaporators operate in parallel. This configuration was then used to calculate SCOP in Table 5, below.

Table 4: Heat pump configurations and performance under worst case sewer conditions

Configuration	Heat Pump	Flow/Return Temp. (°C)		Heat Output	COP	CAPEX
	No.	Condenser	Evaporator	kW	Unit	£'000
Parallel (C + C + C)	1	70/43*	0/5	314	2.52	
	1	70/43*	0/5	314	2.52	
	1	70/43*	0/5	314	2.52	
Total	**3**	**70/40**	**0/5**	**942**	**2.52**	**155**
Series A (C-C + C-C)	1	55/40	0/5	314	3.27	
	1	55/40	0/5	314	3.27	
	1	70/55	0/5	312	2.40	
	1	70/55	0/5	312	2.40	
Total	**4**	**70/40**	**0/5**	**1252**	**2.77**	**192**
Series B (C-C-C)	1	50/40	0/5	313	3.55	
	1	60/50	0/5	312	2.87	
	1	70/60	0/5	311	2.34	
Total	**3**	**70/40**	**0/5**	**936**	**2.84**	**155**

* This is the lowest return temperature that can be achieved by the HFO heat pumps in a single pass

Table 5 shows the seasonal SCOPs and annual SCOP estimated using sewer temperature estimates (see section "Sewer Resource" above). We have estimated a SCOP for this project circa 3.4 during winter; 3.5 during spring, 3.9 during summer, and 3.8 during autumn. Using the proportions of heat load expected to be delivered in each season, this equates to an **annual SCOP of circa 3.6**.

Table 5: Heat Pump SCOP estimates

Season	Sewer Temp.	Flow/Return Temp. (°C)		Heat Load	SCOP
	Average (°C)	Condenser	Evaporator	%	Unit
Winter	12	70/40	4/9	20.2%	3.4
Spring	13	70/40	5/10	21.6%	3.5
Summer	19	70/40	11/16	11.1%	3.9
Autumn	17	70/40	9/14	17.5%	3.8
Annual	**14.7**	**70/40**	**6.7/11.7**	**70.4%**	**3.63**

Thermal store

A thermal store can be a useful way of smoothing out peaks and troughs in heat demand. It can also allow heat to be produced during periods of lower cost electricity.

Using current CIBSE guidance, a thermal store was sized on a recovery period of 1.5 hours. The volume calculated for a thermal store allowing for 1.5 hours of peak heat output is 40m^3. This could comprise 3 no cylindrical tanks each measuring circa 4m in height with an internal diameter of 2m.

The cost of a thermal store will range from £1000 to £1500 per m^3 and A more accurate calculation will need be conducted during detailed design.

Instrumentation, Control and Automation (ICA)

A key component to any WHR is the instrumentation, control and automation (ICA) system that is used to operate the WHR system in concert with the heat pumps. The ICA panel should preferably contain a programmable logic controller (PLC) to control all plant and equipment. PLCs are a water industry standard and known for their reliability, flexibility and very fast response times.

Through the control of variable frequency drives (VFDs) driven pumps and control valves, the ICA minimises electricity consumption. The ICA carefully controls pumps and valves to ensure water flow rates are sufficient to meet the heat demand and no more. The ICA will be carefully integrated with the heat pump control system to ensure LTHW and glycol flow/return temperatures are closely controlled to optimise heat pumps SCOPs.

Energy Centre general arrangement (GA)

Max Fordham have asked for a report assuming all plant and equipment are housed in the existing Maiden Lane plant room building. A potential general arrangement (GA) for such a solution is shown in Figure 7 below. If this GA is not suitable, there are a number of alternative layouts and designs can be explored two of which are shown in Figure 8 and Figure 9. In the Gas shown, we have maintained an access corridor of at least 900mm around all items of major plant and equipment to facilitate maintenance and servicing in accordance with manufacturer's instructions.

Power supply requirements

Power supply requirements have been estimated for key items of WHR system plant and equipment. Table below shows the power requirements for the WHR broken down by each key component.

Table 6: Power requirements for WHR system components

Item	kW	V	FLC Amps	kVA
Wastewater Pumps	20.0	400	34	24
SHARC Plant	5.5	400	9	6
Heat Pumps	337	400	569	394
LTHW/Glycol Circulator Pumps	17.5	400	30	21
Others (PU, valves, ICA, instruments)	4.0	—	—	5
Total*	384	—	—	450

* Subject to detailed design; no allowance for a diversity (assumes simultaneous operation)

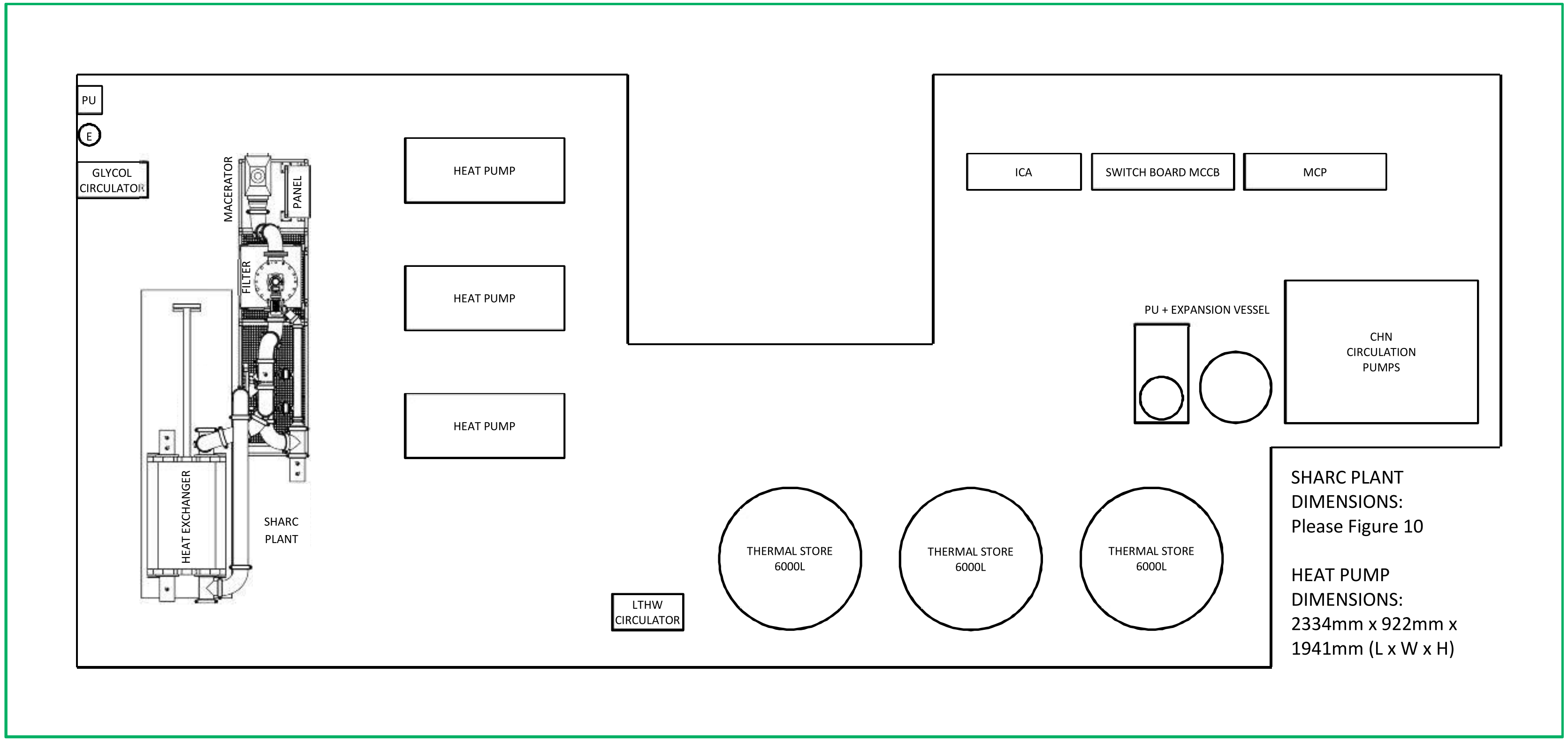


Figure 7: GA of WHR in Maiden Lane plant room – option 1

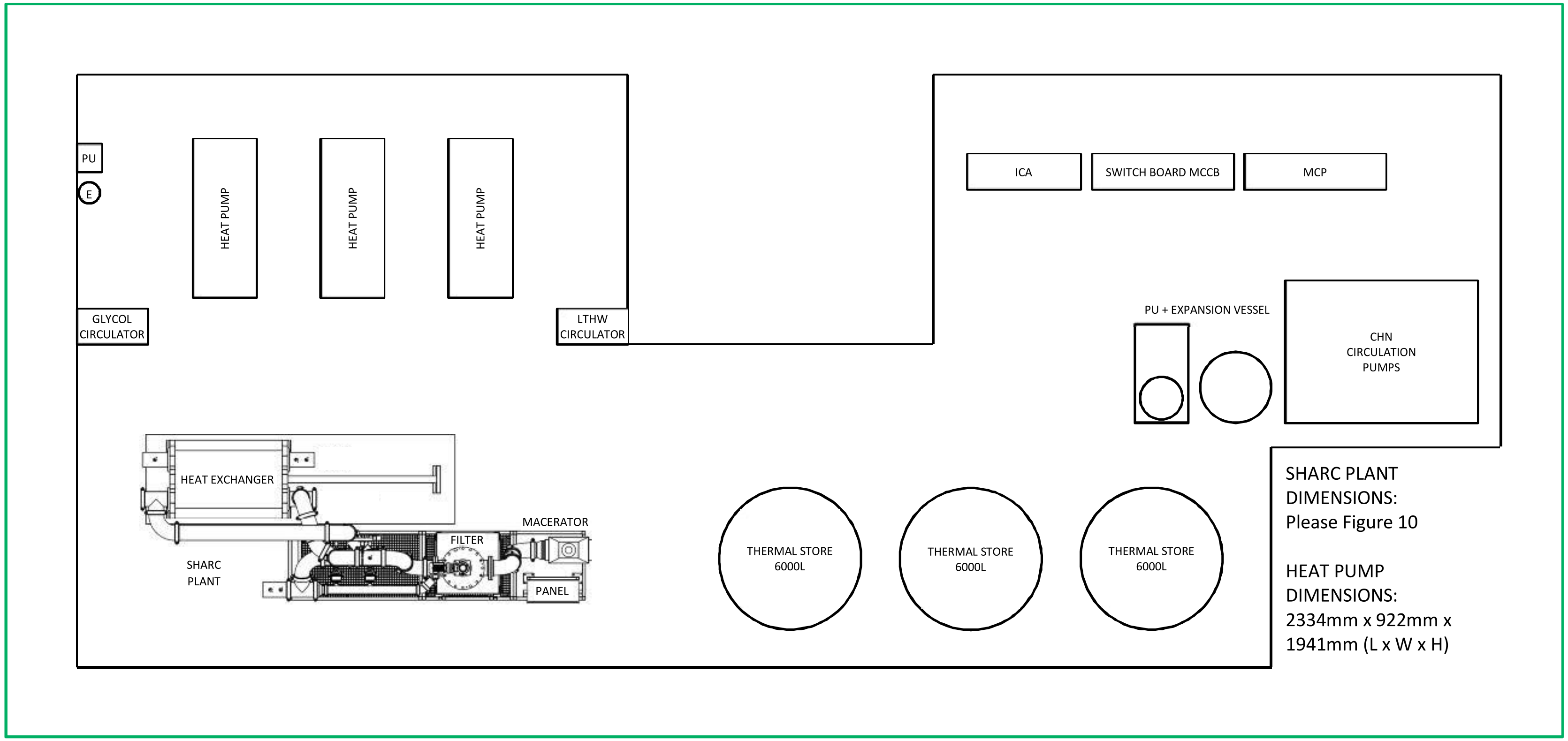
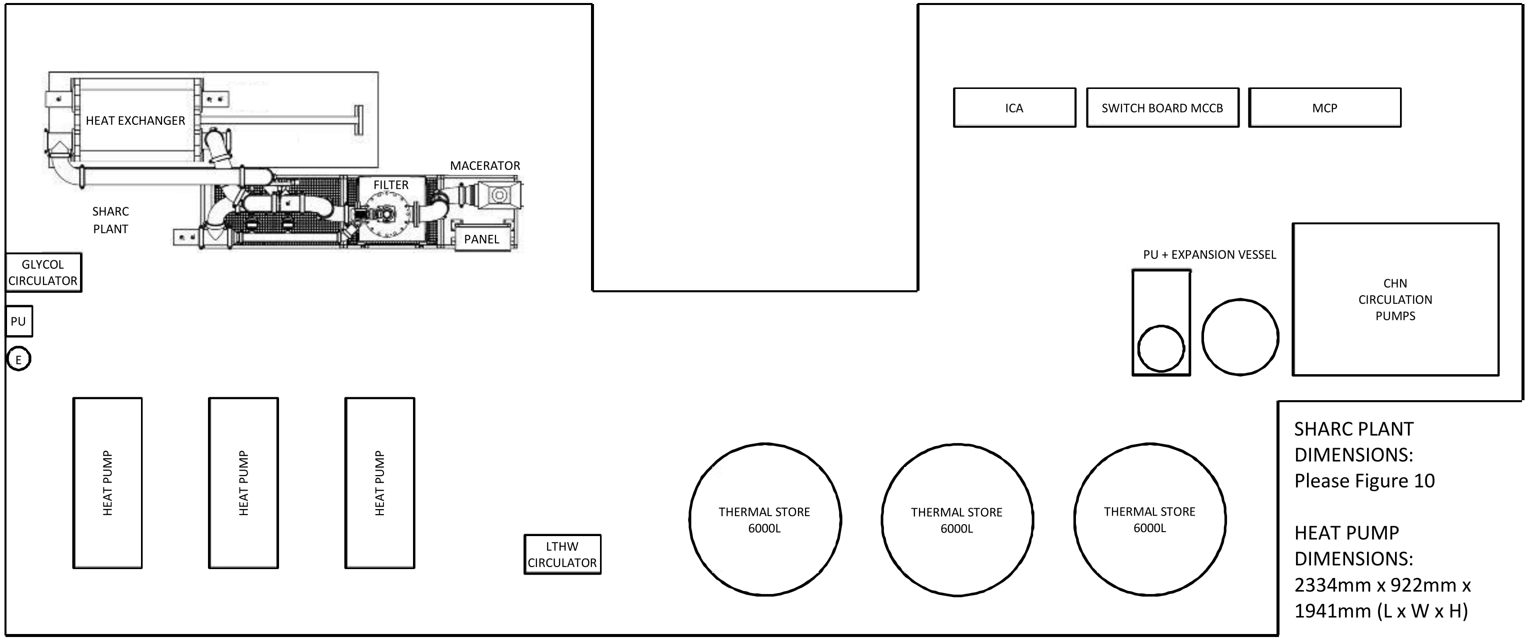


Figure 8: GA of WHR in Maiden Lane plant room – option 2



SHARC PLANT DIMENSIONS: Please Figure 10

HEAT PUMP DIMENSIONS: 2334mm x 922mm x 1941mm (L x W x H)

Figure 9: GA of WHR in Maiden Lane plant room – option 3

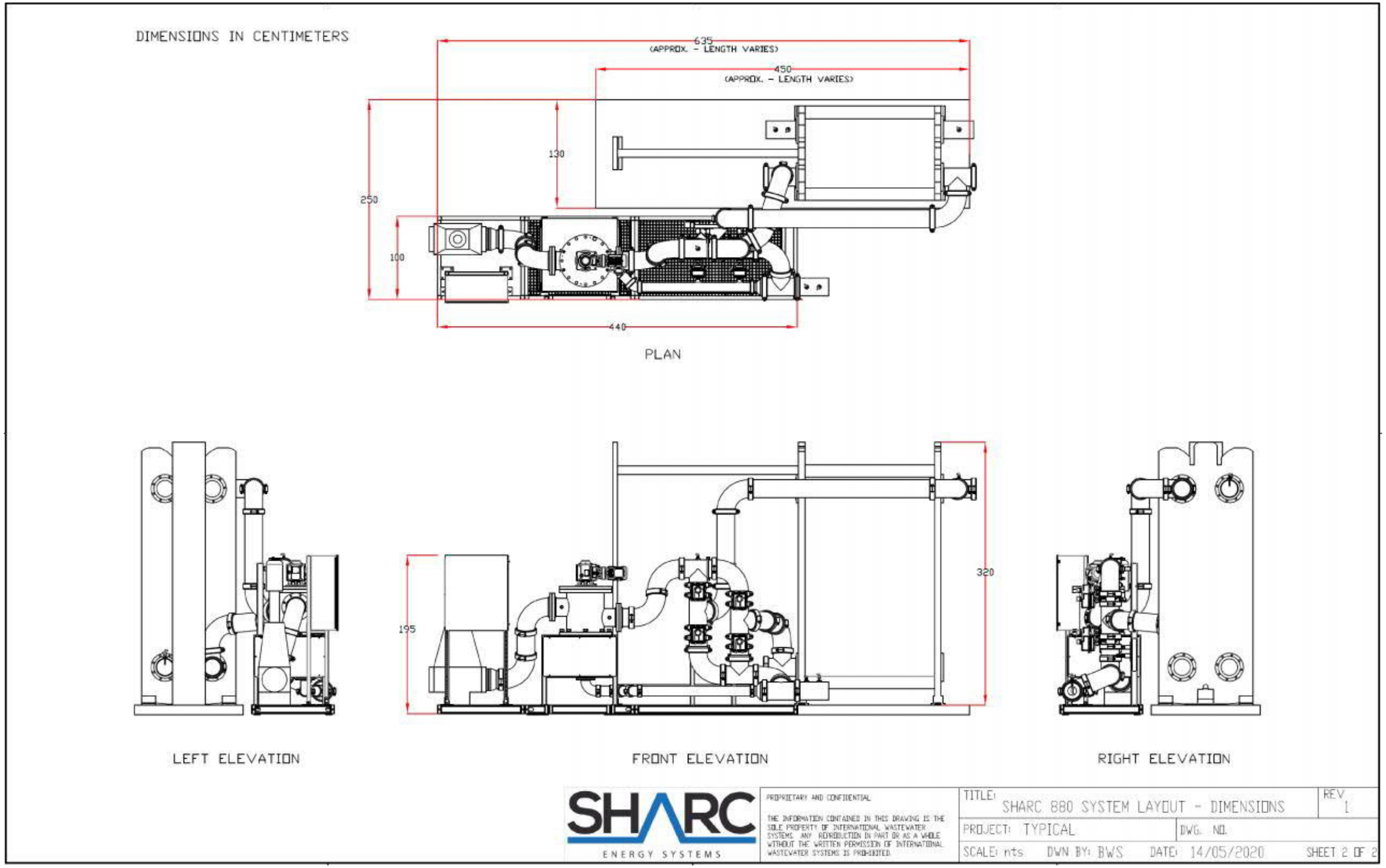


Figure 10: SHARC Plant Dimensions

Project Costs

Capital Expenditure (CAPEX)

Max Fordham have asked for a full turnkey WHR solution for the low-carbon community heating project at Maiden Lane Energy Centre, Camden. The total cost of CAPEX for installation of the WHR solution has been estimated using cost information we have gathered from previous projects, SHARC and the heat pump manufacturer (Trane®). CAPEX is based on the following assumptions, including, but not necessarily limited to:

Assumptions:

Dependencies:

- Final pricing is subject to detailed design and final contract terms and conditions
- Final design of sewer connection subject to discussions with Thames Water

Inclusions:

- Low-carbon WHR heating system design, installation and commissioning, including:
    - Sewer connection
    - Wastewater pumping stations and pipework
    - SHARC Plant with local control panel
    - Heat pumps and local control panel
    - Glycol circuit pumps, valves and pipework
    - LTHW circuit pumps, valves and pipework (up to Thermal stores)
    - Glycol micro pressurisation unit and expansion vessel
- Project management and administration
- Technical input for OFGEM RHI (or similar) application and accreditation

Exclusions:

- Mains power and mains cold water supply
- Heat network design, supply and installation and associated pumps and ancillary works
- Decommissioning, disposal, replacement or modifications of existing infrastructure
- Planning and/or other statutory consents
- Principal Contractor role under CD
- Options:
    - Pre-screen buffer tank (PBT) (estimated cost has been provided)
    - Thermal store (estimated cost has been provided)
    - Sewer connection agreement application
    - Sewer connection agreement fees
    - Civil engineering detailed design (estimated cost has been included)
    - Civil engineering works (estimates cost has been included)
    - Seasonal commissioning

Table 7: WHR Solution CAPEX Price

Item	Cost	Notes
Preliminaries		
Specialist design	£22,139	Prepare specifications and drawings for tender stage
Surveys	£10,000	Sewer flow and temperature monitoring
Project management	£33,279	Up to commissioning
Sub-total	*£65,418*	
WHR System		
Civil works/excavation	£113,749	Includes sewer connection and pumping station
SHARC Plant	£303,009	Awaiting formal SHARC quote
SHARC Plant delivery	£10,000	Estimate
Wastewater pipework	£107,640	Pipework and trenching from pumping station to plant room
Not used	—	Not used
Not used	—	Not used
Commissioning	£25,500	Commissioning of WHR and heat pumps only
Sub-total	*£559,898*	
Plantroom		
Heat Pump	£154,994	Manufacturer's quotation
Thermal Storage	—	See Options below
Pipework, pumps, valves etc.	£150,000	Client specified cost
Installation of above	£152,497	Client specified uplift on above plantroom items
Thermal Insulation	£30,000	Client specified cost
Control Panel and Wiring	£132,750	Client specified cost
Commissioning	£2,835	Client specified cost
Sub-total	*£623,076*	
Total estimated sum	***£1,243,391***	**Cost uncertainty 15%***
Options		
Pre-screen buffer tank	£159,025	Includes GRP tank, pumps, and civil works
Thermal Store	£60,000	40m^3 x £1500 per 1000 litres; insulation included

* Cost uncertainty is mainly surrounding the depth of the sewer, the condition of the sewer and flow rates; once sewer monitoring is undertaken these prices can be re-estimated to a more accurate level

Operational Expenditure (OPEX)

Subject to confirmation through a detailed technical feasibility study, and agreement of final performance standards and KPIs, the annual OPEX for operating for the Recirc Energy heating system will be provided using cost information we have gathered from previous projects.

We would strongly recommend the uptake of a 5-year operation and maintenance package. This will ensure the required expertise is contracted to manage the operation, maintenance and system optimisation to minimise energy and maintenance costs required for operation of the WHR system and heat pumps, whilst maximising heat production and carbon savings.

The total cost of OPEX for the WHR solution has been estimated using cost information we have gathered from previous projects. OPEX is based on the following assumptions, including, but not necessarily limited to:

Assumptions

Dependencies:

- Minimum of a 5-year O&M contract
- Terms and condition of contract (e.g. KPIs, warranties, performance bonds, penalties etc.)

Inclusions:

- Wastewater pumping stations, wastewater pumps and SHARC plant
- Routine and maintenance, servicing and cleaning
- Management of reactive maintenance and repairs

Exclusions

- Heat pumps (an estimate has been provided)
- LTHW and glycol pumps, pipework, valves and ancillaries
- Labour, parts and consumables for reactive maintenance and repairs
- REPEX (replacement costs)
- Options
    - Remote monitoring and optimisation, including:
        - Remote monitoring and alarm response
        - Performance reporting to Client and submissions to Ofgem for RHI (or similar)
    - Heat exchanger cleaning
        - Regular cleaning to maintain heat delivery and heat pump efficiency
        - Cleaning achieve with very little downtime using Recirc's CIP system

Table 8: WHR Solution OPEX Price

Item	Cost/year	Notes
SHARC Plant servicing	£2,000	Routine maintenance; using local contractors
Heat pump servicing	£6,500	Estimated price
Annual clean down	£3,500	SHARC Plant and Pumping Station clean down
Annual Total	***£12,000***	
Options		
Remote monitoring and optimisation	£3,422	Recirc would undertake this work
Heat exchanger cleaning 8 times per year	£6,875	Recirc would remove FOGs with CIP system

Project Programme

Please see Figure 11 (below) for our preliminary project programme**.** The timescales below are indicative and based on previous, similar scale projects.

Camden Council/Max Fordham - Maiden Lane Estate Wastewater Heat Recovery Programme - Rev.1

ID	Task Name	Duration	Start	Finish
1	**Camden Council/Max Fordham - Maiden Lane Estate**	**383 days**	**Mon 01/06/20**	**Thu 18/11/21**
2	**Stage 1 - Desktop Report**	**51 days**	**Mon 01/06/20**	**Mon 10/08/20**
3	Desktop Report - Order Placement	1 day	Mon 01/06/20	Mon 01/06/20
4	Desktop Report Writing	4 wks	Tue 02/06/20	Mon 29/06/20
5	Desktop Report - Client Review	6 wks	Tue 30/06/20	Mon 10/08/20
6	**Stage 2 - Full Feasibility & Tender Pack Preparation**	**70 days**	**Tue 25/08/20**	**Mon 30/11/20**
7	Full Feasibility - Order Placement	1 day	Tue 25/08/20	Tue 25/08/20
8	Sewer flow monitoring	8 wks	Wed 09/09/20	Tue 03/11/20
9	Process Design & System Sizing	4 wks	Wed 07/10/20	Tue 03/11/20
10	Concept Civils Design	4 wks	Wed 07/10/20	Tue 03/11/20
11	MEICA Design	4 wks	Wed 07/10/20	Tue 03/11/20
12	Tender Pack Preparation	14 days	Wed 04/11/20	Mon 23/11/20
13	Final Design Sign-off	1 wk	Tue 24/11/20	Mon 30/11/20
14	**Stage 3 - Procurement**	**60 days**	**Wed 04/11/20**	**Wed 27/01/21**
15	Tender publication	30 days	Wed 04/11/20	Tue 15/12/20
16	Tender evaluation	30 days	Wed 16/12/20	Wed 27/01/21
17	Tender award	0 mons	Wed 27/01/21	Wed 27/01/21
18	**Stage 4 - Plant Procurement and Fabrication**	**171 days**	**Wed 03/02/21**	**Thu 30/09/21**
19	Heat Pumps Order and Energy Centre Balance of Plant	0 days	Wed 03/02/21	Wed 03/02/21
20	Heat Pumps Delivery	10 wks	Thu 04/02/21	Wed 14/04/21
21	Plant Room Balance of Plant	0 days	Wed 03/02/21	Wed 03/02/21
22	Plant Room Balance of Plant Delivery	12 wks	Thu 04/02/21	Wed 28/04/21
23	SHARC Order placement	1 day	Thu 04/02/21	Thu 04/02/21
24	SHARC Skid Fabrication	150 days	Fri 05/02/21	Thu 02/09/21
25	Transport to SHARC from Canada	4 wks	Fri 03/09/21	Thu 30/09/21
26	**Stage 5 - Construction**	**115 days**	**Thu 11/02/21**	**Wed 21/07/21**
27	Mobilisation	4 wks	Thu 11/02/21	Wed 10/03/21
28	On-Site Civils Works	3 mons	Thu 11/03/21	Wed 02/06/21
29	On-Site MEICA Works	3 mons	Thu 29/04/21	Wed 21/07/21
30	**Stage 6 - Commissioning & Handover**	**35 days**	**Fri 01/10/21**	**Thu 18/11/21**
31	Functional Comissioning	3 wks	Fri 01/10/21	Thu 21/10/21
32	Process Commissioning	2 wks	Fri 22/10/21	Thu 04/11/21
33	Handover to Operations	2 wks	Fri 05/11/21	Thu 18/11/21

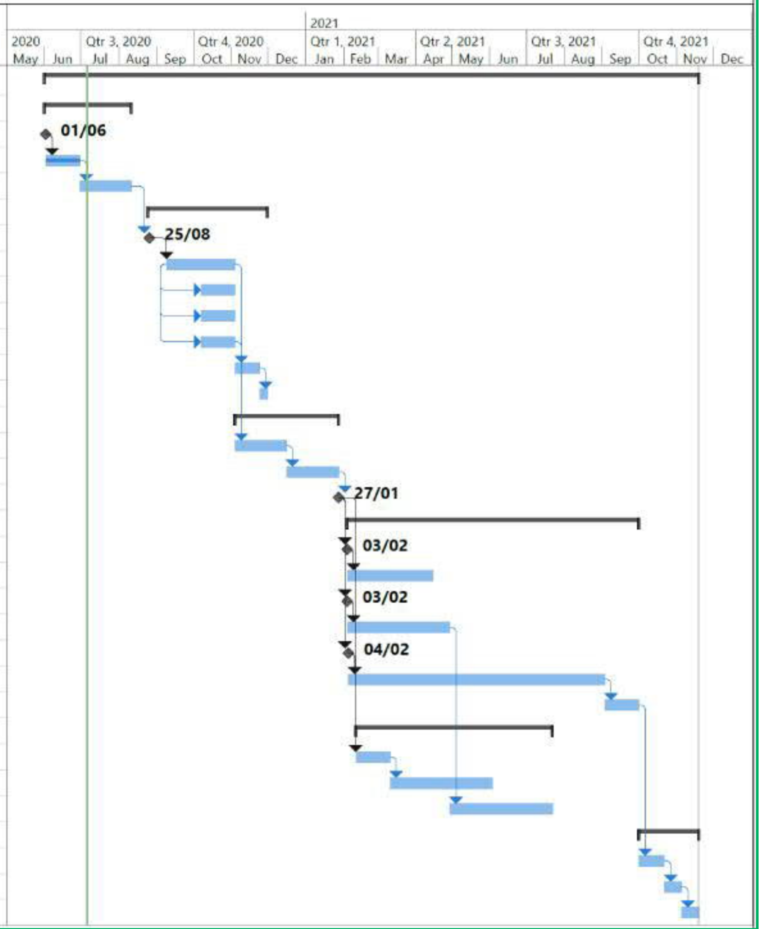


Figure 11: Preliminary Project Programme

11.0 APPENDIX 2 – BORDERS COLLEGE SHARC PRECENDENT INSTALLATION

MAX FORDHAM

Heat from Wastewater

innovative scheme at Borders college campus in Galashiels to supply 1.8GWh of heat per annum

by Ian Dunsmore

Scottish Borders Campus in Galashiels is the first example in the UK of heat being extracted from wastewater networks for use as space heating and hot water, reducing customer costs and carbon emissions. Water that is flushed into the wastewater network from homes and businesses represents a significant source of thermal energy. Usually, this heat is lost as the treated effluent is returned to the environment. A partnership between Scottish Borders College, Scottish Water Horizons Ltd and SHARC Energy Systems has resulted in a scheme that extracts this wasted heat to supply the vast majority of the campus' annual heating and hot water demand.

SHARC unit that separates the liquids and solids - Courtesy of Scottish Water Horizons

The challenge

Scottish Borders Campus developed a carbon reduction plan for their estate, which included reducing the carbon impact of their heating system. This meant identifying a sustainable heating solution which would deliver cost and carbon savings without the need for upfront capital. The campus is shared by Borders College and Heriot Watt University and is located on Nether Road in Galashiels. The campus contains a range of buildings of various stock including the High Mill which dates back to the 1800s.

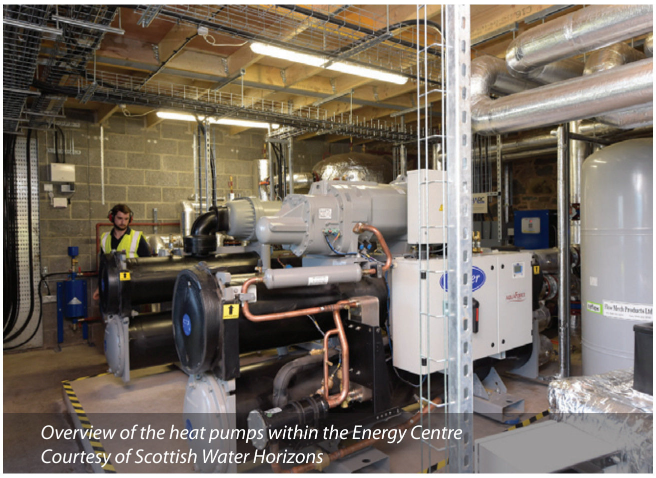
The solution

Scottish Borders Campus investigated a number of technologies before being introduced to a renewable opportunity by Scottish Water Horizons Ltd to recover heat from the public sewer to meet their heating and hot water needs. The solution involved the use of an innovative SHARC heat recovery system which extracts heat from wastewater. The campus was suitably located to benefit from this technology as immediately north of the site is Gala Water, a tributary to the Tweed River.

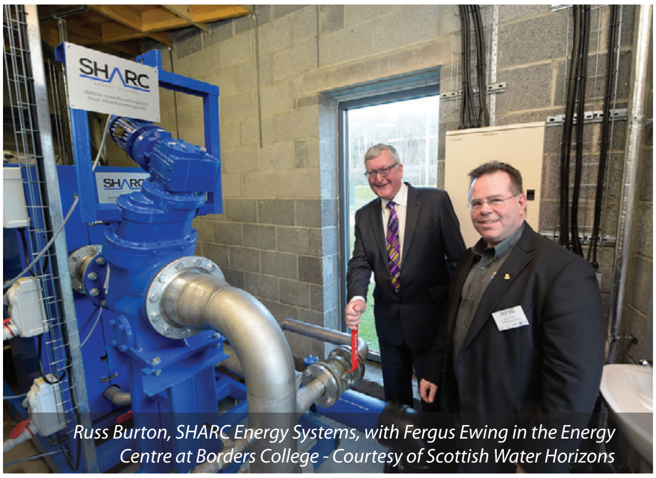
On the banks of the river is a 900mm trunk sewer main that takes wastewater from part of the town to the local treatment works around 0.5km to the east.

Wastewater is a plentiful resource and has a number of benefits over using surface water sources. One of these benefits is that the temperature of wastewater is comparatively high all year round (average of around 12-15°C) while surface water will be at its coldest in the winter months when heat energy is most required. Wastewater is also likely to be available closer to customers than surface water.

The SHARC heat recovery system also had a number of benefits that addressed specific issues the campus had with other technologies, for example space constraints (the SHARC buffer/storage tank is located below ground next to the new energy centre so less intrusive) and delivery of materials to site (wastewater runs within the existing underground network). The technology also enabled cost and carbon savings without the need for upfront capital.



Overview of the heat pumps within the Energy Centre Courtesy of Scottish Water Horizons



Russ Burton, SHARC Energy Systems, with Fergus Ewing in the Energy Centre at Borders College - Courtesy of Scottish Water Horizons

Modelling work carried out in partnership with SHARC Energy Systems also provided assurance that there would be no significant impact on the biological treatment processes within Scottish Water's local treatment works.

The technology

The heat recovery system works in three distinct stages:

1. The patented SHARC system separates solids and liquids within the wastewater stream via a unique clog-proof mechanical filtration system.
2. The warm liquid is passed onto a plate heat exchanger where the heat energy is transferred to the lower temperature side of the heat pumps.
3. A heat pump (applying the same physical processes as a refrigerator or air conditioning plant) increases the heat in the clean water circuit, which is used to heat the college buildings and hot water systems. As heat is transferred to the clean water network using a closed-loop system, wastewater never comes into contact with the clean water flow.

Solids that were removed from the wastewater stream are then re-suspended into the cooler water, returning from the heat exchanger, and sent back to the sewer where they are safely treated and disposed of at the local treatment works.

Given the higher temperature of the wastewater the Coefficient Of Performance (COP) that can be delivered from the heat pumps is higher than for a lower temperature source material. The system at the campus is achieving COP values of 4.8 meaning that for every unit of energy that is put into the heat pump it is generating 4.8 units of heat energy.

The scheme

The scheme was delivered by SHARC Energy Systems on behalf of Scottish Borders Campus with support from Scottish Water Horizons to replace the college's mains gas supply. The main exterior impact of the scheme is the newly built energy centre, adjacent to the Students Union building on an area of land that was previously grassed. This energy centre houses the SHARC equipment along with the heat pumps, all associated pipework, vessels and the control systems.

The system consists of a connection into the existing 900mm sewer which feeds into a small wet well. The wastewater is then pumped over to a larger wet well adjacent to the energy centre. From here the wastewater is pumped through the SHARC system to separate the liquids from the solids.

The warm liquids are then passed through a plate heat exchanger to transfer the heat energy to the lower temperature side of the heat pumps. There are 2 (No.) 400kW Carrier heat pumps in the energy centre which operate on a duty/assist basis. The majority of heating load is done with a single heat pump, but in times of high demand or particularly low temperatures, the second heat pump is used to add extra capacity.

The hot water (circa 60ºC) from the heat pumps is stored in a buffer vessel within the energy centre. The five connected plant rooms around the site (Union, Research, Technology Training Centre TTC, Main and High Mill) then request hot water from this buffer

Scottish Water Horizons Ltd

Scottish Water Horizons, a subsidiary of the publicly owned utility, supports the development of Scotland's sustainable economy by maximising the potential of Scottish Water's assets.

The company is uniquely placed to support the heat recovery system by enabling safe access to Scottish Water's sewer networks and assisting with project and contract management.

By extracting value from these assets Scottish Water Horizons is helping to provide customers with an innovative, sustainable and lower cost heating solution with a reduced carbon impact.

The company is actively exploring similar opportunities using SHARC technology throughout Scotland.

SHARC Energy Systems

Launched in 2014, SHARC Energy Systems is a UK organisation specialising in wastewater heat recovery technology to enable a sustainable energy source. Unique in the UK and Europe, the system generates energy-saving, cost-effective and environmental solutions for heating, cooling and hot water for commercial and residential buildings.

SHARC Energy Systems is a wholly owned subsidiary of International Wastewater Systems, and its technology was developed by its parent company based in Vancouver, Canada.

The wastewater technology system was developed by the founding team of technical and engineering professionals who have over 100 years combined experience in the heating, ventilating and geo-exchange industries. The system utilises a unique clog-proof raw sewage filtration system and Heat Exchange technology that conducts the heat from untreated wastewater.

SHARC Energy Systems brings the technology to the UK for the first time and provides a full design, manufacture and installation service. The SHARC system is suitable for both new build and retrofit projects on residential and commercial developments.

vessel when needed to ensure the respective systems maintain set temperatures within their respective buildings/areas.

To supply hot water to the five plant rooms around the campus it was necessary to install 1km of heat network pipes (500m of flow and 500m of return). Pre-insulated plastic heat network pipe was supplied by Flex Energy, a Glasgow based company.

The new heat network connects directly into the existing heating system. The campus chose to retain their gas boilers as a backup to the new system and these are simply inhibited under normal circumstances to let the heat network supply heat. If there is a need for the boilers to operate, the control system will release the inhibitor and redirect the system so that the boilers supply the heat rather than the heat network.

The buildings being supplied by the new heat network are of varying ages and construction types. The High Mill building is a former Victorian mill over 100 years old, the TTC is an area which includes a mechanical workshop with large doors which are often open to let vehicles in for servicing. These buildings provide very different heating challenges particularly when moving from a gas boiler system operating at relatively high temperatures (flow 82ºC and return 71ºC) to a heat pump solution with a flow temperature of 60ºC and a return of 50ºC.

All of this work was financed using a heat sale model where the customer, Borders College, did not have to commit to any capital expenditure but instead entered into a 20 year heat sale agreement with SHARC Energy Systems. This heat sale agreement provides the campus with cost savings over mains gas as well as cost certainty in the potentially volatile fossil fuel energy market.

The finance was provided through the Green Investment Bank and private funders Equitix and will be repaid through the heat sale agreement along with the Renewable Heat Incentive (RHI) payments that the scheme attracts from central government.

The result

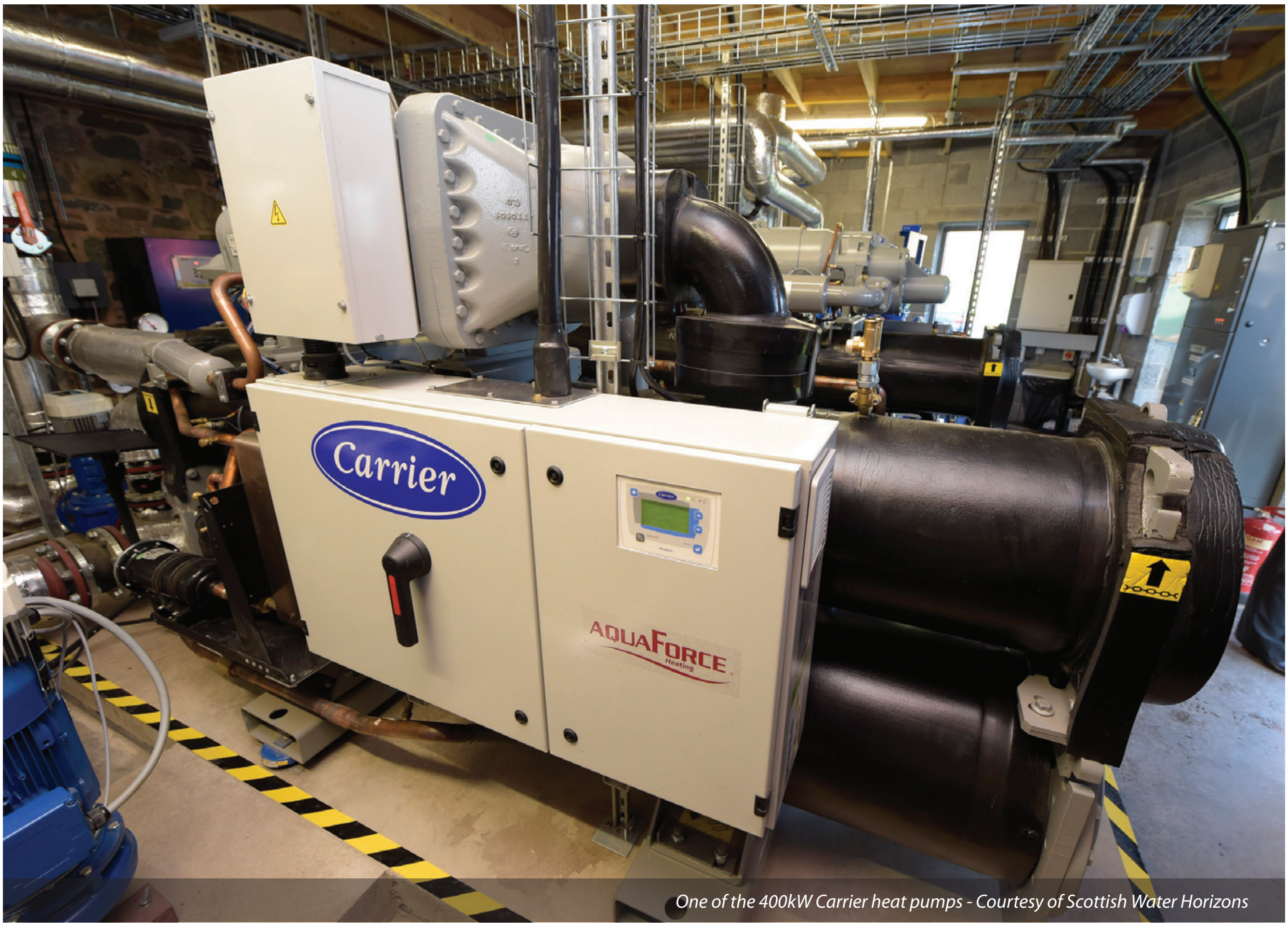
Construction on site commenced in June 2015 and was commissioned between December 2015 and March 2016. The scheme was officially opened by Fergus Ewing (then Minister for Business, Energy and Tourism) at an event attended by over 100 people, including representatives from Scottish Water, Scottish Enterprise, Green Investment Bank and many local authorities and public bodies.

The system will supply circa 1.8-1.9GWh per annum of heat, providing the vast majority of the college's heating needs. So far 125MWh of heat have been delivered to the site and the scheme has generated a lot of interest from both public and private bodies across Scotland as well as other parts of the UK. Over the full annual cycle the college will realise 150 tonnes of carbon savings per annum against their carbon reduction commitments.

The heat from wastewater scheme at Scottish Borders Campus is the first example of its kind in the UK, but there is massive potential for this technology to be rolled out across the country. Scottish Water has over 32,000 miles of wastewater networks, and is using heat maps to actively explore locations where schemes like that at the campus could be developed.

Scottish Water Horizons facilitated safe access to the local wastewater network. SHARC managed the installation and commissioning of the project and is responsible for the on-going operation and maintenance of the scheme.

The editor and publishers would like to thank Ian Dunsmore, Project Manager with Scottish Water Horizons Ltd, for providing the above article for publication.



One of the 400kW Carrier heat pumps - Courtesy of Scottish Water Horizons

12.0 APPENDIX 3 – UKPN SUBSTATION QUOTATION

Registered Office
Newington House
237 Southwark Bridge Road
London SE1 6NP

Company:
UK Power Networks
(Operations) Limited

Registered in England and Wales No: 3870728

Mr. James Bowman
Max Fordham
42-43 Gloucester Crescent
London
NW1 7PE

Date: 01 July 2020

Our Ref: 8500146627 / QID 3500090857

Customer Ref:

Dear Mr. Bowman,

Site Address: District heating scheme, Maiden Lane estate, London, NW1 9XZ

Thank you for your recent enquiry regarding the above site. I am pleased to be able to provide you with a Quote to carry out the work requested. I am writing to you on behalf of London Power Networks plc the licensed distributor of electricity for the above address trading as and referred to in this Quote as "UK Power Networks".

The Works will enable the provision of an import capacity of 600 kVA and a maximum export capacity of 0 kVA. This encompasses the connection of 1no. 800kVA HV/LV transformer with provision of 1600A ACB metered service.

UK Power Networks would like to carry out all of the requested work for you. However, there are other companies who can do some or all of the work for you; these are Independent Connection Providers (ICPs). You can approach NERS accredited ICPs directly, or you can approach an Independent Distribution Network Operator (IDNO) to request this work and they will arrange for an ICP to carry out the Contestable Works. To find out more about which ICPs work in our area and what work they can undertake please click here.

To give you as much choice as possible we are able to offer you **the following options** for getting your work done:

How much is it going to cost?

		Price excluding VAT	Price including VAT
A	UK Power Networks carries out all of the requested 'contestable' and 'non-contestable' works required for your connection	£100,951.37	£121,141.67
B	UK Power Networks carries out all the 'non-contestable' work and the 'contestable closing joint'. The ICP carries out all other requested 'contestable' work	£12,159.41	£14,591.29
C	UK Power Networks carries out the 'non-contestable' works only. The ICP carries out all of the works classified as 'contestable'	£9,844.41	£11,813.29

A short guide is available to help you understand the three different Prices (options A, B and C). To see this guide please click here.

Terms and Conditions

The Quote is subject to version 7 (September 2016) of our **Terms and Conditions For Connection and Diversionary Works** (the "Terms and Conditions") which you can view here. Alternatively, please let me know if you would like me to send you a copy in the post. These create legally binding obligations so it is important that you take the time to read and understand them. They also contain definitions of terms used in this document and in the linked pages on our website that you may find helpful.

Special Conditions

This offer is subject to the following:-

- The appointed UKPN substation building officer approving the customers proposal for the new substation housing.
- There will be no shared metallic structures, cables or pipes with any other buildings that receive independent PME electricity services – refer to EDS 06- 0017 for guidance.

When can you expect your electricity connection?

Once you have accepted this Quote we will call you to discuss a programme of Works. Subject to the Terms and Conditions the Works referred to in this Quote will be completed on or before 01 December 2020.

We will try to meet your requested dates wherever possible but the completion date will be dependent on:

- The date that the Quote is accepted;
- How much of the work you wish UK Power Networks to complete;
- Any further discussions we may have with you regarding the programming of the works; and
- The completion of work by other people or companies that must be done before we can complete our work.

Interactivity

We have not received a request from any other customer for connections to the same part of our Distribution System, but to find out what happens if they do, please click here.

Post quote call

I will contact you within the next few days to discuss your quote, to ensure you understand the work we will do for the quoted price, your responsibilities, any dependencies and the likely timescales for the work. UK Power Networks are always looking to improve our service offering and as such, the post quote call may be recorded for training purposes. We will not share the recorded call with anyone outside of our connections business and it will be deleted as soon as we have completed the training review. However, if you do not want us to record the call please let me know at the beginning of the call.

What you need to do next

Before you decide to proceed it is really important that you take note of our **Terms and Conditions,** any **special conditions** detailed above and the details in **Your Information Pack** which includes information contained within the hyperlinked text, all of which constitute your **Quote**.

If you would like to accept this Quote you will need to ensure that the requested payment is in our bank account in full and cleared funds and that we have received your signed Acceptance Form from section 5 below by 5pm on 29 September 2020.

If you would like UK Power Networks to carry out all of the Works please accept option A. If you would prefer to use an ICP to carry out the Contestable Work (or an IDNO to arrange for an ICP to carry out the Contestable Works), you can pass this Quote to them and they can accept either option B or option C. Alternatively, you can accept option B or option C yourself, but you will need to ensure that your appointed ICP or IDNO understands what they must do, and what UK Power Networks will do for these options. **You can only accept one option**.

If you have any questions about this Quote or need more information, please do not hesitate to contact me.

Yours sincerely,

LMetselaar

Lee Metselaar

Telephone: 01279 824724
Mobile: 07875 115 505
Email: lee.metselaar@ukpowernetworks.co.uk

Please support our safety campaign and join the growing number of companies signing up to our [Pledge]

To download your free safety leaflets and resources visit
UK Power Networks - Safety Page

Your Information Pack

The following pack provides all of the information you should need to successfully complete your electrical connection for the work you have been quoted. Please pay particular attention to the information that is specific to your project.

Do not hesitate to contact me should you require any further support.

Section 1 Scope of Works

Please read the details in this section in conjunction with the customer proposal plan (referred to in the Drawing Schedule in Section 4).

A	Complete assessment and design, provide and install 180m of 11kV cable, install 1 x 11kV/LV 800kVA substation, provide 1600A ACB with CT metering provision, complete final HV joints to mains cable network and all non-contestable elements. UK Power Networks carries out all the Contestable and Non-Contestable Works.
B	Complete assessment and design, complete final HV joints to mains cable network and complete all non-contestable elements You will need to arrange for the completion of the remaining Contestable Works by an accredited ICP. If option B is accepted, your appointed ICP will be responsible for the production of all detailed constructible designs, which must be submitted to UK Power Networks for review and approved prior to the commencement of any Contestable Works. No charge will be made by UK Power Networks for this service.
C	Complete assessment and design and non-contestable elements only. You will need to arrange for the completion of the Contestable Works by an accredited ICP. If option C is accepted, your appointed ICP will be responsible for the production of all detailed constructible designs, which must be submitted to UK Power Networks for review and approved prior to the commencement of any Contestable Works. No charge will be made by UK Power Networks for this service.

Your Connections

The table below provides a summary of the technical characteristics and the connection types you have requested:

Type of Property	No. of MPANs	Metering Voltage	Phase Type	Import Capacity (kVA)	Export Capacity (kW)
Landlords Supply	1	400V	Three Phase, 50HZ	600	
Meter Position	**Service Cable**	**Fuse Size**	**Earthing**	**Metering**	
Internal Meter box	Customer to size service cables	N/A	Direct Earth(TN-S)	CT Metering	

Phases of work

Our delivery time scale of this work may be subject to our performance standards, as detailed in 'Our Connections Standards of Performance' leaflet that can be found here. The standards make reference to your work in totality, including the delivery of the work that you may request to be completed in discrete parts (which are referred to as phases). This Quote covers 1 phase(s) of work.

Section 2 Cost Breakdown

Totals

Option	A	B	C
Net Price (Excluding VAT)	**£100,951.37**	**£12,159.41**	**£9,844.41**

Breakdown of Costs

Description of CONTESTABLE WORK that is included in option A only	
Work involved	**Net price (£)**
HV Plant and Switchgear	
• Establish an 800kVA secondary substation within a brick-built chamber. Includes 800kVA transformer, Ring Main Unit, 1600A air circuit breaker, RTU, internal small power/lighting & substation ancillaries. Excludes earthing, civil works and HV/LV jointing. • Delivery of plant to site during normal weekday working hours • 300mm HV indoor end box termination • Fit customer LV cables in UKPN substation • Labour for an Authorised Person/Senior Authorised Person in normal working hours. • Sand & cap/shingle substation	£71,536.35
HV Underground Mains	
• Excavate & Reinstate 11kV joint hole in a footway surface type. • Supply only of 11kV 300mm aluminium Triplex mains cable • Install 11kV cable to duct or cable tray	£13,077.23
Miscellaneous	
• Connect and install COP5 LV metering termination cubicle and multicore termination. • Non-standard Civil Design charge per sub-station.	£4,178.38
TOTAL	£88,791.96

Description of CONTESTABLE FINAL CLOSING JOINT WORK that is included in option A and in option B	
Work involved	**Net price (£)**
HV Underground Mains	
• 11kV 300mm Triplex to 95-300mm three core straight joint	£2,315.00
TOTAL	£2,315.00

Description of NON-CONTESTABLE WORK that is included in option A and in option B and in option C	
Work involved	**Net price (£)**
HV Plant and Switchgear	
• Commissioning of a Remote Terminal Unit (RTU) • 11kV outage associated with the provision of an 11kV substation	£5,850.61
Miscellaneous	
• Inspection of substation civil works • Legal fees for a Freehold/Leasehold for the establishment of a substation in a new physical	£1,561.80

location.	
Transactional Charges	
• Assessment & Design Charges	£2,432.00
Other charges	
TOTAL	£9,844.41

Please note that payment is required in full, in advance of the work being programmed.

Section 3 Your Responsibilities

This section provides information about the work that you are responsible for should you accept this Quote.

We have made all of our general information about your responsibilities available in our Knowledge Centre on our internet site at www.ukpowernetworks.co.uk. Links to each of the relevant articles are in the table below.

Please let me know if you think we can improve the information we have provided.

Job Specific Responsibilities

Subject	Link to our Knowledge Library
On-site trenches and cable route	Section 3.1 Click here
Ducts	Section 3.2 Click here
Commercial or industrial connections - CT metering large low voltage connections more than 400As	Section 3.10 Click here
Substations: Associated with LV connections	Section 3.11 Click here
Land rights required from You in connection with land within Your occupation, ownership or control (the freehold/leasehold of the substation site)	Section 3.20 Click here

Generic Responsibilities Applicable to all Quotes

Subject	Link to our Knowledge Library
Construction (Design & Management) Regulations 2015 (CDM)	Section 3.25 Click here
Appoint an electricity supplier	Section 3.26 Click here
Works to be undertaken by the ICP/IDNO if UK Power Networks is undertaking the non-contestable Works only	Section 3.27 Click here
Land rights for option B or C - where UK Power Networks is undertaking the non-contestable Works only	Section 3.28 Click here

Section 4 Information to Help You Plan For Your Work

Drawing Schedule

The table below shows a summary of the standard drawings that may be useful for this Quote, along with hyperlinks to the drawings that are currently applicable. Our drawings are revised periodically so the links in the table below may not work in the future if the drawings are superseded. However the latest versions of all of our standard drawings can be found here. If you have not used our G81 web pages before you will be asked to register your credentials for future logins and updates.

Drawing Number	Drawing Description
8500146627draft	Customer proposal plan
ECS 02-0019	LV/HV/EHV cable trench details View
EDS 08-2110.16	Balancing and Settlements Code of Practice 5 LV & HV Meter Chamber View
Substation drawing	This will be provided separately at a later date (after the Quote)

Job Specific Information

Subject	Link to our Knowledge Library
Supply characteristics for HV and EHV Points of Supply	Section 4.3 Click here
Earth Fault Loop Impedance (EFLI)	Section 4.4 Click here
Cables between UK Power Networks and Customer installations up to 400A	Section 4.5 Click here
Private generation	Section 4.6 Click here
Interactive process	Section 4.10 Click here

Generic Information Applicable to all Quotes

Subject	Link to our Knowledge Library
Information common to all Quotes	Section 4.1 Click here

If you are unhappy with our service please follow our Complaints Procedure Specific to Commercial and Industrial Projects which can be found here. This document details your right to contact Ofgem for a formal determination if we have been unable to resolve the matter to your satisfaction.

Section 5 Acceptance Form

Job Reference: 8500146627 / 3500090857

Site Address: District heating scheme, Maiden Lane estate, London, NW1 9XZ

Please return your completed form by post or email:

CC Proj.
UK Power Networks
Metropolitan House
Darkes Lane
Potters Bar, Herts, EN6 1AG

Email: billingteam-networks@ukpowernetworks.co.uk

Please indicate which option you accept:

		Please tick one only	Price excluding VAT	Price including VAT
A	UK Power Networks carries out all of the requested 'contestable' and 'non-contestable' works required for your connection		£100,951.37	£121,141.67
B	UK Power Networks carries out all the 'non-contestable' work and the 'contestable closing joint'. The ICP carries out all other requested 'contestable' work		£12,159.41	£14,591.29
C	UK Power Networks carries out the 'non-contestable' works only. The ICP carries out all of the works classified as 'contestable'		£9,844.41	£11,813.29

Payment Profile

I understand that the Price, including VAT, must be paid in full to accept this Quote. I also understand that where VAT has been charged a Tax Invoice for the Price will be issued by UK Power Networks on receipt of payment.

Please indicate your method of payment:

Cheque	Please make cheques payable to **UK Power Networks** and **put our reference number on the back.**
Debit/Credit Card	Please call **0203 282 0610** and have your card to hand. We are sorry we cannot accept American Express/Diners Club.
BACS/CHAPS	**Account:** HSBC Bank Plc **Sort Code:** 40 05 30 **Account Number:** 02302934 **UK Power Networks Ref. Number** 3500090857 **(You MUST include this reference so we know which job is being paid):**

The Invoice Address	Your Site Contact
Name / Company name:	Name / Company name:
Contact name:	Contact name:
Address:	Address:
Telephone:	Telephone:
Email:	Email:

Your Acceptance

I accept your quotation for carrying out the DNO Works in accordance with the Quote for the option I have chosen overleaf.

To accept this Quote, the signed Acceptance Form and payment in cleared funds must reach UK Power Networks by 5pm on 29 September 2020. Acceptance Forms and payments received after this date may be returned and you will need to request a new Quote.

Signed:	Date:
Print name:	
Agent acting on behalf of:	
Telephone:	
Email:	

Job Reference: 8500146627 / 3500090857

Acceptance Form Part 2

Land Rights

If you are appointing a Solicitor to complete any legal work associated with acquiring substation sites and easements work, please provide UK Power Networks with their details by completing the table below.

Please also provide us with the name and address of the owner of any affected land.

Solicitors Information

Name / Company name:
Contact name:
Address:
Telephone:
Email:

Land Owners Information

Name / Company name:
Contact name:
Address:
Telephone:
Email:

13.0 APPENDIX 4 – EXAMPLE SCOP CALCULATION

Bin method SCOP calculation air to water heat pump chiller
BS EN 14825 Annex B Table B.1 for Bin data
70degC flow temperature from shell and tube water cooled condenser to district heating network
Annual heating load based on typically retrofit dwelling degree day calc
Allowance of 1kW heat pump output per dwelling, circa 70% of annual load, gas fired boilers cover peaks
750kW heat pump

COP data from manufacture at operating conditions full and part load
Manufacture A - GEA Ammonia heat pump

Bin No.	Bin Temp.	Degree Day Eq.	No. Hours Occur.	Heat Load (kW)	No. Hours Occur.	DHW Load (kW)	Losses Load (kW)
j	Tj	DD	Hja1	Ph(Tj)	Hja2		
21	-10	26	1	2962	219	252	147
22	-9	25	25	2848	219	252	147
23	-8	24	23	2734	219	252	147
24	-7	23	24	2620	219	252	147
25	-6	22	27	2506	219	252	147
26	-5	21	68	2392	219	252	147
27	-4	20	91	2278	219	252	147
28	-3	19	89	2164	219	252	147
29	-2	18	165	2051	219	252	147
30	-1	17	173	1937	219	252	147
31	0	16	240	1823	219	252	147
32	1	15	280	1709	219	252	147
33	2	14	320	1595	219	252	147
34	3	13	357	1481	219	252	147
35	4	12	356	1367	219	252	147
36	5	11	303	1253	219	252	147
37	6	10	330	1139	219	252	147
38	7	9	326	1025	219	252	147
39	8	8	348	911	219	252	147
40	9	7	335	797	219	252	147
41	10	6	315	684	219	252	147
42	11	5	215	570	219	252	147
43	12	4	169	456	219	252	147
44	13	3	151	342	219	252	147
45	14	2	105	228	219	252	147
46	15	1	74	114	219	252	147
na	16	0	0	0	219	252	147
na	17	0	0	0	219	252	147
na	18	0	0	0	219	252	147
na	19	0	0	0	219	252	147
na	20	0	0	0	219	252	147
na	21	0	0	0	219	252	147
na	22	0	0	0	219	252	147
na	23	0	0	0	219	252	147
na	24	0	0	0	219	252	147
na	25	0	0	0	219	252	147
na	26	0	0	0	219	252	147
na	27	0	0	0	219	252	147
na	28	0	0	0	219	252	147
na	29	0	0	0	219	252	147
na	30	0	0	0	219	252	147

Total Heat Load (kW)	Annual Heat Load (kW)
	Hja x Ph
3360	90218
3246	158456
3133	150140
3019	150140
2905	154925
2791	249934
2677	294591
2563	279895
2449	425599
2335	422295
2221	524709
2107	565720
1993	597618
1879	615959
1765	573922
1652	466952
1538	463192
1424	421497
1310	404409
1196	354399
1082	302565
968	209720
854	164266
740	138862
626	111179
512	95686
398	87256
398	87256
398	87256
398	87256
398	87256
398	87256
398	87256
398	87256
398	87256
398	87256
398	87256
398	87256
398	87256
398	87256
398	87256

HP COPbin	HP Output (kW)	HP Work (kW)	HP Annual Output (kWh)	HP Annual Work (kWh)
ASHP	ASHP	ASHP	ASHP	ASHP
2.3	750	331	87608	38657
2.3	750	324	96045	41524
2.4	750	318	95342	40404
2.4	750	312	95694	39766
2.5	750	306	96749	39439
2.5	750	300	111163	44465
2.5	750	295	119249	46829
2.6	750	289	118546	45714
2.6	750	284	145265	55027
2.7	750	279	148078	55117
2.7	750	274	171633	62793
2.8	750	270	185696	66797
2.8	750	265	199759	70668
2.9	750	261	212767	74047
2.9	750	257	212415	72742
3.0	750	253	193782	65317
3.0	750	249	203274	67455
3.1	750	245	201868	65966
3.1	750	241	209603	67464
3.2	750	238	205032	65015
3.2	750	234	198001	61869
3.2	750	231	162844	50152
3.3	750	228	146672	44531
3.3	740	222	138862	41570
3.4	626	185	111179	32824
3.4	512	149	95686	27866
3.3	398	119	87256	26125
3.4	398	118	87256	25815
3.4	398	117	87256	25514
3.5	398	115	87256	25219
3.5	398	114	87256	24930
3.5	398	113	87256	24649
3.6	398	111	87256	24373
3.6	398	110	87256	24104
3.7	398	109	87256	23840
3.7	398	108	87256	23583
3.7	398	108	87256	23583
3.7	398	108	87256	23583
3.7	398	108	87256	23583
3.7	398	108	87256	23583
3.7	398	108	87256	23583

Total Annual Input (kWh)
38657
41524
40404
39766
39439
44465
46829
45714
55027
55117
62793
66797
70668
74047
72742
65317
67455
65966
67464
65015
61869
50152
44531
41570
32824
27866
26125
25815
25514
25219
24930
24649
24373
24104
23840
23583
23583
23583
23583
23583
23583

Total Annual Heat Load 5271653 kWh

Total Annual Energy Input 1750085 kWh

Hybrid System Seasonal COP (SCOPnet) 3.01