ARUP

London Stadium Decarbonisation of Heat Feasibility Study

Feasibility Report

London Stadium 185 and London Legacy Development Corporation

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Contents

Glossary

Feasibility study glossary of terms

ASHP	Air Source Heat Pump
ATES	Aquifer Thermal Energy Storage
BMS	Building Management System
BTES	Borehole Thermal Energy Storage
CapEx	Capital Expenditure
CHW	Chilled Water
CoP	Coefficient of Performance
DESNZ	Department for Energy Security and Net Zero
DNO	Distribution Network Operator
EU	European Union
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
LTHW	Low Temperature Hot Water
LV	Low Voltage
ODP	Ozone Depletion Potential
O&M	Operation and Maintenance
OpEx	Operational Expenditure
PHE	Plate heat exchanger
sCoP	Seasonal Coefficient of Performance
Stadium	London Stadium 185 Ltd.
TX	Transformer
T&D	Transmission and distribution
VRF	Variable Refrigerant Flow
WSHP	Water Source Heat Pump

Summary

Feasibility study

This feasibility study investigates opportunities for heat decarbonisation at the London Stadium.

London Stadium is connected to the East London Energy heat network and uses two heat metered connections to provide heat for space heating, hot water and pitch heating. Opportunities for heat decarbonisation included utilising waste heat from the existing chiller farm and from smaller chillers around the site, in addition to an option to decarbonise heat by switching to an electric heating solution.

The options identified in this study are given from a technical perspective, and a commercial perspective should also be sought considering the Stadium's heat Supply Agreement and the corresponding Concession Agreement.

Table A, right, shows a summary of the four options that are developed further in the report. In addition to these main solutions the option to recover heat from the smaller chillers around site is described. Each of the solutions presented is assessed against the following metrics:

- Heat recovery potential
- CapEx costs
- OpEx savings
- Payback period
- Carbon savings
- Embodied carbon
- Additional co-benefits
- Maintenance requirements
- District heat network upgrade/interface requirement
- Fire safety
- Planning considerations

A summary of the findings can be seen in Table B on the next page.

Recommended next steps

- The BMS opportunities highlighted in the Baseline report offer a heating, cooling and ventilation energy use reduction between 10-20%, which can reduce emissions from heat by around 62-125 tCO_2e/year. It is recommended that these opportunities are implemented.
- After considering the metrics considered in this report an in-depth feasibility study for the preferred option should be conducted.
- Engagement with key stakeholders such as Bring Energy and the DNO will be required as part of the solution development.

Option	Description
Heat recovery from chillers - Condenser side	Recover waste heat from the chillers at 60°C by replacing the chillers with heat recovery chillers, the heat is then upgraded to 70°C using a Water Source Heat Pump (WSHP)
Heat recovery from chillers - Evaporator side	Heat is recovered from the chilled water circuit using WSHPs that can upgrade the chilled water return temperature at 16°C to 70°C
Simultaneous Air Source Heat Pumps - Replace one chiller	One chiller coming to the end of its life is replaced with a simultaneous Air Source Heat Pumps (ASHP) to produce cooling and heating, the heat is upgraded from 45°C to 70°C using a WSHP
Simultaneous Air Source Heat Pumps - Meet entire heat demand	Three chillers are replaced with simultaneous ASHPs to produce cooling and heating, the heat is upgraded from 45°C to 70°C using a WSHP

Table A. Summary of heat decarbonisation solutions

Results summary

	Current operation (baseline)	Building optimisation measures	Feasibility study options			
			1. Heat recovery from chillers - Condenser side	2. Heat recovery from chillers - Evaporator side	3. Simultaneous Air Source Heat Pumps - Replace one chiller	4. Simultaneous Air Source Heat Pumps – Meet entire heat demand
Heat required from the heat network, GWh	3.6*	10/20% saving on baseline	3.0	2.4	0.4	0.0
Annual heat generated from the solution, GWh	0	N/A	0.7	1.1	3.2	3.7
Electricity required for heating, GWh			0.12	0.10	0.88	0.89
Carbon from heat network (Bring Carbon Factor), tCO2 (annual, 2024)	628	-	532	428	76	0
Carbon from electricity for heating, tCO2e (annual, 2024)	0	-	26	22	197	199
Total carbon emitted from heating (Bring Carbon Factor), tCO2e (annual, 2024)	628	-	558	450	273	199
Total carbon emitted from heating (Bring Carbon Factor), tCO2e (annual, 2030)	628**	-	538	433	119	43
CapEx cost, £m	£0m	Consulting fees and small equipment	£2.7m	£1.2m	£2m	£4.4m
OpEx savings over 15 years, £m	£0m	10/20% saving on baseline	£0.2m	£0.1m	£0.6m	£0.9m
Payback period, years (£/ X years)	-	-	Does not pay back, using the simple payback method, within the life of the asset.			
Cost of carbon saving, £/tCO2e***	-	-	£1,700	£350	£170	£370
Embodied carbon, tCO$_2$e			320	200	520	1,380

Table B. Summary of heat decarbonisation solutions

*Baseline heat demand in Arup Baseline report is reported as 3.4 GWh, this is the weather and event day corrected value. To maximise the opportunity for heat recovery from higher heat and cooling use on event days the metered data value of 3.6 GWh was used to model the proposed solutions.

**Assuming low carbon sources not taken from the heat network

*** Calculated by: (CapEx - OpEx savings over 15 years) divided by Operational carbon saving over 15 years

Results summary

			Feasibility study options			
	Current operation (baseline)	Building optimisation measures	1. Heat recovery from chillers - Condenser side	2. Heat recovery from chillers - Evaporator side	3. Simultaneous Air Source Heat Pumps - Replace one chiller	4. Simultaneous Air Source Heat Pumps – Meet entire heat demand
Additional co-benefits		Can be done straight away, low capital cost		Can be done straight away, no existing equipment to be replaced	High efficiency heat generation from simultaneous heat pump	High efficiency heat generation from simultaneous heat pump
Maintenance requirements	As existing	If TRV valves are installed, maintenance of TRV batteries is required	Increased maintenance than existing chiller due to additional heat exchanger, new control systems required, and maintenance of new LTHW pipework and PHEs in each heat meter plant room	Additional maintenance for WSHPs, new pipework and PHEs in each heat meter plant room required	ASHP require maintenance due to defrost cycles and compressors can experience wear due to simultaneous generation, additional maintenance for WSHPs, new pipework and PHEs in each heat meter plant room required	
Fire safety		N/A	The proposed equipment uses the same refrigerant currently in use onsite. In the future, if alternative refrigerants are considered, their flammability and fire safety must be taken into account.			
Planning considerations		N/A	New equipment in added to the chiller farm location which change the appearance of the chiller farm and surrounding areas, will need to be assessed against the local planning rules.			
Solution impact on heat network (technical only)		N/A	Recovery of wasted heat only, and modification to secondary circuit.	Recovery of wasted heat only, and modification to secondary circuit.	Some generation of heat on site and modification of secondary circuit.	Full generation of heat on site and modification of secondary circuit.
Commercial considerations		N/A	The options identified in this study are given from a technical perspective, and a commercial perspective should also be sought considering the Stadium's heat Supply Agreement and the corresponding Concession Agreement.			

1. Introduction

Project background

The baseline report presented the results for the baseline heat, cooling, and electrical energy model. Following the baseline report, this report presents feasible solutions for the decarbonisation of heat at the Stadium.

This report was produced for London Stadium and London Legacy Development Corporation, part of the GLA Group. The GLA aims to be net zero carbon by 2030.

This report was funded by the GLA's Zero Carbon Accelerator programme, which supports feasibility studies into heat decarbonisation options.

The report includes a summary of the options considered:

- Heat recovery from onsite chillers
- Heat recovery from other waste heat sources at the Stadium
- Other forms of heat pumps
- More efficient use of the BMS system

Heat recovery and efficient use of the BMS system reduce the heat required from the East London Energy heat network, reducing the carbon at the Stadium.

Installing heat pumps will enable electrification of the heat supply on site, which could be part of a Stadium-only or wider ELE network electrification solution. As the electricity grid decarbonises, electric solutions will provide a low-carbon source of heat. Figure 1.1 shows the projection for grid carbon emissions to 2042 and the Bring Energy heat network carbon factor for 2023-2024. For this report, it is assumed that the heat network carbon factor will remain constant, as it is essentially fossil-fuel fired.

Bring Energy, who now operate the East London Energy heat network, were consulted as part of this project. They have plans to decarbonise the heat network through electrification, however this work is in the early stages and is a complicated exercise, which extends to 2035.

Following the investigation of the options, four solutions were developed into feasibility level engineering solutions. Feasibility sketches and an assessment against the following criteria are presented for the four options developed:

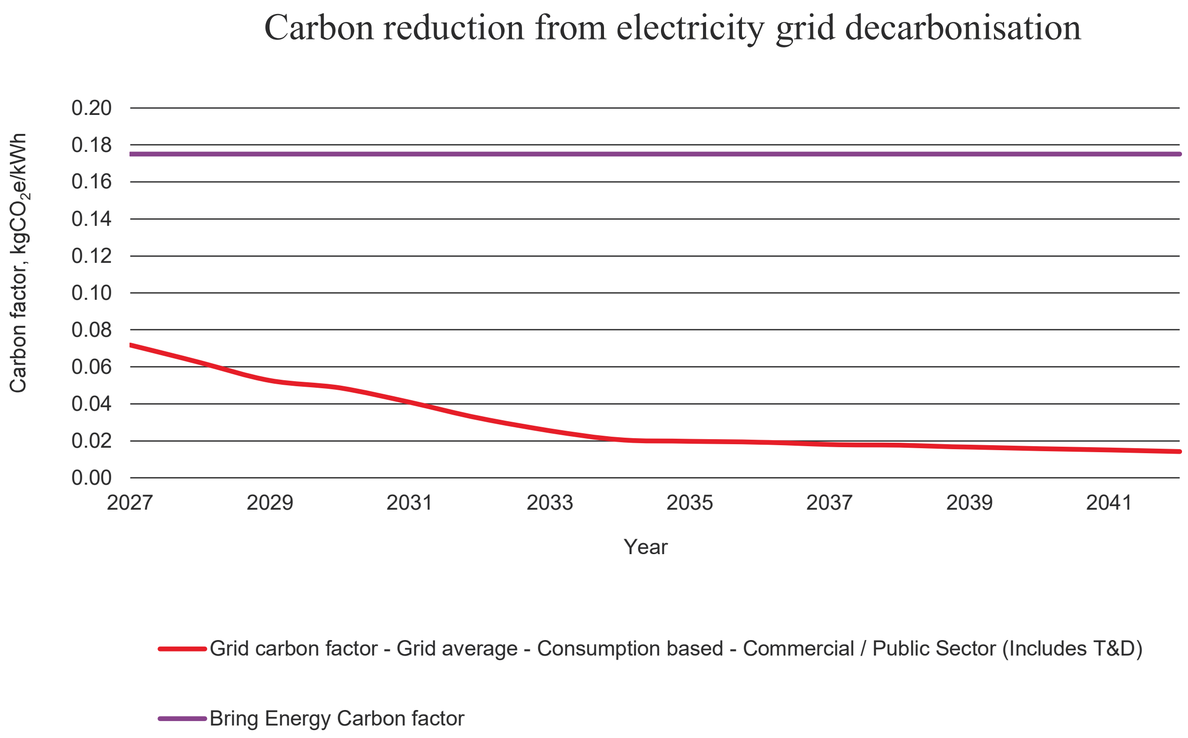
- Heat recovery potential
- CapEx costs
- OpEx savings
- Payback period
- Carbon savings
- Embodied carbon
- Additional co-benefits
- Maintenance requirements
- District heat network upgrade/interface requirement (technical interface)
- Fire safety
- Planning considerations

The four options listed are developed to a RIBA Stage 1 level of detail:

- Heat recovery from chillers - Condenser side
- Heat recovery from chillers - Evaporator side
- Simultaneous Air Source Heat Pumps - Replace one chiller
- Simultaneous Air Source Heat Pumps – Meet entire heat demand

1. Introduction

Bring Energy current carbon factor compared to BEIS's* predictions on decarbonisation of the electricity grid



Please note that this assumes no decarbonisation of the heat network and a consistent blend of fuels being used in the Bring Energy energy centre

Figure 1.1. Electricity and heat network carbon emission factors.

*Grid carbon factor from Table 1, Grid average - Consumption based - Commercial / Public Sector (Includes T&D)
https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

2. Heat decarbonisation technologies

Investigation of relevant technologies

This section details the technologies investigated as part of the feasibility report and the following described technologies identified for recovering heat at the Stadium:

a) Heat pumps:

- Air Source Heat Pumps s (ASHPs)
- Cascaded Water Source Heat Pump (WSHP)
- Simultaneous Air Source Heat Pumps
- Refrigerant selection

b) Chiller heat recovery

c) Thermal storage

2. Heat decarbonisation technologies

a. Heat pumps

Air Source Heat Pumps (ASHPs)

ASHPs are a low-carbon energy production technology that uses electricity to provide heating and/or cooling. Air is drawn into the evaporator plate heat exchanger (PHE) via fans that transfer heat to a refrigerant circuit. The increased temperature refrigerant flows in a closed loop to the condenser, where the heat is then transferred to the heating circuit and dumped into the heat sink. This concept is shown in Figure 2.1.

ASHPs typically require electrical connections to the site to be increased, or at the minimum, a larger capacity to be bought from the electricity supplier due to the increased electrical requirement relative to traditional fossil fuel-powered technologies.

Due to the high noise ratings of the fans, installing ASHPs within a densely populated area will require acoustic enclosures to ensure the fans meet local noise requirements. They are, however, not significantly louder than chillers of the same capacity.

Airflow around ASHP fans leads to cold plumes affecting the local environment, which should be considered when installing large installations of ASHPs.

ASHPs can have Coefficients of Performance (CoP) ranging from 2.5 to 3.5 at design conditions, with higher CoPs of 6 to 7 for simultaneous ASHPs. The highest operating temperature for ASHPs is currently around 55°C.

To achieve the current Stadium secondary heat circuit operating temperature of 70°C, a Water Source Heat Pump (WSHP) for boosting temperatures is required. This, therefore, reduces the combined CoP due to the additional power required for the WSHP.

Cascaded Water Source Heat Pump

WSHPs operate in the same manner as ASHPs; however, the evaporator and condenser reject or extract heat from water sources instead of the air. WSHPs offer greater flexibility, as their efficiency is not subject to external air conditions, and they typically offer improved levels of efficiency.

WSHPs offer the capacity to provide flow and return at higher temperatures; as such, it is often the case that the low-LTHW produced by ASHPs is fed into a WSHP to then be raised to a higher temperature. This is referred to as a “cascade” system. While it enables the production of higher-temperature water, it will result in a lower net efficiency relative to single-unit systems and higher capital cost and embodied carbon.

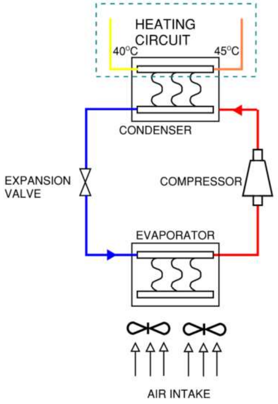


Figure 2.1. Heating ASHP

2. Heat decarbonisation technologies

a. Heat pumps

Simultaneous Air Source Heat Pumps

Simultaneous ASHPs allow for simultaneous heating and cooling supply from the same unit or reversible heating-only or cooling-only operation. Figure 2.2 illustrates the working refrigerant flow within the ASHP in simultaneous heating and cooling mode. The refrigerant flows from the cooling circuit evaporator to the heating circuit condenser via compressors and is expanded back through the expansion valves. This, therefore, leaves the air-side exchangers not in operation, mimicking a Water Source Heat Pump.

The changeover from heating or cooling modes to simultaneous operation is accomplished via a 4-port valve that disconnects the air-side heat exchangers when both heating and cooling demands require supply.

Simultaneous ASHPs are favourable when the heating and cooling demands coincide at the same point in time throughout the operation.

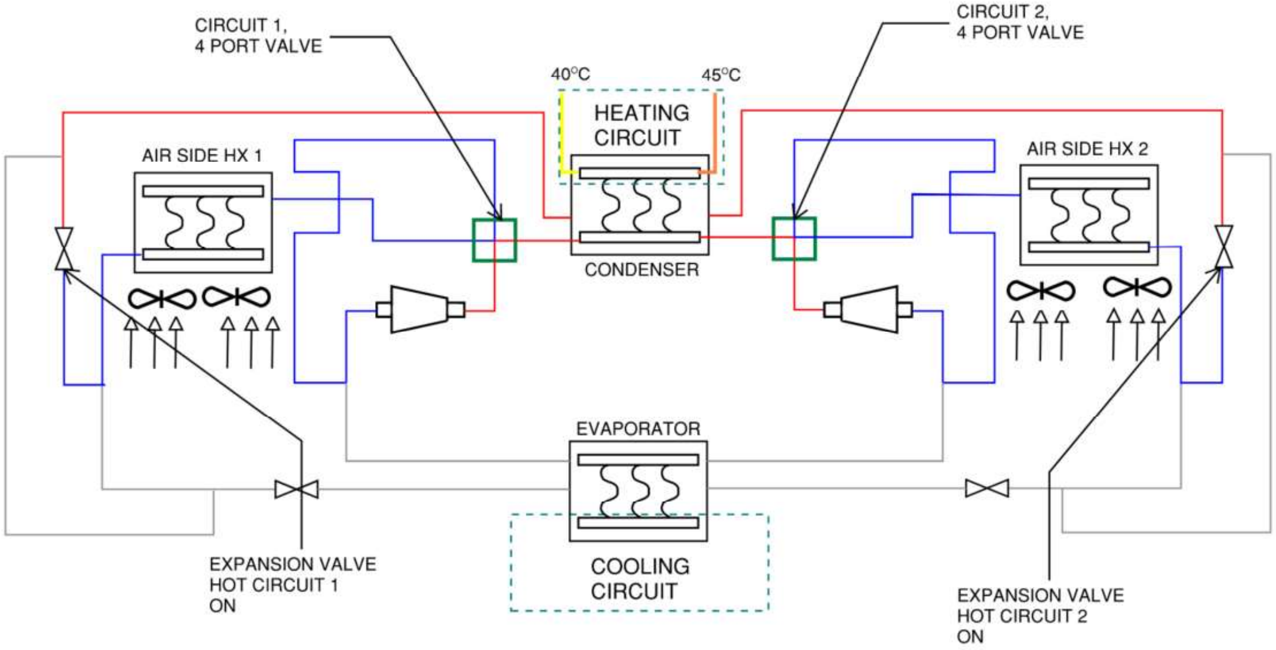


Figure 2.2. Simultaneous ASHP supplying both heating and cooling

2. Heat decarbonisation technologies

a. Heat pumps

Simultaneous ASHPs generally operate with lower cooling capacity in simultaneous mode compared to the heating capacity; however, this varies by manufacturer. Specification sheets from different manufacturers have shown that the balance of heating to cooling can be specified so that there is equal heating to cooling, more cooling than heating, or more heating than cooling when operating in simultaneous mode.

The simultaneous ASHP will turn down to operate at part load conditions depending on the lower of the two demands, and any remaining load will need to be met by a chiller or heat supply technology.

Due to both heating and cooling demands being met, the Seasonal Coefficient of Performance (SCoP) of the ASHP will include heating and cooling capacities, with CoP figures much larger than heating or cooling-only modes.

Similarly to standard ASHPs, a Water Source Heat Pump (WSHP) will need to be cascaded with the ASHP to achieve the network temperatures, which will reduce the overall CoP.

2. Heat decarbonisation technologies

a. Heat pumps

Refrigerant selection

Heating and cooling systems use refrigerants to drive the thermodynamic circuits that allow heat exchange.

Refrigerant usage started almost 200 years ago with the use of natural refrigerants. Toxicity and flammability concerns then led to the development of synthetic refrigerants, which have been found to have negative environmental impacts, particularly with regard to their Ozone Depletion Potential (ODP) and Global Warming Potential (GWP).

Since then, F-gas legislation has been reactive to refrigerant use in the industry and the developing emphasis on environmental concerns. Following the UK's departure from the European Union (EU), the UK's F-Gas Regulations have remained in alignment with the EU. In accordance with the EU & UK F-gas Regulation EU No 517/2014 of 16/04/14, the regulation aimed to reduce the availability of Hydrofluorocarbons (HFCs) and Hydrofluoroolefins (HFOs) in the marketplace. It is expected that several amendments to the original legislation will come into place by 2027 in the EU, with the UK following the implementation strategy.

Currently natural refrigerants are available with low GWP are ammonia, propane and carbon dioxide (CO_2). The choice of refrigerant impacts the temperatures that the heating and cooling units can achieve as well as the efficiency the system.

Ammonia is very efficient at these working temperatures, but needs to be carefully designed due to its toxicity. HFCs such as R134a are less toxic, but also less efficient.

Large scale natural refrigerant heating and cooling systems are currently not available as off-the-shelf units, meaning that bespoke solutions are required. However, more manufacturers are developing systems using low GWP refrigerants to reduce the negative impact on the environment from the leakage of F-gases into the atmosphere.

At the next design stage, the refrigerant type should be considered to minimise the GWP of the refrigerants used at the Stadium and maximise the efficiency of heating and cooling generation.

Table 2.1. Typical refrigerants used for chillers and heat pumps

Refrigerant	GWP	Type
R-410A	2,088	HFC
R-134a	1,430	HFC
R-32	633	HFC
R-513a	631	HFO
R-717	0	Ammonia, NH_4
R-290	3	Propane
R-744	1	CO_2

2. Heat decarbonisation technologies

b. Chiller heat recovery

Chillers operate in a reverse cycle to heat pumps to provide cooling loads by removing heat from the cooling circuit and rejecting the heat to a heat sink.

Typically, the heat is rejected to air through an air-cooled condenser, or in the case of water-cooled chillers, the heat is rejected to cooling towers located on the roof. Although the amount of heat rejected is not enough to single-handedly meet the heat demands, the wasted heat can be utilised to supplement the heating demands already being fed by other heat sources. There are two options for recovering heat from air-cooled chillers:

- Using a desuperheater, which can recover 15-30% of rejected heat.
- Total heat recovery, which recovers 100% of rejected heat but may compromise the chiller efficiency.

The site heat demand is much greater than the cooling demand; therefore, the second option has been considered in the analysis.

Figure 2.3 illustrates the operating principles behind heat recovery chillers. The refrigerant absorbs heat from the cooling circuit, causing evaporation. The low-pressure refrigerant gas is then compressed and fed through the condenser, transferring heat to the heat sink and causing the refrigerant to liquefy. The refrigerant then flows through the expansion valve to reduce to a low-pressure state. The condenser refrigerant containing the rejected heat from the sink flows to a water-cooled heat recovery condenser within the heating circuit on the secondary side.

The heating load generated is a by-product of the chiller. This option will appear favourable when there is a constant cooling demand being met or when the heating and cooling demands coincide at the same time.

This chiller will always maintain the leaving hot water temperature. As a result, the performance of the chiller will be downgraded to produce hot water to the specified temperature while also controlling the leaving chilled water temperature. The leaving hot water temperature is a by-product of the cooling cycle.

The heat recovery condenser can transfer 100% of the chiller's total heat of rejection to the hot water loop. The leaving water temperature can reach a maximum temperature of 60°C under steady state and constant hot water flow conditions.

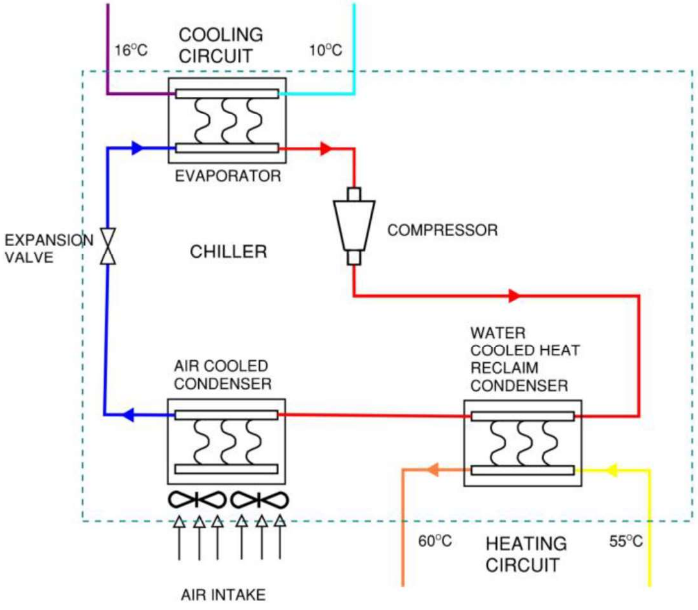


Figure 2.3. Chiller with heat recovery condenser

2. Heat decarbonisation technologies

c. Thermal storage

There are three principal thermal energy storage technologies that are available for consideration at the Stadium: thermal stores, seasonal thermal energy stores, and buffer vessels. The differences between the technologies are outlined in Table 2.2.

Table 2.2. Thermal storage technologies

Storage Technology	Description
Intra-day Thermal Storage	Thermal Storage, particularly through the usage of tanks or pits, is used to store excess hourly heat energy for a particular system. As a large tank or pit filled with water, the heat energy within the thermal store is “charged up” whenever the hourly heat demand exceeds the hourly heat supplied. Conversely, whenever there is a shortfall in energy supply, the thermal store is discharged to distribute heat as necessary. The UK government refers to this technology as “Intra-day” energy storage.
Seasonal Thermal Energy Storage	Seasonal Thermal Energy Storage, also known as Inter-Seasonal Thermal Energy Storage, is the storage of heat or coolth for up to several months. Typically, excess heat – and in particular, waste heat from items such as cooling equipment or solar collectors – is gathered during hot months, to then be released during colder months of the year. There are several types of available Seasonal Thermal Energy Storage technologies, including Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES). There are also other possible solutions, involving pit storage, where dug pits are filled with gravel and water as storage mediums, or large-scale thermal storage with underground water tanks.
Buffer vessels	Buffer vessels are an essential component of heat pump and hot water systems; they are smaller than Thermal Stores, but similarly are insulated water tanks that function to balance the hot water system, and enable the heat pump to work efficiently by eliminating short cycling. They ensure that a constant flow and return enter and leave the heat pump to prevent excessive upwards and downwards modulation, and the resulting mechanical damage. Additionally, buffer vessels help reduce the peak demand by smoothing out peaks associated with turning on and off equipment. Buffer tanks are localised to their respective heat pump system. Buffer tanks are typically supplied with the heat pump units.

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3. Investigation of relevant opportunities

Baseline

The following section details any opportunities for heat decarbonisation at the Stadium including any opportunities identified for heat recovery.

The options detailed in Table 3.1 are presented in this section.

Table 3.1. Opportunities investigated

Option	Description
1. Heat recovery from chillers - Condenser side	Recover waste heat from the chillers at 60°C by replacing the chillers with heat recovery chillers, the heat is then upgraded to 70°C using a Water Source Heat Pump (WSHP)
2. Heat recovery from chillers - Evaporator side	Heat is recovered from the chilled water circuit using WSHPs that can upgrade the chilled water return temperature at 16°C to 70°C
3. Simultaneous Air Source Heat Pumps - Replace one chiller	One chiller coming to the end of its life is replaced with a simultaneous Air Source Heat Pumps (ASHP) to produce cooling and heating, the heat is upgraded from 45°C to 70°C using a WSHP.4.
4. Simultaneous Air Source Heat Pumps – Meet entire heat demand	Three chillers are replaced with simultaneous ASHPs to produce cooling and heating, the heat is upgraded from 45°C to 70°C using a WSHP.
Heat recovery from small chillers	One of the split system VRF units is investigated to determine how waste heat can be utilised, summarising the options for recovering heat.
More efficient use of the BMS system	Savings for heat, cost and carbon for realising the BMS optimisation measures are presented.

3. Investigation of relevant opportunities

Connection to heat recovery solutions

For each of the solutions considered a connection to one or both of the Heat Meter Plant rooms is required. This report describes the current configuration for each of the heat meter substations and how heat recovery solutions are typically connected to the heat network substation.

The heat network supplies heat to each of the two heat substations at the Stadium at a temperature of 90°C, the design return temperature is 55°C, the existing arrangement in each of the heat meter substations is shown in Figure 3.1. The secondary (London Stadium) side is designed to a flow temperature of 70°C and return temperature of 40°C. The connection to the district heat network means that the secondary network is designed to operate with a constant return temperature where possible.

Traditional heat recovery methods preheat the return of the hot water network as shown in the Figure 3.2 arrangement. Under the current heat network agreement with East London Energy, there is an obligation for the return temperature to the heat network to have a weighted monthly secondary temperature below 53°C with a maximum return temperature of 85°C. This means that the temperature labelled '>40°C' in Figure 3.2 is currently subject to this obligation.

It is therefore difficult to connect any heat recovery technologies using this configuration without affecting the return temperature to the heat network and incurring a charge.

Another way to connect the heat recovery source that meets the current return temperature obligations, is in parallel either to one or both of the substations each with two existing Plate Heat Exchangers or PHEs, this arrangement is shown in the schematic for each of the solutions proposed.

This matter was discussed with Bring Energy at our meeting on 4 March 2025. They requested to review our drawings to comment on whether they complied with the Stadium's obligations under their contract with them.

3. Investigation of relevant opportunities

Connection to heat recovery solutions

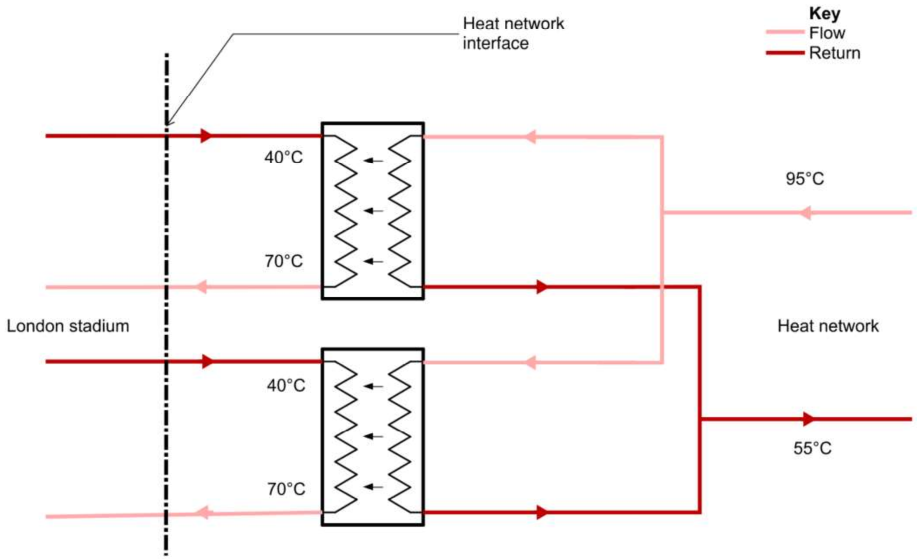

Figure 3.1. Existing arrangement in each heat meter plant room

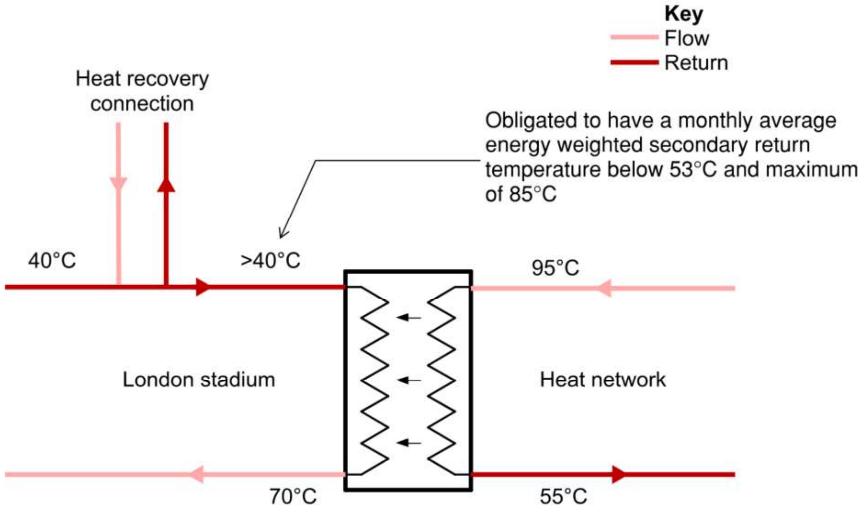

Figure 3.2. Typical connection to heat recovery solutions

3. Investigation of relevant opportunities

Connection to heat recovery solutions to the heat network

There is the possibility to connect heat recovery technologies implemented at the Stadium to the wider heat network. However, there are a number of technical challenges associated with connecting heat pumps to an existing heat network that need to be considered:

- Low flow temperature mismatch: most heat pumps operate most efficiently at lower temperatures whereas heat networks operate at high temperature, this means that more operational and embodied carbon is used to provide the right temperature heat to the network than directly to each building connected to the network.
- The network temperature can be reduced to improve the efficiency of heat networks when connecting heat pumps, however this can only be done if every building on the network can take heat at a lower temperature which may require some buildings conducting large building-side modifications (e.g. larger radiators) to be able to use the heat at a lower temperature. Lowering the operating temperature of the heat network may remove the need to use a cascaded heat pump solution if high temperature ASHPs can deliver heat at the reduced network temperature.
- Heat pump operation can require larger flow rates than gas boilers, so existing network pipes will need to be checked to ensure they are adequately sized to deliver heat from heat pumps. Should larger pipes be required for the heat pumps, it would result in costly changes to the network.
- Control of the network becomes difficult when multiple sources of heat are connected. The flow and return temperatures need to be managed for each building and heat source connected.
- In low load periods heat pumps will operate inefficiently, which could negatively impact the network. Heat pumps have reduced efficiency when there is a smaller temperature difference between the water leaving and entering the heat, so pumps are required to run for a longer periods to achieve the desired temperature when less heat is being transferred to the system.

Due to the scale of heat recovery and heat generation compared to network requirements, the solutions developed as part of this report are not suitable for providing heat to the network. Further investigation into the existing network is required to determine if connecting heat recovery from the Stadium to the East London Energy heat network is possible.

In general, there is sufficient space where the chillers are installed at the London Stadium to install additional ASHPs that could supply heating to the ELE heat network. If this is of interest, it is recommended that this is discussed with Bring Energy, for their further decarbonisation plans.

3. Investigation of relevant opportunities

Thermal storage

Each of the solutions developed includes the use of a thermal store, which is charged in times of excess heat generation and discharged in times of peak demand.

The thermal store has been sized to maximise the amount of heat recovered over the year while minimising the losses experienced from the surface of the vessel.

Any solutions developed further can also consider the use of a chilled water thermal store, this will optimise the heat recovery opportunity on site by storing coolth when there is a higher heat demand and then discharging when cooling is required.

Additionally, the heat and cooling thermal stores can be charged at night to make use of favourable electricity prices, then be discharged in the day when electricity costs are higher.

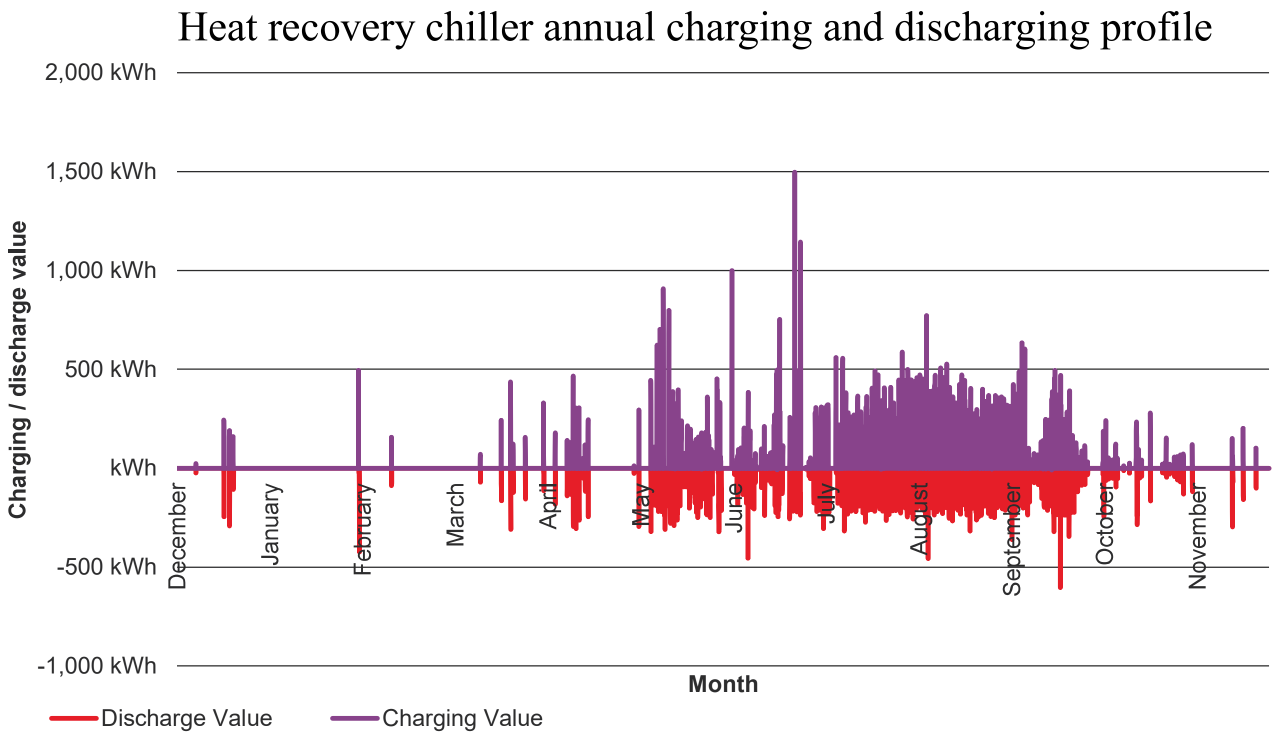

Figure 3.3. Annual thermal store charging and thermal store charging profile for the replacement of two chillers with heat recovery chillers at the London Stadium

3. Investigation of relevant opportunities

Overview of proposed solutions

Table 3.2 outlines the work required to implement the four options developed to provide low-carbon heat at the Stadium. For all the solutions considered, the proposed refrigerants are synthetic HFCs with similar GWPs to the refrigerant currently used in the chillers are the Stadium (R-134a). If refrigerants with lower global warming potential are considered in the future, their flammability and fire safety must be taken into account. Discussions with Bring Energy are also important on the commercial aspects of implementing the solutions.

Table 3.2. Work required to implement each of the heat recovery solutions

Work required	Heat recovery from onsite chillers – condenser side heat recovery	Heat recovery from onsite chillers – evaporator (CHW) side heat recovery	Simultaneous Air Source Heat Pumps - Replace one chiller	Simultaneous Air Source Heat Pumps – Meet entire heat demand
Heat recovery solution	Replace two end-of-life chillers with heat recovery chillers.	Five WSHPs are connected to the CHW circuit running from the Stadium to the chillers, the connection point is near the chiller farm.	Replace one end of life chiller with a simultaneous ASHP.	Replace three chillers with simultaneous ASHPs
Connect and install WSHPS	Connect the LTHW produced from the heat recovery chillers to three WSHPs, the WSHPs boost the LTHW temperature from 60°C to 70°C.	The WSHPs recover heat from the CHW circuit to produce LTHW at 70°C.	Connect the LTHW produced from the simultaneous ASHP to one WSHP, the WSHP boosts the LTHW temperature from 45°C to 70°C.	Connect the LTHW produced from the simultaneous ASHPs to three WSHPs, the WSHPs boosts the LTHW temperature from 45°C to 70°C.
WSHP location	For all the solutions proposed an outdoor plant room located near the chiller farm will be required to house the WSHPs and any ancillary equipment required for the heat recovery solutions, planning permission may be required to construct the outside GRP plant room.			
Thermal store installation	Install a thermal store to capture excess heat generated when the recovered heat surpasses site demand. This stored heat will be released during periods of high demand. The thermal store proposed for all option is approximately 7 meters tall and will alter the appearance of the chiller farm and will likely require approval from the local planning council (multiple smaller and shorter thermal stores can be considered in place of one large vessel to minimise the visual impact but these will increase the footprint).			
LTHW Pipework	Run LTHW pipework from the WSHPs and thermal store underground to both heat network substations. This will involve laying a trench across the car park and along the sides of the Stadium. A value engineering solution could involve running the pipework above ground along the Stadium wall.			
Plate heat exchanger space	Allocate space for a plate heat exchanger in or around each plant room to connect the heat recovery solution to each heat network substation.			

3. Investigation of relevant opportunities

d. BMS Optimisation opportunities

The baseline report highlighted a number of measures that could be implemented to reduce energy usage at the Stadium.

It is estimated that a 10-20% reduction can be achieved for heating, cooling and ventilation energy usage from implementing the optimisation measures.

The impact that this reduction has on the annual heat consumption is shown in Figure 3.23.

Table 3.13 summarises the impact of heat usage, cost for heat and carbon emissions from the heat network from implementing the BMS optimisation measures.

	Current	Possible saving
Heat used, GWh	3.59	0.36 - 0.72
Cost of heat, £	223,000	22,000-44,000
Carbon emissions per year, tCO_2e	627	62 - 126

Table 3.13. Current heat usage with heat, cost and carbon savings from implementing BMS optimisation measures

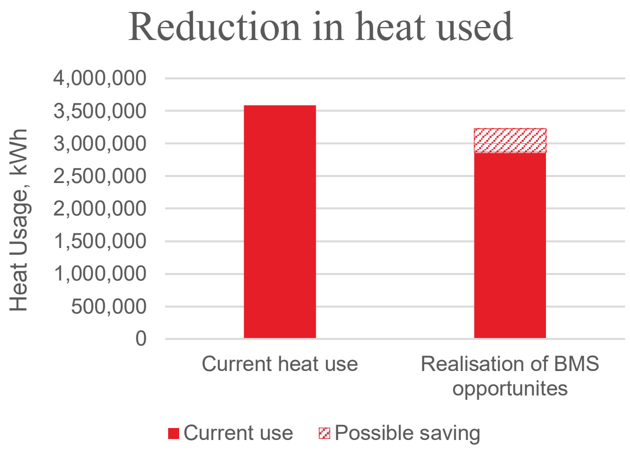

Figure 3.23. Opportunity for heat use reduction from BMS optimisation opportunities

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4. Techno-economic feasibility

Heat recovery potential

Each scenario presented in Section 3 was modelled to determine the amount of heat generated by each solution and the remainder that will be met by the Bring Energy heat network. The heat generated electrically by each of the solutions is shown in purple in Figure 4.1, and the remaining heat that will be required from the network is shown in red.

The proposed solutions generate more heat than needed for the current operation because there are losses from the thermal store.

The amount of heat that can be generated from heat recovery is greater when connecting to the evaporator side of the chiller as the rejected heat from the building can be upgraded using electric WSHPs to provide around 30% of the heat demand, compared to around 20% when connecting to the condenser side.

For the simultaneous ASHP replacement, the replacement of one chiller can produce greater than 80% of the heat demand for the Stadium. This assumes that when the heating load is larger than the simultaneous heating and cooling demand that the simultaneous ASHP can provide heating up to the heating capacity of the module (this will need to be investigated further at the next design stage).

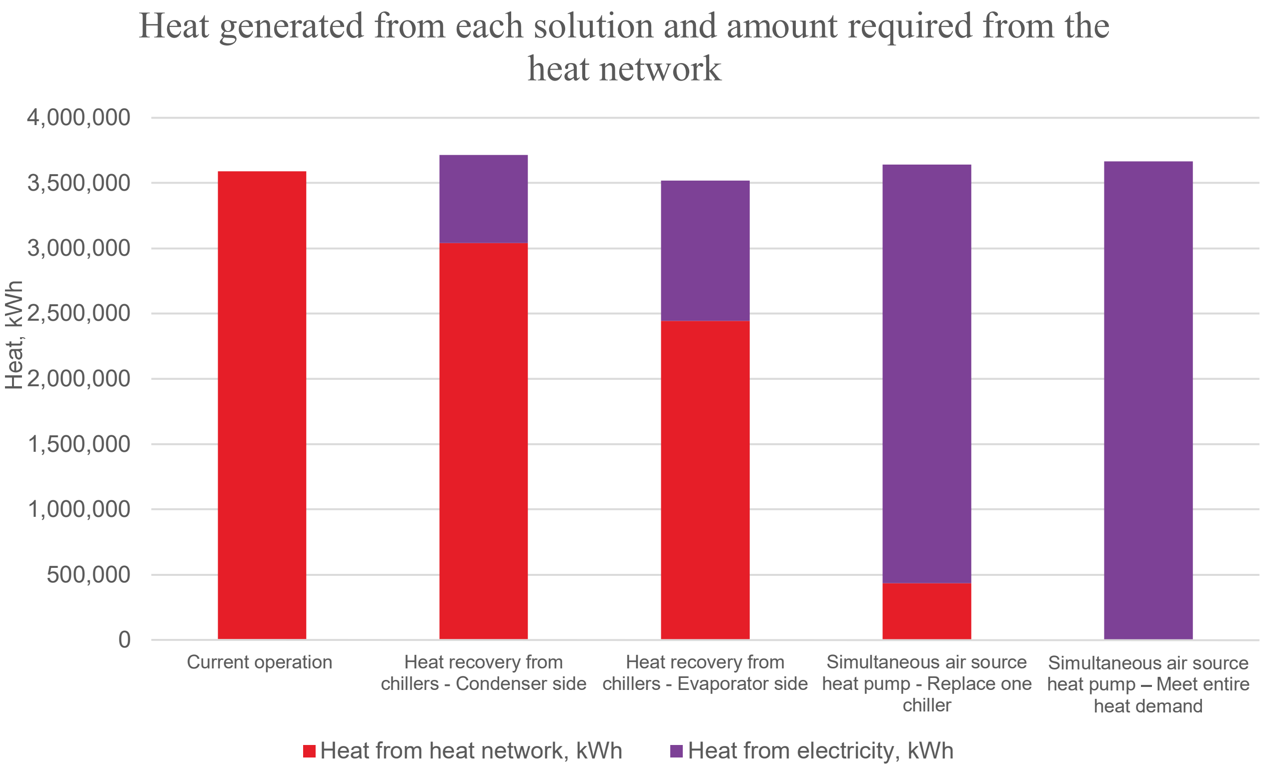

Figure 4.1. Heat generation from electricity and heat network for each solution

4. Techno-economic feasibility

Capital cost

The capital cost for each of the solutions proposed is shown in Figure 4.2. The costs are based on SPONS Mechanical and electrical services price book and are accurate to ±40%.

Cost assumptions and exclusions

- The calculated costs include the following items (any other costs are excluded):
    - Capital costs including controls
    - Installation costs
    - Civil works (Costs include all pipework underground – running pipe above ground can reduce the cost).
    - Design fees
    - Commissioning
- **Costs of all replacement chillers not included in costs**, as it is assumed that chillers would have to be replaced even if no heat recovery interventions are implemented. As such, where chillers are being replaced with ASHPs, the capital costs shown are additional to the cost of the chiller that would have to have been bought at the time of replacement.
- See Appendix A for assumptions related to costing.

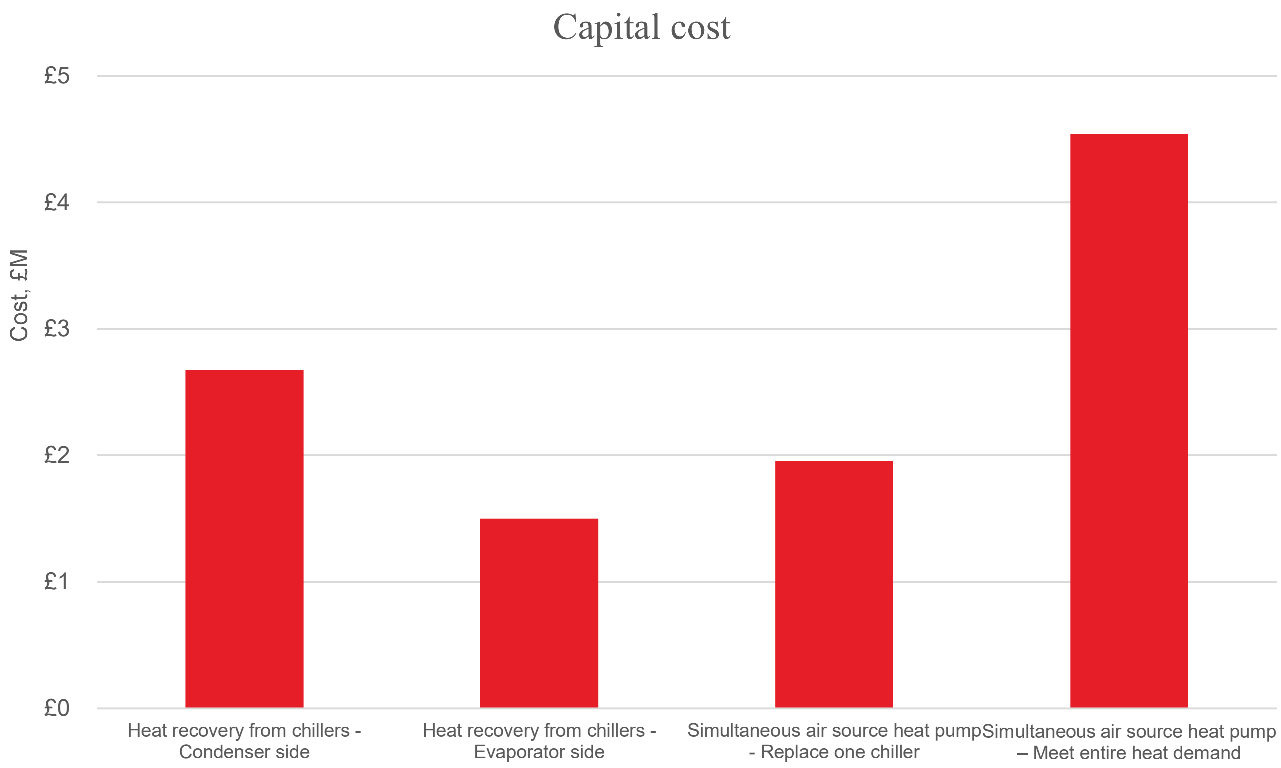

Figure 4.2. Capital cost for each solution (less replaced chillers costs)

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4. Techno-economic feasibility

Operational cost

The operational cost for each scenario is considered, the cost is made up of the electricity used for heating and the remainder of the heat required that will be provided from the network.

For the heat cost, the capacity cost is kept constant but, in the future, this could reduce if the agreement is renewed to reduce the capacity required from the heat network. This would reduce the operational cost of the solutions proposed. The impact removing the capacity charge on the cumulative operational cost savings compared to the current operation is shown in the next slide.

It is seen that the operational cost for heat recovery from the chillers is higher than the current operation, this is due to the relative high cost of electricity compared to heat and the large portion of the cost that is attributed to the heat capacity agreement.

The two options to replace chillers with simultaneous heat pumps reduces the operational cost at the site, this is due to the high efficiency achieved when operating in simultaneous mode.

No costs are added for O&M of the additional plant.

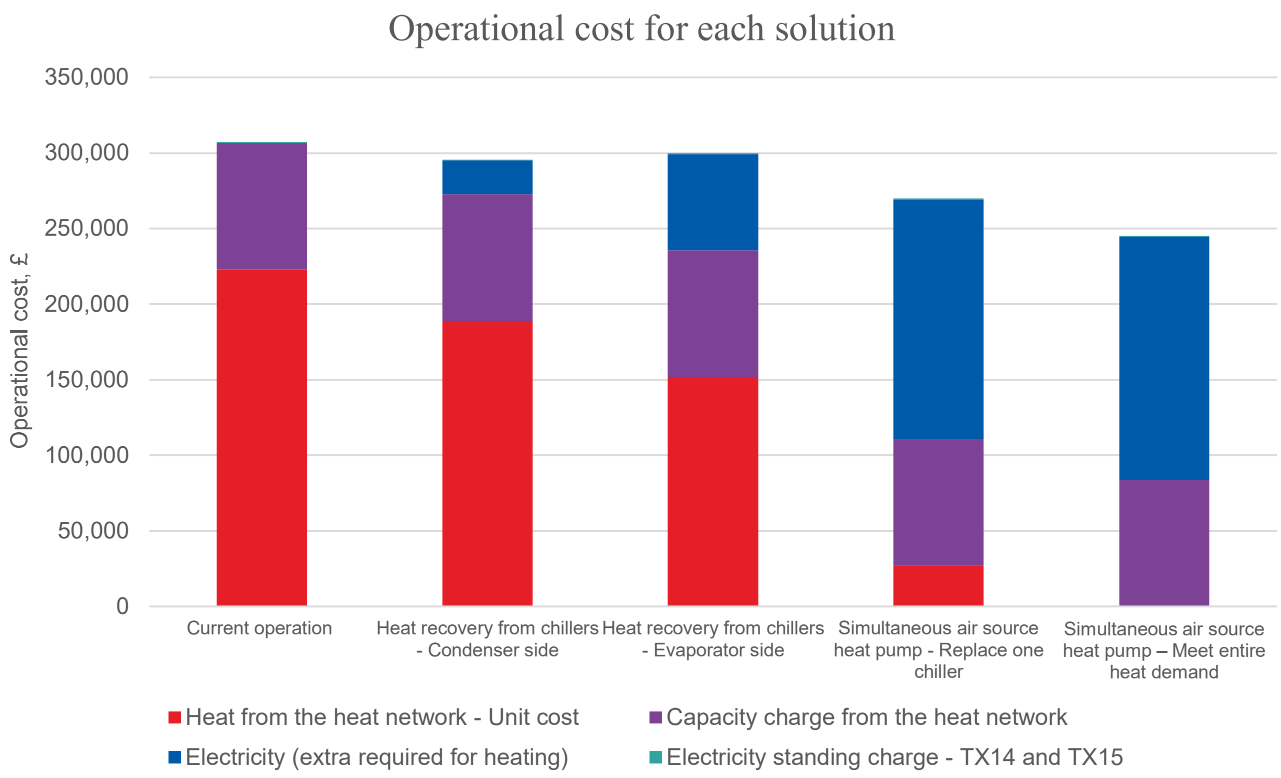

Figure 4.3. Annual operational cost for each solution including standing charges and unit costs

4. Techno-economic feasibility

Operational carbon

The operational carbon emissions and savings were calculated for the current usage using the carbon factors provided from Bring Energy for the heat supplied from the network, the emissions from electricity use the Department for Energy Security and Net Zero (DESNZ) Greenhouse gas reporting conversion factors from 2024 including the Transmission and Distribution (T&D) losses.

It can be seen that as the amount of heat being provided by electricity increases (Figure 4.1 Slide 44), the carbon associated with providing heat to the Stadium decreases.

As the electricity grid decarbonises, the emissions due to electricity will decrease. The reduction in carbon due to grid decarbonisation is shown in the next slide.

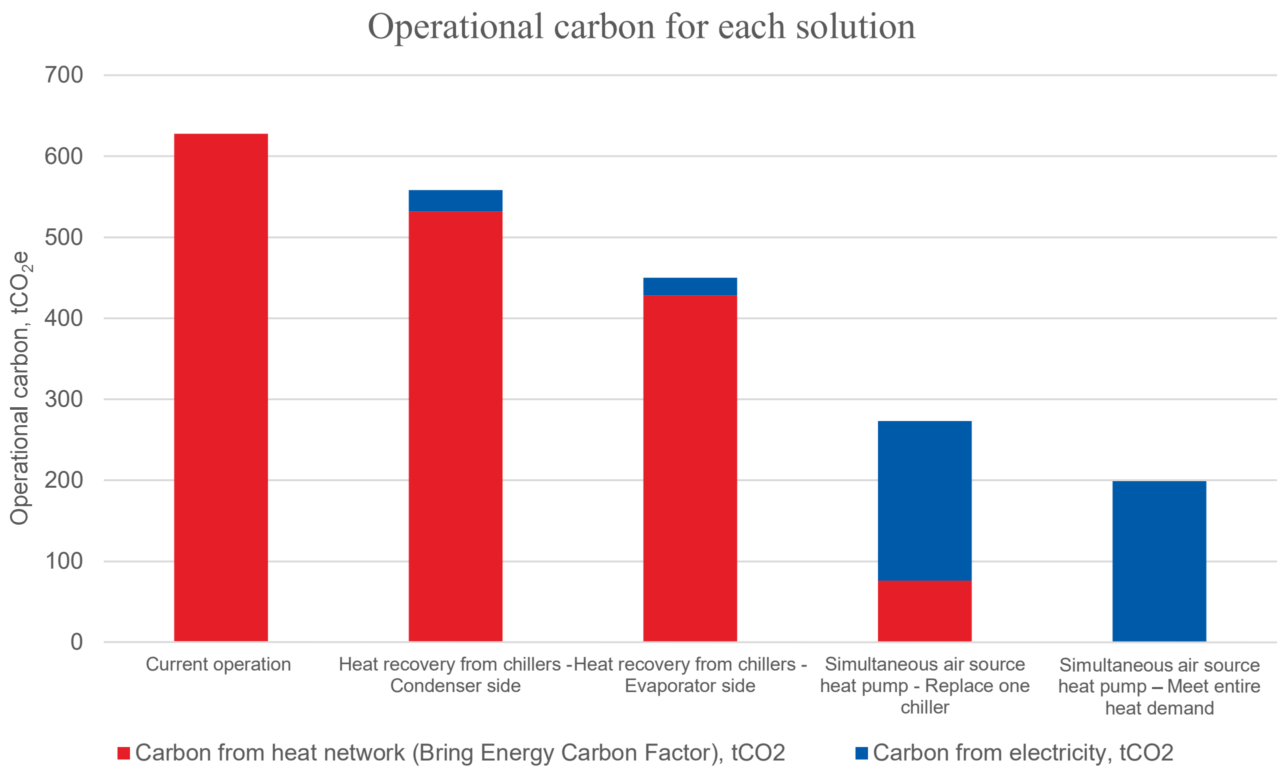

Figure 4.4. Annual operational carbon for each solution

4. Techno-economic feasibility

Operational carbon

Carbon emissions till 2042 are modelled, this assumes a couple of years to implement the solutions and a lifetime expectancy of 15 years for the main piece of plant installed.

It is seen that as the grid decarbonises the solutions that use more electricity to generate heat provide heat to the Stadium with a lower carbon factor to those dependent on the heat network.

This graph assumes that the carbon emissions associated with heat from the Bring Energy heat network remain constant, however the network have plans to decarbonise so it is expected that the carbon emission factor for the heat network will also decrease with time.

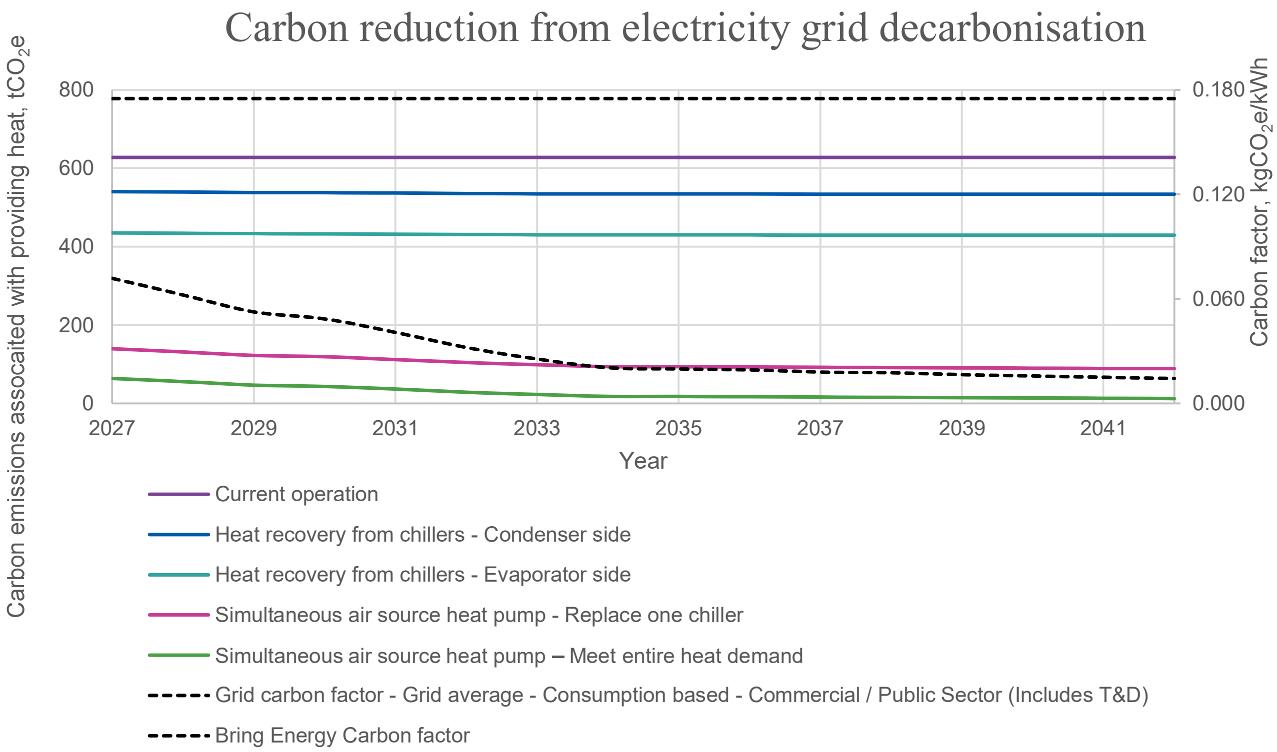

Figure 4.5. Operational carbon to 2042 for each solution

4. Techno-economic feasibility

Embodied carbon

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

The material impact of the main plant for each solution has been considered when carrying out the embodied carbon calculations. An assessment of the construction work required to implement each solution has not been included.

A comparison of the embodied carbon and the operational carbon savings realised for each solution are displayed in the next slide.

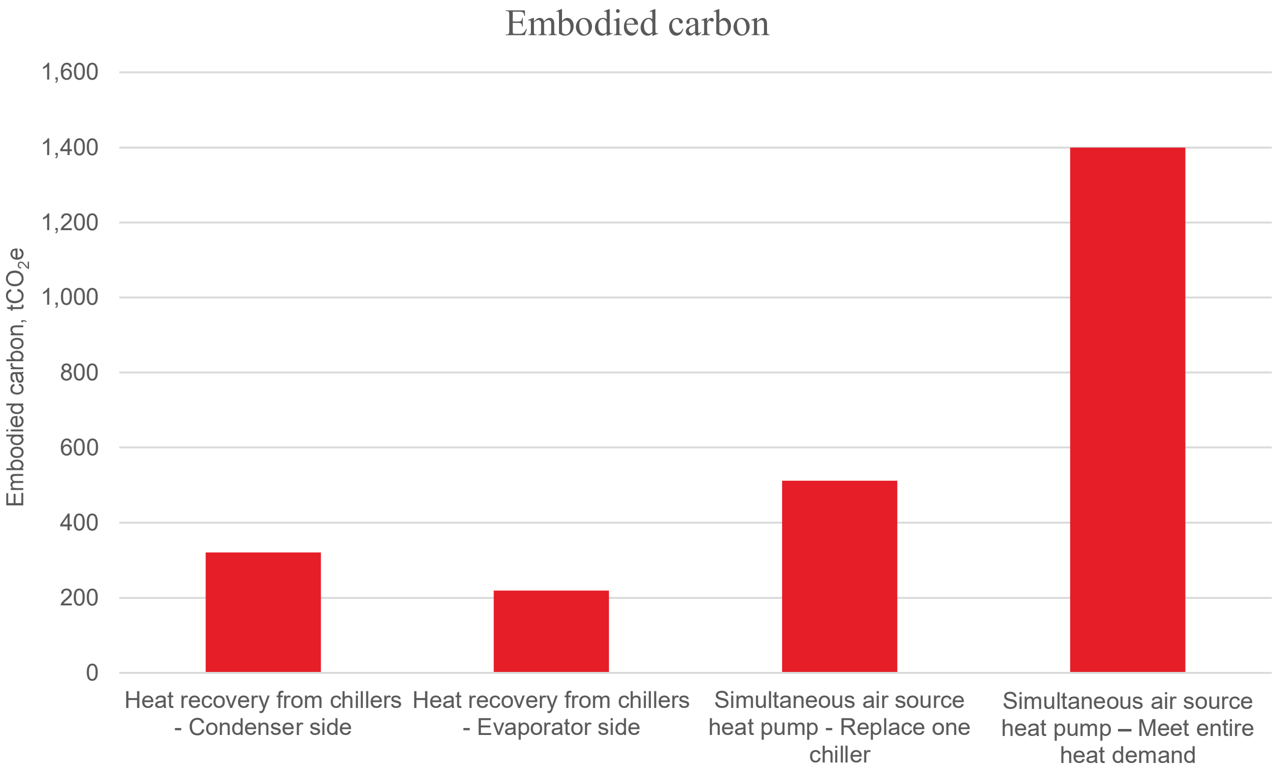

Figure 4.6. Embodied carbon each solution

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4. Techno-economic feasibility

Embodied carbon

Figure 4.7 shows a graph of the embodied and operational carbon savings for each of the solutions developed.

Where the operational carbon saving line (diagonal) crosses the embodied carbon line shows the year in which the carbon from construction is paid-back and overall carbon savings are achieved.

It is observed that the embodied carbon payback time for all of the solutions is less than 15 years (typical plant lifetime):

- Heat recovery from chillers - Condenser side: 3.6 years
- Heat recovery from chillers – Evaporator side: 1.0 years
- Simultaneous Air Source Heat Pumps - Replace one chiller: 1.1 years,
- Simultaneous Air Source Heat Pumps – Meet entire heat demand: 2.4 years,

The two options for recovering heat from the chillers have a carbon payback time greater than 15 years.

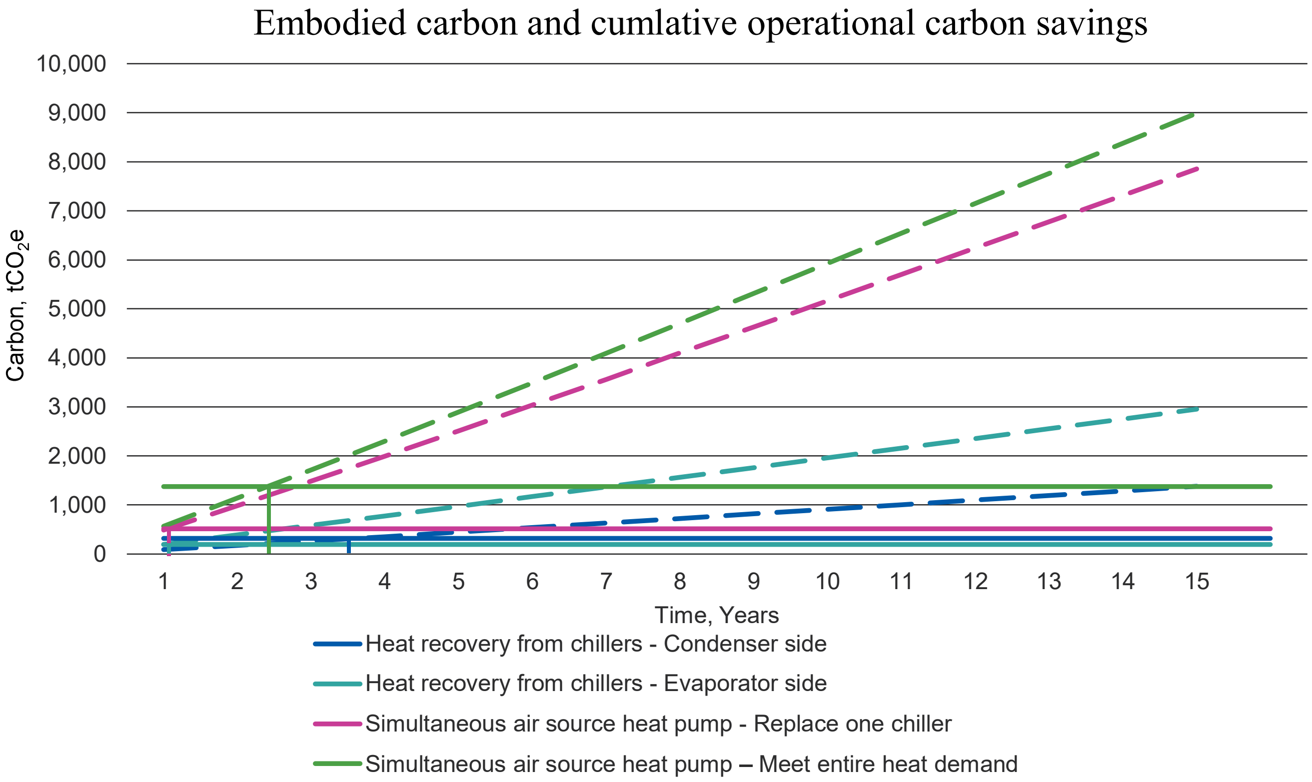

Figure 4.7. Embodied and operational carbon for a 15 year equipment lifetime

Table 4.1. Summary of proposed solutions

			Feasibility study options			
	Current operation (baseline)	Building optimisation measures	1. Heat recovery from chillers - Condenser side	2. Heat recovery from chillers - Evaporator side	3. Simultaneous Air Source Heat Pumps - Replace one chiller	4. Simultaneous Air Source Heat Pumps – Meet entire heat demand
Heat required from the heat network, GWh	3.6*	10/20% saving on baseline	3.0	2.4	0.4	0.0
Annual heat generated from the solution, GWh	0	N/A	0.7	1.1	3.2	3.7
Electricity required for heating, GWh			0.12	0.10	0.88	0.89
Carbon from heat network (Bring Carbon Factor), tCO2 (annual, 2024)	628	-	532	428	76	0
Carbon from electricity for heating, tCO2e (annual, 2024)	0	-	26	22	197	199
Total carbon emitted from heating (Bring Carbon Factor), tCO2e (annual, 2024)	628	-	558	450	273	199
Total carbon emitted from heating (Bring Carbon Factor), tCO2e (annual, 2030)	628**	-	538	433	119	43
CapEx cost, £m	£0m	Consulting fees and small equipment	£2.7m	£1.2m	£2m	£4.4m
OpEx savings over 15 years, £m	£0m	10/20% saving on baseline	£0.2m	£0.1m	£0.6m	£0.9m
Payback period, years (£/ X years)	-	-	Does not pay back, using the simple payback method, within the life of the asset.			
Cost of carbon saving, £/tCO2e***	-	-	£1,700	£350	£170	£370
Embodied carbon, tCO$_2$e			320	200	520	1,380

Table B. Summary of heat decarbonisation solutions

*Baseline heat demand in Arup Baseline report is reported as 3.4 GWh, this is the weather and event day corrected value. To maximise the opportunity for heat recovery from higher heat and cooling use on event days the metered data value of 3.6 GWh was used to model the proposed solutions.

**Assuming low carbon sources not taken from the heat network

*** Calculated by: (CapEx - OpEx savings over 15 years) divided by Operational carbon saving over 15 years

Table 4.1. Summary of proposed solutions

			Feasibility study options			
	Current operation (baseline)	**Building optimisation measures**	**1. Heat recovery from chillers - Condenser side**	**2. Heat recovery from chillers - Evaporator side**	**3. Simultaneous Air Source Heat Pumps - Replace one chiller**	**4. Simultaneous Air Source Heat Pumps – Meet entire heat demand**
Additional co-benefits		Can be done straight away, low capital cost		Can be done straight away, no existing kit to be replaced	High efficiency heat generation from simultaneous heat pump	High efficiency heat generation from simultaneous heat pump
Maintenance requirements	As existing	If TRV valves are installed, maintenance of TRV batteries is required	Increased maintenance than existing chiller due to additional heat exchanger, new control systems required, and maintenance of new LTHW pipework and PHEs in each heat meter plant room	Additional maintenance for WSHPs, new pipework and PHEs in each heat meter plant room required	ASHP require maintenance due to defrost cycles and compressors can experience wear due to simultaneous generation, additional maintenance for WSHPs, new pipework and PHEs in each heat meter plant room required	
Solution impact on heat network		N/A	Recovery of wasted heat only, and modification to secondary circuit.	Recovery of wasted heat only, and modification to secondary circuit.	Some generation of heat on site and modification of secondary circuit.	Full generation of heat on site and modification of secondary circuit.
Fire safety		N/A	The proposed equipment uses the same refrigerant currently in use onsite. In the future, if alternative refrigerants are considered, their flammability and fire safety must be taken into account.			
Planning considerations		N/A	New equipment in added to the chiller farm location which change the appearance of the chiller farm and surrounding areas, will need to be assessed against the local planning rules.			
Commercial considerations		N/A	The options identified in this study are given from a technical perspective, and a commercial perspective should also be sought considering the Stadium’s heat Supply Agreement and the corresponding Concession Agreement.			

5. Conclusions and next steps

Conclusion

The investigation of options to decarbonise heat at the Stadium was conducted, and the following options have been presented in the report:

- Heat recovery from chillers - Condenser side
- Heat recovery from chillers - Evaporator side
- Simultaneous Air Source Heat Pumps - Replace one chiller
- Simultaneous Air Source Heat Pumps – Meet entire heat demand
- Heat recovery from small chillers
- More efficient use of the BMS system

Of the options proposed, the first four were developed into feasibility level engineering solutions. The option to recover heat from the small chillers was not considered further because, once assessed, it was determined that the opportunity to recover heat from the units is not a viable option due to the limitations of the equipment location.

In the future, the options for replacing the units or connecting them to the main chilled water system should be considered when the smaller chillers around the site come to the end of their life.

BMS optimisation measures can be implemented with a low cost and have estimated carbon savings of 62-125 tCO_2e per year. The optimisation measures proposed in Arup's baseline report[1] have no or low capital cost to implement, it is recommended that the Stadium proceed with the building optimisation measures recommended.

The four feasibility level solutions are summarised in Table 4.1. If CapEx per tonne of carbon saved is the most important factor, Option 3 the Simultaneous Air Source Heat Pumps - Replace one chiller' is the best option, but this will have an impact on the existing heating supply agreements. The recommended solution if based on smallest CapEx and minimal impact on existing heating supply agreements is option '2 Heat recovery from chiller – Evaporator side'.

Before any heat decarbonisation solution is developed further, consideration of any commercial constraints under the existing district heating Supply Agreements should be made. Engagement with Bring Energy's asset improvement team is also recommended.

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[1] Baseline Report – London Stadium Arup, See appendix

5. Conclusions and next steps

Next steps

- Decide on the best way to reduce the operational carbon, also considering the terms within the heat Supply Agreement with Bring Energy.
- Progress to Task B and to bring the solution to a RIBA Stage 2 level of design.
- Coordinate with Bring Energy's asset improvement team regarding any updates to the ability to generate heat onsite.
- Implement building optimisation measures to reuse heat, cooling and electricity usage at the Stadium.

Further design considerations at the next stage:

- At the next design stage, the refrigerant type should be considered to minimise the GWP of the refrigerants used at the Stadium and maximise the efficiency of heating and cooling generation.
- Consider thermal stores for chilled water to utilise lower electricity costs (and usually lower associated grid carbon factors) at night time and use this cooling during the day.
- Review design of simultaneous ASHPs, have one smaller unit for simultaneous and some reversible units with thermal storage.
- Confirm operation of simultaneous ASHP when the heating demand is greater than the simultaneous load.

Appendix A

Modelling assumptions

Appendix A

Modelling assumptions

	Assumption	Reference
1.	Chiller COP for the existing chillers on site is assumed as 3.5, constant COP through the year	Carrier 30XA 252-1702 data sheet
2.	Hourly outdoor air temperature data for EGLL weather station used	Downloaded from: https://mesonet.agron.iastate.edu/request/download.phtml?network=GB__ASOS
3.	Cooling demand is profiled for the main 4 × 777 kW chillers only (doesn't account for the smaller units around site)	
4.	Thermal stores used in solutions are assumed to be fully charged year round	

5.	Costs used:
	• Heat:
	  • Heat Meter 1 capacity cost per year: £40,000
	  • Heat Meter 2 capacity cost per year: £44,000
	  • Heat unit cost: 0.062 p/kWh
	• Electricity:
	  • TX14 standing charge: 0.85 £/day
	  • TX15 standing charge: 0.87 £/day
	  • Day rate: 0.20 £/kWh
	  • Night rate: 0.16 £/kWh
		Costs taken from 2024 heat and electricity bills provided by London Stadium

6.	Assume that any additional electricity consumption from the new solutions installed is fed from TX14 and TX15	
7.	Carbon factors used: • Heat: 0.175 $kgCO_{2e}$/kWh • Electricity: 0.223 $kgCO_{2e}$/kWh	Heat from Bring Energy East London Energy heat network Electricity from DESNZ Greenhouse gas reporting: conversion factors 2024, UK electricity generated and T&D losses
8.	• Capital costs: • Benchmarked from previous projects, with inflation factored by to 2025 • SPONS (2025) • Preliminaries assumed to be 15% of capital costs • Overheads and profit assumed to be 8% of capital costs + preliminaries • Contingency assumed to be 20% of capital costs + preliminaries + overheads and profit	
9.	Embodied carbon: • Based on previous EDS sheets • Manufacturer datasheets for plant equipment solution	

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