Technological and Ecological Feasibility Study on the Use of Water Source Heat Pumps on the River Wensum

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Acknowledgments

Adapt would like to acknowledge the contributions and support from:

Silviu Catana, Heat Pump Design Engineer and project support from Richard Brown, RA Brown Heating Services Ltd.

This project report has been made possible with calculations and technical specifications and costings provided by RA Brown Ltd.

Gilla Sunnenberg, (Heat map GIS analysis), Senior Research Associate, School of Environmental Science, University of East Anglia.

Steve Marsh, Ener-vate Ltd for his contribution to the section on commercial ESCo models and risks.

Prof. Gordon Copp, Freshwater Fish and Salmonids Team, Centre for Environment, Fisheries and Aquaculture Science for literature references.

In addition information and advice has been provided by:

Tom Hunter, Rivers Engineer, The Broads Authority.

Nicola Steer, Environment and Planning Officer and Stephen Oates, Senior Advisor on deployment of renewables, Environment Agency.

Adapt would also like to acknowledge and thank **Norwich City Council** and the **Department of Energy and Climate Change's Heat Network Development Unit** supporting this project, in particular:

Tony Jones, Norwich City Council for helpful advice and key feedback on interim and draft reports and John Saunders and Alex Fox, DECC's HNDU team, for advice during the interim meeting and final comments.

Adapt is also grateful for additional contributions of data and advice from Richard Willson, Clair Tullet and Jeff Taylor at Norwich City Council.

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Document revisions

This document was produced using **Adapt Report Template v1.3** 18/02/2016

Title	Technological and Ecological Feasibility Study on the Use of Water Source Heat Pumps on the River Wensum
Originator	Pete Metcalfe Key Contributions from Silviu Catana, Richard Brown & Steven Marsh

Version	Date	Details	File name/ location	Modified by
1	18/05	Draft for Client Review	Projects/H00104	PM
2	03/06	Revised draft	Projects/H00104	PM
3	03/06	Final proof	Projects/H00104	PW
4	08/07	DECC suggested revisions	Projects/H00104	PM

Final version

Prepared by:	Pete Metcalfe
Approved by:	Penny Wright, Chief Operating Officer, The Adapt Low Carbon Group.
Date	08/07/2016

Executive summary

Background

00.1 This study outlines the feasibility of installing conceptual heat networks from water source heat pumps (WSHP's[1]) on the river Wensum flowing through the City of Norwich. An open source design where river water is abstracted and returned to the river has been chosen for two conceptual case studies[2]. These are used purely as example cases and no WSHP designs are planned for these existing developments.

Key Constraints

00.2 For these WSHP applications there are three principle constraining factors in extracting heat from river water for use in heat pumps:

1. The minimum river water temperature at the time when the heat is needed.
2. The change in temperature (removal of heat) between the abstracted and returned water known as the temperature differential
3. The rate of flow of water, by volume or mass, that can be abstracted, passed across surfaces to exchange heat and returned to the river

Knowing the limits from these factors is essential in order to determine the heat available.

River temperatures

00.3 The first and most important constraining factor is river temperature. This is because the technical (heat exchanger) operational limits prevent heat being extracted (and the heat pumps working) when river water exiting the exchanger approaches 3 °C. Meaning, for a minimum 2°C differential (reducing river water pumped through heat exchangers by 2 °C) the WSHP operational lower limit would occur when the river water temperature is below 5 °C.

00.4 River temperature logs taken as part of this study between November '15 and April '16 are indicative only of a very mild winter but show that temperatures below 5 °C would prevent WSHP operation for 7 days in January '16. Again the gas boilers would be required to take over the duty during days when heat pumps are inoperable due to low river temperatures (<5 °C).

00.5 River water temperatures below 5 °C may occur for considerably longer periods in winters more typical of the last 20 years. Without accurate daily river water temperature data during cold winter conditions it is impossible to determine the extent that this will impact the operation of WSHP's and their related economic case. Further temperature logging over colder winters is recommended. In this respect a system that is optimised for a 2 °C differential, similar to the one proposed would be recommended, since this takes into account the likely worst case of minimum river temperatures when heat is required the most.

Uncertainty in ecological and regulatory constraints

00.6 The technical limits relating to 1, 2 and 3 can be established based on heat pump, water pumps, and heat exchanger specifications. However the findings of this feasibility study suggests that there is

[1] This is also referred to as SWSHP for *surface* water source heat pumps in other publications. The surface 'S' has been dropped in this report for convenience.

[2] Open source has been chosen due to apparent amenity constraints which would limit 'closed loop' pipework in the river and along the bank side. This is outlined later in the report (see Amenity constraints)

insufficient scientific evidence to comfortably define thresholds for ecological impacts from colder water discharges, both in temperature (2) and volume (3), into rivers. In this case answers to 2 and 3 will be required only by approval sought from the Environment Agency through a formal discharge consent application procedure.

00.7 In respect to 2, at the time of this study a precautionary 2 °C has been advised for a maximum temperature differential by a regulatory spokesperson. A 3 °C limit has been applied to the only current working open loop river source heat pump system in the UK at the time of this report. This is in the Thames – a much larger river flow than the river Wensum so able to discharge approximately 13,000 m^3 per day, 0.2% of the Thames mean annual average flow of 5,685,000 m^3/day ($Q95_{winter}$ not estimated). 0.2% of the river Wensum annual average daily flow (380,000 m^3/day) for comparison is approximately 800m^3 per day.

00.8 The initial DECC surface water heat map suggested 4 MW of heat could be potentially available from this stretch of the river Wensum using a 3 °C temperature differential, though this could require over 40,000 m^3 per day to be passed through heat exchangers with a 2 °C temperature differential. This is approximately 10% of the annual *mean average* daily flow but applying the more accepted conservative approach this would be 25% of the rivers Q95 winter flow. For a 3 °C differential this would require approximately 17% of the estimated Q95 flow.

00.9 Standard discharge consent rules for heat exchangers limit discharges to only 1000 m^3 per day but with up to 8 °C difference in temperature to the river temperature, though it is unclear if this relates to warmer discharges. Therefore advice was sought from the regulatory authority as dictated by the then Draft SWSHP Code of Practice on discharge limits to volume and temperature for the river Wensum.

00.10 No advice has been made available by regulators, or indicative references found, with regard to the second factor - how much of a river's flow can be feasibly diverted through heat exchangers and returned to the river. Depleted reaches, of concern to regulators with regard to hydro energy schemes, are not directly applicable to heat pump applications where abstraction and return is within a shorter stretch of river.

Development heat load led approach

00.11 Instead, following advice from DECC's Heat Network Development Unit representatives, a building heat demand led approach has been taken using the 2 °C differential in order to determine the volume of river water required. An example multi-building development - St. Anne's Quarter - with 437 flats, but excluding commercial space, has been used as the main case study to specify a conceptual heat network and heat pump system.

00.12 The results of the system sizing for St. Anne's Quarter 437 flat development (including buffer vessels to cope with peak hot water demands), would require a maximum of 2,800 m^3 of river Wensum water per day to satisfy heating and hot water loads when the air temperature is -2 °C or just above. Back up gas boilers would be required to take over when heat pumps cannot supply these higher loads when outside temperatures below -2 °C.

00.13 Therefore for larger developments such as St. Anne's Quarter will require non-standard permit application for heat exchanger discharge greater 1,000 m^3 per day during winter when river temperatures are low. Therefore the limits will ultimately be based on regulatory decisions.

Development led case study results

00.14 The case study for St Anne's Quarter reports that a WSHP solution for a 437 flat new development (excluding commercial space) is both technically and financially viable.

00.15 Capital cost estimated for the St. Anne's Quarter WSHP heat network is approximately £1.9M and for a comparative gas boiler equivalent is approximately £1.5M. Simple pay back periods start from 8 years extending to 18 years depending on the utility cost assumptions and whether social or more commercial heat prices are charged.

Impact of phased occupancy and DECC pricing projections

00.16 The developers estimate that full occupancy will be achieved in 3-4 years though details for specific blocks of flats has not been available. A linear increase in occupancy from 0-437 units has been assumed in the financial model over 3 years with full occupancy (and revenue) reached by the start of year 4 for the purposes of estimating the sensitivity of phased construction/heat sales to IRR. The capital expenditure for laying the heat network has also been phased similarly over 3 years.

00.17 Projected prices for commercial/public sector electricity and gas purchasing, which takes into account expected policy changes, published by DECC for project appraisal has been applied in addition to the prices for sensitivity assessment above.

00.18 In order for the WSHP IRR to meet the minimum 11% attractive for ESCo investment a 12.75 p/kWh heat sale price would be required when applying central gas and electricity price projections (DECC) over the next 40 years. This within the price range found for a survey of existing community heat schemes (5.5- 14.9 p/kWh, but exceeds the unit cost of 9.5-11.6p/kWh for a combi boiler heat supply for an average flat estimated by a consumer watchdog organisation[3].

00.19 Adjusting gas and electricity prices to align with lower unit costs reported by Norwich City Council, (indexed to the DECC projections), would reduce the WSHP heat charge required for meeting an 11% IRR to 12.6 p/kWh.

00.20 With the utility price scenarios described, the WSHP heat price required to achieve at least a pre-tax 11% IRR expected by ESCo investors over a 40 year period for heat networks at St. Anne's Quarter's still falls within the upper range of heat prices observed by a survey of community heating schemes in the UK. Therefore, accepting a higher heat charge than a natural gas heated counterfactual, a WSHP solution for this 437 flat new development (excluding commercial space) is both technically and financially viable.

Impact of increasing volume and temperature differential limits

00.21 Applying the 2 °C differential for discharge temperatures for the main case study multi-residential development with 437 flats - St. Anne's Quarter - indicates that a maximum discharge flow of 2,800 cubic metres (m^3) per day would be required or 1.7% of the estimated Q95 winter flow. There is uncertainty whether this would be consented since no regulatory guidance could be offered on the maximum discharge volumes possible at this temperature differential with respect to river Wensum's flow at the time of this study (Winter 2015/16).

00.22 Quantifying the impact of increasing this differential requires more accurate demand data in conjunction with river water temperature data. For the same heat demand marginal savings could be achieved by reducing the water volume required and associated pumping costs and/or potentially increasing the heat pump COP to some extent. However, quantifying the implications of this for the financial results would require a more detailed re-assessment of how heat pumps could be optimised for this additional capacity.

00.23 Increasing the temperature differential for the same 2,800m^3 volume of river water utilised per day for St. Anne's Quarter would increase the quantity of heat harvested from the river and allow an extension to the heat network supply capacity. This would, however, require additional heat pumps and, again, to

[3] This estimate accounts for the cost of installation, fuel and maintenance of a standard domestic gas combi boiler per unit heat supplied over its lifetime with an average gas cost of 5.5p/kWh, Which? (March 2015).

quantify costs/benefits, a reassessment of a properly optimised system against a reliably representative dataset of daily river temperatures to compare with any new loads on a more granular basis.

Greenhouse gas performance comparisons

There is a substantive reduction in emissions of over 7,000 tonnes of CO_2eq over 25 years where WSHP is utilised instead of the counterfactual, centralised natural gas boilers. This is due to the assumptions for marginal long term emission factors modelled by the Government's DECC for changes to grid electricity use. A change in electricity demand will only impact the marginal grid generation source (the most likely to be modulated in response to changes in demand). The modelling also assumes the marginal source will have increasingly lower carbon electricity generation compared to the average supply. This improves the emissions performance of electrically driven heat pumps compared to direct combustion of natural gas for heat.

Concluding remarks

00.24 Making conclusions on the financial feasibility of WSHP's on the river Wensum in Norwich based on the case study examples is however heavily dependent on river water temperatures, utility purchase costs and heat sale price. Access to projected costs from commercial and public sector utility purchasing agreements, and the drivers for selling heat reflected in the unit charge, and further logging of river water temperatures should be fully explored in detail for any specific project conclusions. As should potential for changes in the Governments renewable heat tariff and policies supporting investments in WSHP's.

00.25 The utility cost scenarios explored in this study means that with phased occupancy the WSHP is feasible but would not compete with natural gas boilers on the grounds of least cost for consumers. However the WSHP would provide substantial carbon savings compared to gas boilers, based on emissions projections for future electricity supply provided by DECC.

Summary of objectives and scope

00.26 This report documents Adapt's proposed approach for a technological / ecological study on the use of a water source heat pump on the river Wensum flowing through Norwich City. This is a conceptual level feasibility study to establish how much heat may be available to heat pumps and to identify any constraints on its utilisation.

00.27 This report documents the study findings which includes:

1. **Technical feasibility** – an assessment of the likely physical, ecological and technical constraints that may be associated with a river Wensum source heat pump application.
2. **Financial viability -** an assessment of estimated costs of installation, operation, maintenance and replacement against the income over suitable time periods.

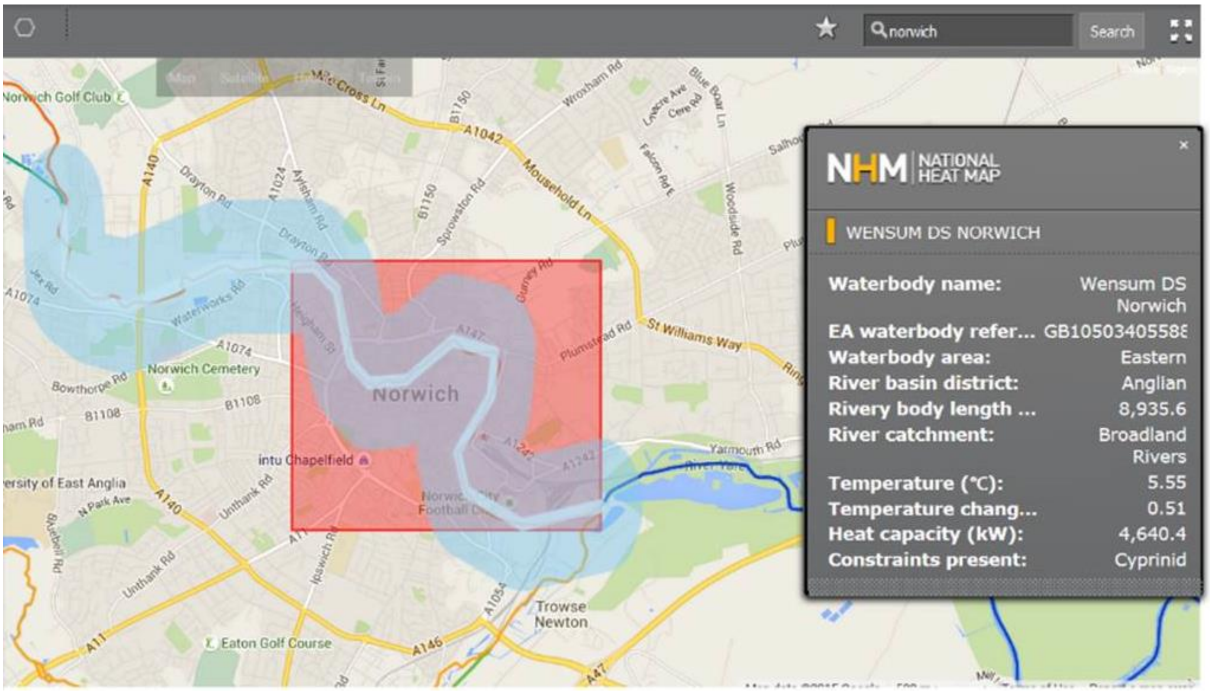
00.28 **Two case study examples** are investigated as part of the feasibility, applying notional heat networks for utilising heat from the river via heat pump systems. The first relates to the type of new build residential schemes likely to occur in Norwich and a second considers a retrofit example. These are used purely as example cases for feasibility testing and no WSHP designs are planned for these existing developments.

We have split the whole assessment in to seven tasks, corresponding to each section of the report

	Task	Section
Technical Feasibility	1. Analyse the maximum seasonal river heat availability from temperature and flow data	01
	2. Identify potential heat loads that could be supplied by river source heat pumps	02
	3. Identify environmental constraints and regulatory implications on magnitude of heat available from river source heat pumps and associated heat networks	03
	4. Specify a conceptual water source heat pump system to match small heat networks heat demand to seasonal river heat availability	04
	5. Options for expansion and links to larger high temperature heat networks planned for the City	05
Financial viability	6. Financial viability including, business models, risks and mitigation	06

01 River heat availability

01.1 The starting point for this feasibility assessment has been the UK national heat map commissioned and funded by the UK Government's Department of Energy and Climate Change (DECC). This online mapping tool estimates the river heat capacity available for a single open loop water source heat pump. For the highlighted (Blue band) 8.9 km stretch of the river Wensum through Norwich, the heat map estimates a heat pump capacity available for a single heat pump of 4.64 MW with respect to a 0.51°C change in river temperature (Fig 1). The method of estimating this heat availability is based on a study by Atkins commissioned by DECC.



Attribute	Meaning
Water body	Environment Agency WFD Waterbody Name
EA Waterbody ID	Environment Agency WFD Waterbody ID
EA area name	Environment Agency Area name
River basin district name	Environment Agency River Basin District Name
Length of water body (m)	Total length of river body, including all branches shown on map
River catchment	Environment Agency Catchment Name
Temperature (Celsius)	Estimate of water temperature, created by interpolating data from the Environment Agency surface water temperature archive
Heat capacity (kW)	Heat capacity available for abstraction using a single water source heat pump, in kilowatts. This estimate includes the EFI constraint.
Temperature change (Celsius)	Change in temperature of the waterbody, resulting from the extraction of the total heat total heat capacity shown, using an open-loop water-source heat pump
Constraints present	List of constraints present at site (from SSSI, SPA, SAC, RAMSAR, Shellfish)

Fig 1 The National heat map user interface showing the estimated heat availability from the river. *The river Wensum is surrounded by a blue buffer the study are is the red box. The information in the dark grey box on the right relates to the river Wensum (blue buffer). Acknowledgements: Commissioned and funded by the Department of Energy and Climate Change. Images Google Maps Inc.*

01.2 Atkins' methodology estimates heat availability by assuming open loop heat pumps remove 3 degrees of heat from an estimate of the maximum *consumptive* volume abstraction rate available from the river. The maximum consumptive abstraction rate has been derived from modelled naturalised winter river flows in combination with minimum environmental flow indicators[4] as an ecological constraint. It does not appear to incorporate actual river flow data (with impacts from existing licenced abstractions) and recommendations are made to seek local data.

01.3 Having sought information from the Environment Agency with regard to abstraction licencing and discharge consents it became clear that the available abstraction volume would not be the primary determinant for the volume of river water available for heat pumps. Use of water for open loop water source heat pumps are non-consumptive so this is much less of a concern for regulators. Rather, the impact of the cooler discharge temperature from the heat pump on the receiving river has been the primary concern from a regulatory perspective.

River Wensum flow data

01.4 To begin to understand the degree of potential cooling effect on the river Wensum, actual river flow data is required. There are no gauging stations within the study area therefore river flow information has been derived from the National River Flow Archive for the nearest flow gauging station at Costessey Mill and a minor tributary the River Tudd. The daily average flow rates (cubic metres per second) have been combined to estimate the duration of flow rates throughout the year (Fig 2).

01.5 This is the best available data but has limitations since this does not account for net impact of subsequent abstractions and discharges between Costessey and the study area. However, though the maximum volume allowed for one particular abstraction licence could potentially be significant, the actual recorded *annual* volumes used for the last 4 years have been lower than the average *daily* river flow at Q95[5]. Q95 for the river Wensum is a flow equal or greater than 1.9 m^3 per second being met 95% of the time.

Gross heat potential

01.6 Estimates of the crude theoretical maximum heat are given in Table 1. These estimates are simply the maximum heat content that could be made available from the overall average change (drop) in the river temperature for the respective winter flow rate. However, this potential heat availability is dependent on the rate of heat removal via pumping, and subsequent discharge of cooler water back to the river channel., a similar magnitude of heat to that published by the DECC Heat Map - 4 MW - would be met for the Q95 flow for a 0.5°C reduction in river temperature.

01.7 The average river temperature reduction would not result in an immediate, even spread of heat – i.e. cooler water discharged would not fully equilibrate with the river water temperature arriving at the overall drop in temperatures in Table 1. Instead a plume of cooler water discharged from the heat exchanger will extend for some distance beyond the discharge point mixing with river water to eventually equilibrate. The impact of this will be considered in the section assessing environmental constraints.

[4] Environmental flow indicators (EFI's) are used as a national minimum flow screening threshold. They are used by regulatory bodies to assist with making abstraction license allowances. Flows below the EFIs thresholds show potentially higher risk to rivers' ecological status.

[5] According to the Environment Agency there are three licenced abstractions between the study reach and Costessey mill and a further 4 in the study area. Excluding a drinks manufacturer abstracting a maximum of 10,900 m^3 per day 250m down river of Carrow Bridge) the most significant of all of these is for potable water supply registered to Anglian Water PLC which has works immediately upriver from the study area. Annual maximum licenced is 120,000m^3 per day. Annual licence returns show that 12,500 to 14,500m^3 per year has been abstracted. Permission is required by Anglian Water in order that the Environment Agency can release more detailed abstraction rate data. Permission was sought but not given. Discharge consents licenced to the river below Carrow Bridge from a beverage company are around 3,000 m^3 per day which the EA report is used in full.

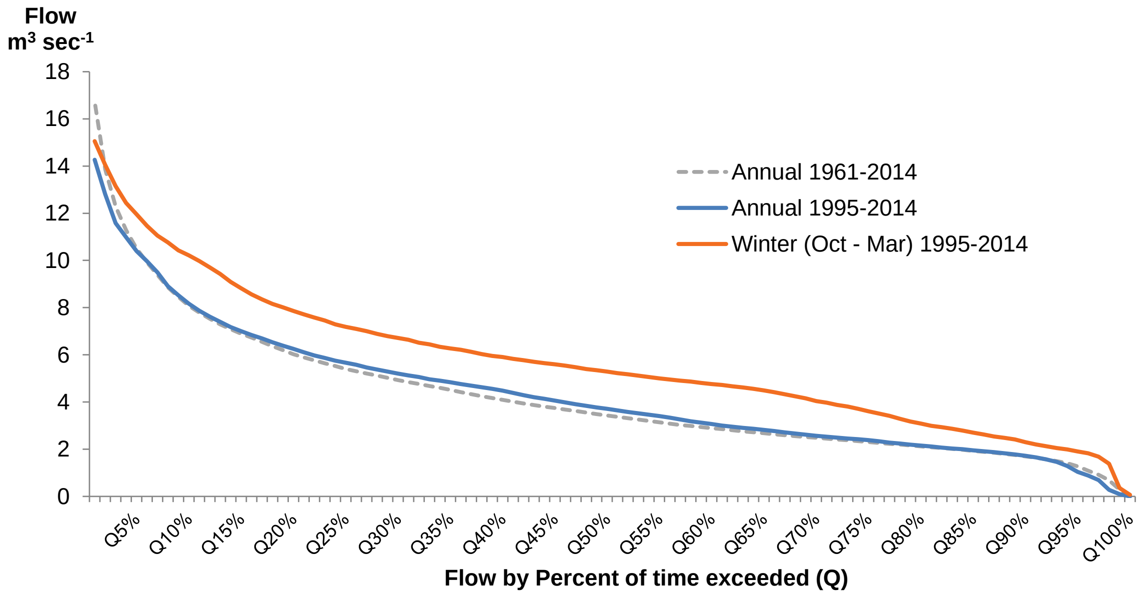


Fig 2 Winter flow duration curve for the river Wensum. *For the purpose of the assessment the flow duration data only for months October to March when more heat is required are also shown.* ***Data Source*** **National River Flow Archive[6].**

Flow rate		Maximum potential kW Heat available for respective reduction in total river flow temperature					
Winter flow	$m^3 sec^{-1}$	River temperature drop	0.01°C	0.05°C	0.1°C	0.25°C	0.5°C
Q98%	1.38		60	290	580	1,450	2,900
Q95%	1.90		80	400	800	1,990	3,980
Q70%	4.04		170	850	1,690	4,230	8,460
Q50%	5.29		220	1,110	2,210	5,540	11,070
Q30%	6.71		280	1,400	2,810	7,020	14,050

Table 1 Crude theoretical absolute maximum heat available from different winter flow rates. *This has been derived from the archived gauging station flow data 1995 -2014.*

[6] National River Flow Archive http://nrfa.ceh.ac.uk/

River water temperature

01.8 A key technical constraint is the lower operational temperature limit of heat exchangers. The Atkins study indicates that heat pump manufacturers specify a 3°C limit for discharge temperature which is in accordance with our heat pump design engineer's experience. Below this temperature risks ice formation on the inside plate surfaces, compromising their effectiveness. Therefore low river water temperatures may constrain the heat pump operation. The Environment Agency surface water temperature data relevant to the study area is presented in Fig 3.

01.9 6% of the river water temperature samples are 4°C or less (4°C allows for at least 1°C differential for heat exchange). For 5°C this rises to 10% of samples. However, samples have not been taken at regular intervals or consistent times and December has a lower sample frequency. In addition the temperature sampling methods have not been established so the sample depth, consistency and accuracy is not known for these data. In winter depressed air temperatures may cool surface water to a greater extent compared to water at a depth. A heat pump intake would be unlikely to be placed near the river surface.

01.10 Due to the uncertainty associated with the Environment Agency's surface water data quality, scientific grade, calibrated water temperature loggers[7] have been stationed in the river Wensum at three different depths - river bed, 60cm+/-30cm tidal, and surface air temperature. These have been positioned alongside vertical river bank pilings to coincide with a likely position of bankside abstraction intakes, sited 10 metres down river from Carrow Road Bridge (Fig 6). The hourly logged temperature data between mid November 2015 and April 2016 are shown in Fig 4.

01.11 The consistently lower water temperature of the 30-60cm water logger suggests that surface water temperature is influenced by air temperatures and therefore the EA data would not be representative of the river water level utilised for heat pump abstractions.

01.12 The temperature data logged from the river bed are therefore more appropriate to indicate constraints on the heat pump operation from temperatures. In January 2016 there was a seven day period (16th - 22nd) where the water temperature at the river bed was less than 5°C, three of these days the temperature dropped below 4.5°C.

01.13 A key limitation of the logged data, is that it represents river temperatures from only one exceptionally mild winter. The month of December 2015 has been the warmest on record for the UK and also East Anglia (5.7°C above average). Therefore this data will not reflect typical minimum river water temperatures.

01.14 There is not a consistent relationship between air temperature and the water temperature logged to extrapolate from average air temperatures (Fig 5). Possibly this is because being chalk fed the river Wensum is expected to have a high groundwater base flow component. So responses to low air temperatures would be buffered somewhat by the thermal inertia of contributing groundwater systems.

01.15 Gas boilers are necessary to cover heat demand on days when river water temperatures are too low to operate the heat pump. For the purposes of our assessment, and given the limitations of river water temperature data available, we have assumed conservatively that days when water temperatures will be too low for heat pump operation will coincide with air temperatures being equal or below -2°C. In these conditions the back-up boilers will be required to take over heating and hot water duty.

[7] TG4100 Aquatic 2 submersible data loggers

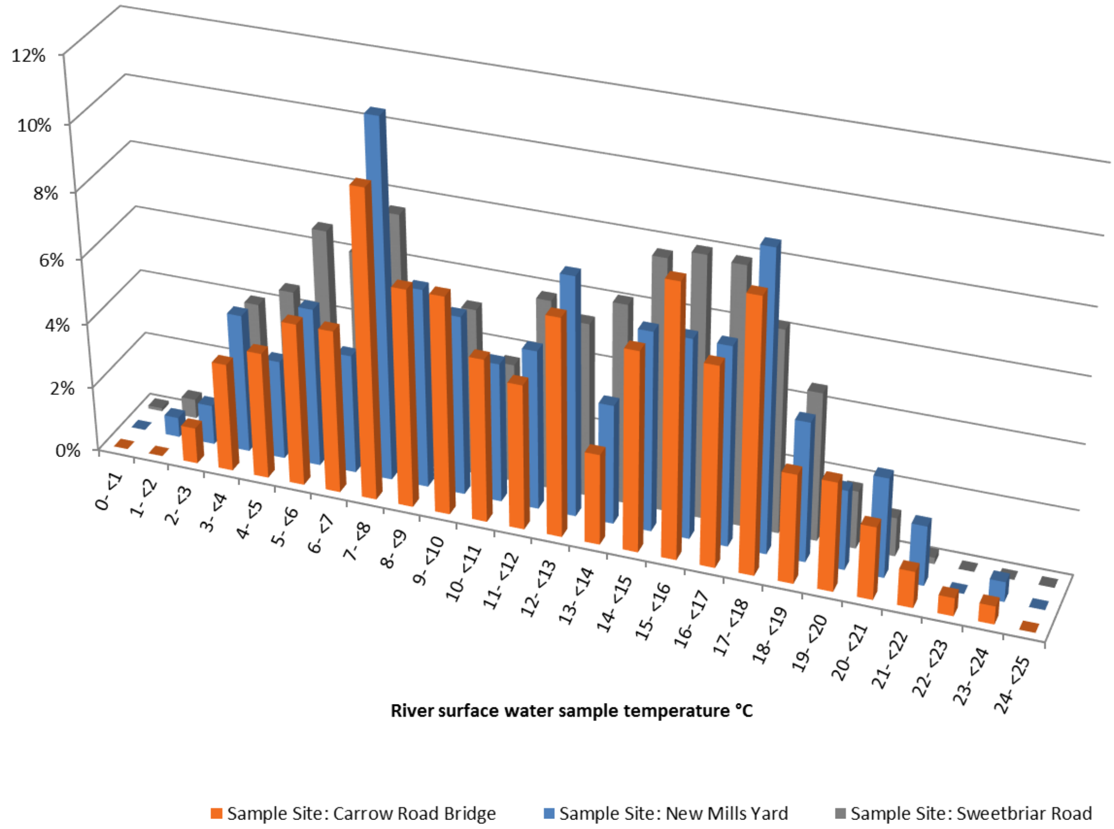


Fig 3 Environment Agency archive surface water temperature data for the study area. *Samples have been taken at two locations within the study area (180 spot samples taken at Carrow Road bridge 2000 -2012, and 164 spot samples at New Mills Yard 2000-2015)*

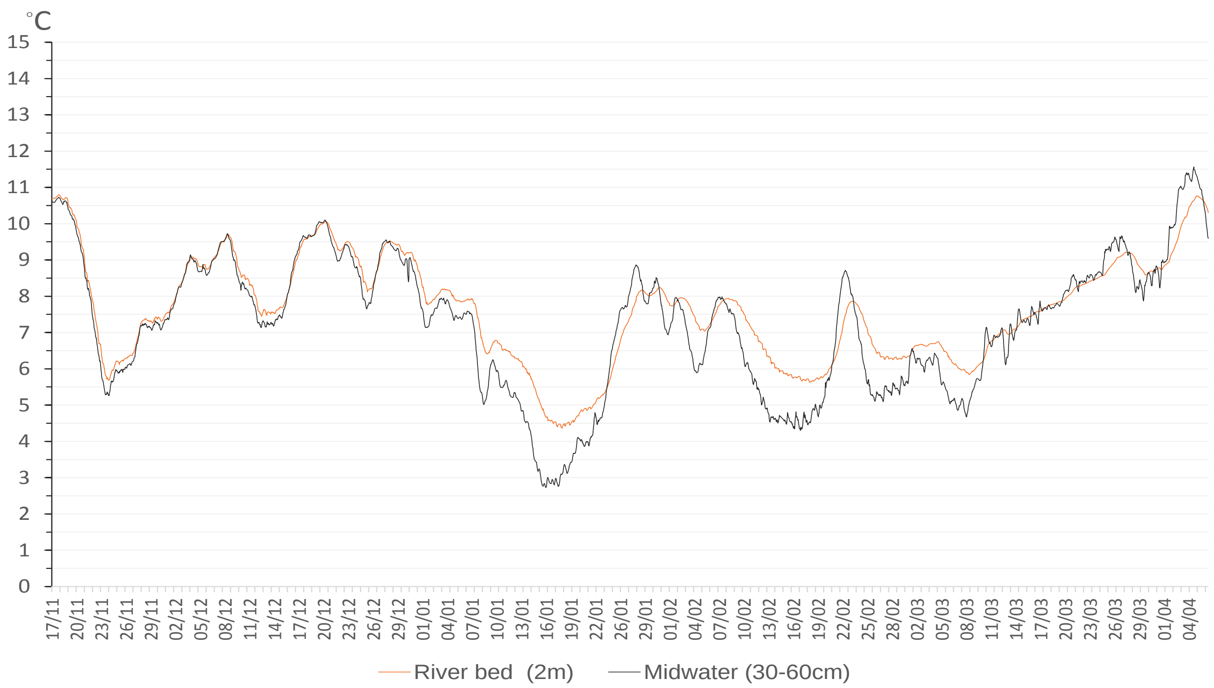


Fig 4 2015/16 Winter river water hourly temperature data logged for this study. *The more granular fluctuations at the lower temperatures at mid water are likely to reflect the greater influence of air temperature when the logger nears the surface at the tidal minima.*

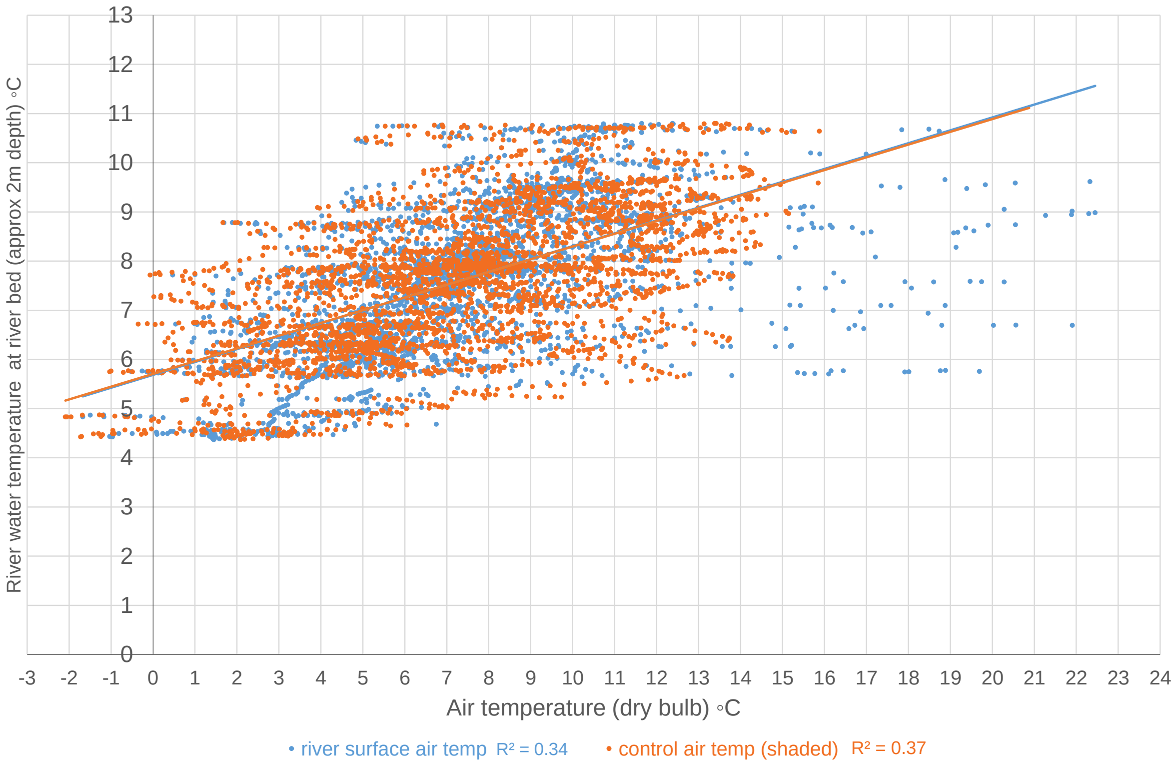


Fig 5 Hourly air temperature and river water temperature scatter plot. *River surface temperature logger exhibits temperature >15°C due to exposure to radiative heat from direct sunlight. Control temperature has been logged simultaneously at a sheltered, shaded site but open to the ambient air temperature approximately 3 km from the river site. R^2 values indicate that less than 40% of variation in hourly water temperature correlates with the variation in hourly air temperature. Taking daily mean average air temperature to reduce the diurnal fluctuation of air temperatures only increases the $R^2$to 47.6%.*

Fig 6 Location for temperature monitoring. *Loggers were placed on the river bed and mid-water on chains, away from contact with the steel piling*

02 Identifying suitable heat loads

DECC heat map data

02.1 An investigation of heat loads on a wider city spatial scale was originally proposed for this assessment. This approach had been based on the potentially larger heat capacity of the river indicated by the DECC water source heat data for the River Wensum through the study areas. A 4 MW capacity for a 'single water source heat pump' suggests much larger heat network potential.

02.2 A second factor for taking this approach had been access to a more detailed DECC spatial heat map data set, only available to local authorities. This appeared to offer a useful dataset of heat loads for individually located buildings and addresses.

02.3 The dataset consisting of estimated and actual building heat demand in kWh is located geographically at points was imported into a Geographical Information System Software package (QGIS) for further analysis. GIS was also used to fulfil the requirements to supply all maps used in this project in a GIS data format.

02.4 Ordinance Survey MasterMap® building and street scale data (considered the most up-to-date and accurate planning scale dataset), was used to capture this point data and map heat demand to respective building area, to qualify the heat area density data and allow indicative routing of a larger heat network through building and road map data.

02.5 An example showing the heat map for the study area is shown overleaf in Fig 7. Not all of the data has been presented for the reasons given below.

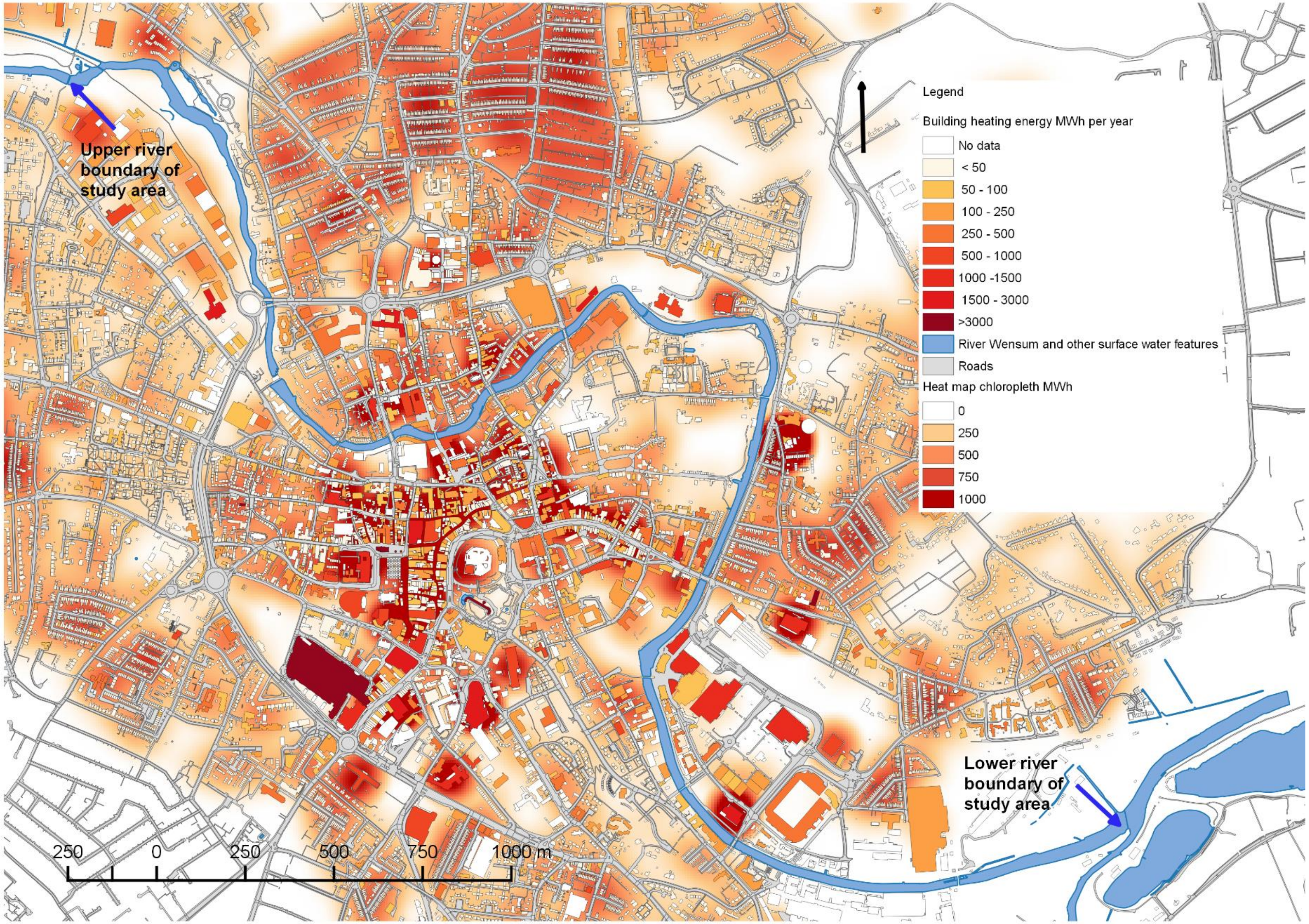
02.6 In analysing the heat demand dataset a considerable amount of additional effort has been required to remove erroneous data and identify and relocate points that appear to be located incorrectly. In these cases heat demand has been clearly incongruent with buildings locations in the OS MasterMap® data.

02.7 The data also appears to have applied blanket figures across many buildings seemingly based on default energy performance certificate reference data and given as total annual heat energy demand (kWh) which is less useful for sizing heat network capacity.

02.8 Later in this study regulatory advice places precautionary restrictions on discharge consent impacting the quantity of river heat capacity for utilisation - which considerably reduces the 4MW potential published in the water source heat map for a single water source heat pump scheme.

02.9 For these reasons the greater spatial scale of the heat map has become less relevant to this assessment. In this respect the heat map will therefore only be used for considering, at a basic level, the general routing of heat mains from larger district heating schemes. This will be used to explore the possibility of linking smaller WSHP networks using the St Anne's Quarter case study as an example.

Fig 7 Example CSE local authority heat map data assigned to OS MasterMap® building footprints



Selection of Case study examples

02.10 The scope of this feasibility study includes two examples.

1. **A new development** - A supply of river heat via heat pumps to the type of new developments likely to represent future residential building schemes in central Norwich seen as 'areas of interest' by Norwich City Council.

2. **A retrofit to an existing building** - River source heat pumps supplying heat to an existing building as a retrofit example, with some interest expressed by Norwich City Council in social residential buildings.

St Anne's Quarter

02.11 St Anne's Wharf has been selected as one of the areas of interest. This area of land has already received planning permission and has plans to develop the land into a residential complex of flats called St Anne's Quarter.

02.12 St Anne's Quarter is an early stage development proposed for the South East of the City wall boundary on the West bank of the river Wensum. The East bank of the river is the redeveloped river side complex. The planned development has not specified the use of water source heat pumps, this is used here only in the context of a case study example for the purposes of a feasibility assessment.

02.13 Though perhaps marginally larger than the kinds of developments expected elsewhere in future years, the St Anne's Quarter development has been chosen as a case study to broadly represent the design efficiency and typical dwelling density of future new buildings likely along this area of the riverside development area.

St James House

02.14 St James House is a single building owned by Norwich City Council that incorporates sheltered homes for older citizens.

02.15 There is no plan to install heat pumps in this smaller building. St James House is approximately 200 metres from the river, (Fig 8) and is used primarily as an example to indicate a typical social residential building heat load, rather than a viable WSHP retrofit opportunity.

02.16 The heat demand figures have been based on the past gas consumption figures, and do not reflect the current building's energy demand which may differ due to recent refurbishment.

Fig 8 St James House location. *Left showing its distance from the river, and above closer detail of its layout. Google Imagery © 2016 and Google Map data © 2016.*

Heat loads: St Anne's Quarter

02.17 The development comprises of 437 flats distributed between 24 buildings (blocks) that are to be built in 5 phases.

02.18 There are also commercial properties on the ground floors. The heat loads considered here are only for supply of heat to the residential properties.

02.19 Peak heat demands in Table 2 were obtained from the architects of St. Anne's Quarter. These are derived from heat loss calculations using dwelling dimensions from simplified AutoCAD, design U-values, infiltration and ventilation assumptions on the hot water peak demand based on occupancy.

02.20 The space heating loss (heat loads) specified are related to a minus 2°C design temperature. The heat loads do not include communal spaces. These heat loads are considered to be minor for the purposes of this assessment.

02.21 These heat loads have been profiled (Fig 9) for the technical sizing of the water source heat pump and also the need for back up heating plant using regional heating degree days (partly following EN12831[8]). Heating degree days represent the sum of daily outside and inside average temperature differences to be met by heating over a time period such as a week, month or year*.

02.22 The hot water demand profile is based on occupancy and is assumed to be reasonably constant throughout the year and the constant load assumption is used to size the demand and requirements for buffer capacity (this is covered in greater detail in section 4).

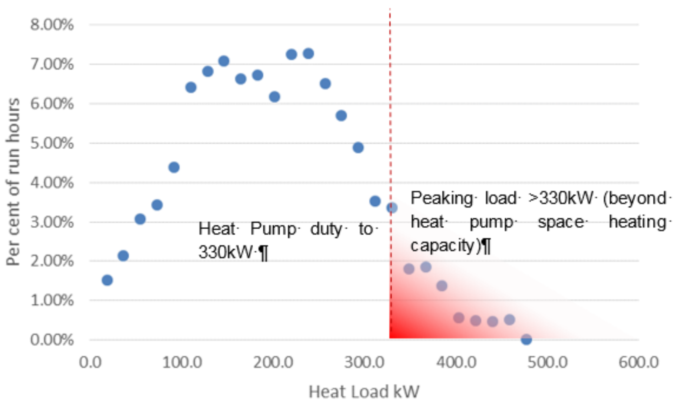


Fig 9 Space heating load profile for St. Anne's Quarter.

This has been derived using degree days following the BS EN 12831:2003 standard method.

**Degree days are based on sum of differences from lower outside average 24 hr air temperature to a 15.5°C base (the remaining temp lift to 21°C is assumed to be satisfied by residual heat gains from people, equipment and insolation). The area to the left of 330kW indicates the loads that are beyond the heat pump capacity where run hours relate to peaking plant. Back up gas boilers are required to supplement the shortfall in this assessment.*

Heat loads: St James House

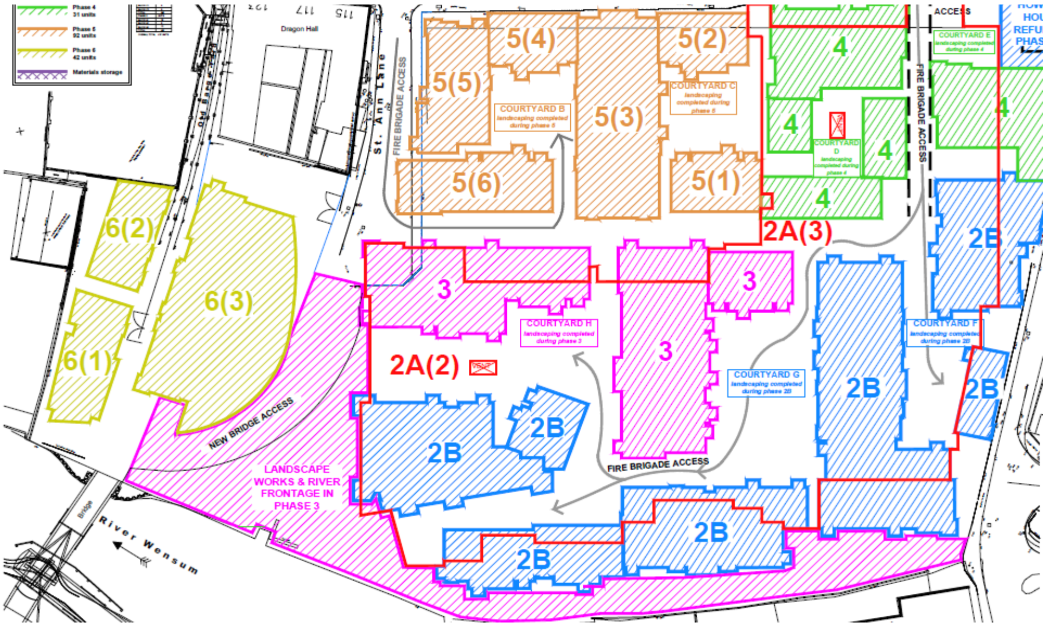
02.23 St James House is a single two story H block containing 34 flats. It is 170 metres to the North bank of the river Wensum, which at this point is flowing from West to East down river as it curves around the city. The heat loads have been derived from monthly gas usage records from the past 5 years.

[8] BS EN 12831:2003 Heating systems in buildings. Method for calculation of the design heat load.

Table 2 Peak heat loads obtained from Ingleton Wood, the architects of St Anne's Quarter development. *These are not based on detailed dynamic simulations for heat loss modelling.*

Building Phase	Peak space heating demand (kW)			Peak hot water demand (kW)		
	Flat Block	minus 1 degC	minus 2°C	Block	dT @40 degC	dT @50 degC
6	A1	23	24	A1	235	294
6	A2	7	8	A2	193	242
6	A3	12	13	A3	218	273
5	B1	22	23	B1	336	420
5	B2	11	11	B2	202	252
5	B3	10	11	B3	193	242
5	B4	7	7	B4	185	231
5	C1	7	7	C1	185	231
5	C2	6	6	C2	185	231
4	D1	3	3	D1	193	242
4	D2	4	4	D2	143	179
4	D3	2	2	D3	101	126
4	D4	12	13	D4	227	284
4	E1	11	12	E1	193	242
2b	F1	7	7	F1	185	231
2b	F2	14	14	F2	235	294
2b	F3	16	17	F3	252	315
2b	G1	21	22	G1	336	420
2b	G2	19	20	G2	252	315
3	G3	28	30	G3	336	420
3	G4	6	6	G4	193	242
2b	H1	11	12	H1	202	252
2b	H2	6	6	H2	185	231
2b	H3	29	30	H3	353	441
3	H4	22	23	H4	244	305

Fig 10 Location of the building phases associated with table 2 in the St. Anne's Quarter development.



03 Environmental constraints

Regulatory context

European Union Water Framework Directive

03.1 Impacts on the ecology of natural water courses is within the remit of the European Union Water Framework Directive 2000/60/EC (WFD)[9]. This Directive sets an enormous challenge in meeting the objectives of the improvement and the protection of the water environment and is the major driver for the sustainable management of water in the UK.

03.2 The WFD requires water bodies to reach 'good ecological status' or 'good ecological potential' if heavily modified. There is also a 'no deterioration' obligation for new modifications that have the potential to cause a deterioration in ecological status or prevent achievement of 'good ecological status' or 'good ecological potential'.

03.3 The river Wensum within the most of the study area (New Mills Yard to the river Yare) is designated as heavily modified and has been classed as moderate overall ecological status in 2015. Specifically this was expected for the stretches in the study area which had been classed as poor ecological status in 2009, but having good ecological potential. The WFD objectives for the study area are to achieve good ecological status by 2021 and 2027 and maintain the high status for fish and invertebrates. These objectives are therefore a key concern for the regulatory agency when considering new kinds of installations requiring non-standard discharge consents (see 'Discharge consent standard rules').

The UK Eels regulations and the EU Eel Directive

03.4 The UK Eels Regulations 2009 require placement of a screen over conduits for abstraction or out takes with a water flow over 20 m^3 per 24 hours. Mesh size is not specified by the regulations but the Environment Agency are given powers to notify abstraction licence and permit holders the screen dimensions required and also allow powers to carry out inspections. The European Union Eels Directive requires management plans to be implemented nationally to improve the status of eel populations.

The EU Freshwater Fish Directive

03.5 Though the European Union Freshwater Fish Directive has been revoked and its obligations superseded by those of the WFD, it is still relevant to this assessment with regard to the UK Technical Advisory Group's (UKTAG[10]) recommendations for use in calculations to achieve a good WFD target class and day-to-day operational control of discharges and abstractions.

03.6 In this respect the UK TAG recommends adopting the Freshwater Fish Directive maximum of 3°C change in temperature for a non-high status[11] Cyprinid fish community such as the Wensum. 3°C applies to a 98 percentile limit (allowing breach for 2% of time) downstream of a point of thermal discharge at the edge of the mixing zone[12].

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[9] Transposition into national law in the UK occurred for England and Wales through The Water Environment (Water Framework Directive) (England and Wales) Regulations 2003 (Statutory Instrument 2003 No. 3242).

[10] UK Technical Advisory UKTAG is a partnership of the UK environment and conservation agencies which was set up by the UK-wide WFD policy group consisting of UK government administrations. UKTAG is currently chaired by the Environment Agency and supported by a UKTAG Coordinator. It was created to provide coordinated advice on the science and technical aspects of the WFD.

[11] High status only applies to 3 rivers or canals in the UK 2015 WFD classification.

[12] UKTAG (2010) Page 6, Water Framework Directive: An approach to the Revoked Directives: –the Freshwater Fish Directive, the Shellfish Directive and the Dangerous substances Directive.

03.7 However the reference only to maximum temperatures and relative uplift in temperatures suggest this is only giving consideration to discharges with increased temperature relative to the river temperature. This ambiguity is also present within the UK's standard rules for discharges from heat exchangers

Discharge consent standard rules

03.8 The discharge consent guidance issues standard rules relating to the discharge from heat exchangers (SR2010 No.2). When referred to in an environmental permit, these rules will allow the operator to discharge up to 1,000 m^3 per day of water from a cooling circuit or heat exchanger, [provided that no polluting chemicals are present], to inland surface freshwaters where the temperature change between the inlet and outlet is less than 8°C and the outlet temperature does not exceed 25°C.

03.9 The discharge must be to the same water body from which the water was abstracted but not within 200 metres of another cooling or heating discharge.

03.10 SR2010 No2 also restricts any heat exchanger discharge from exceeding 25% of the river flow at its 95% exceeded flow during the period of use (with adjustments allowed for seasonal operation of the discharge). This is to protect low flow situations for smaller rivers/streams with flow volumes less than 4000 m^3 per day so is not relevant to the river Wensum ($Q95_{winter}$ >160,000 m^3 per day).

03.11 The discharge must not be made within 500 metres upstream from a designated shellfish water, European Site, Ramsar site, Site of Special Scientific Interest (SSSI), National Nature Reserve, Local Nature Reserve or any body of water identified as containing a Protected Species (under the EU Habitat Directive) or within 100 metres from a Local Wildlife Site.

03.12 Any discharge that contravenes these rules is considered non-standard and the application process requires specialist judgement by the Environment Agency. This may extend the time and cost of application beyond that of 'standard' applications.

Regulators position

03.13 Pre-application discussions have been sought with the Environment Agency (EA) following CIBSE's Surface Water Heat Pump Code of Best Practice for feasibility stage assessments. The EA referred to their regional ecologist[13] and also to a central team specialising in discharge consent guidance. With indications that feedback could be provided from this team regarding the implications of SR2010 and WSHP's. The central discharge team has not provided any feedback or guidance. Guidance has been sought from the EA's senior advisor and technical lead for wider deployment of water source heating systems.

03.14 The view offered by the senior adviser is that the onus should be placed on the applicant requiring discharge consent to demonstrate in their application that the proposed discharge would not impact the current WFD ecological status and objectives. However, if more than one application is received by different parties then the Environment Agency will be required to make an assessment of the cumulative impacts on the river's ecological status.

[13] Referral had been made to EA Ecologist Rob Brown. Rob only had concerns where discharges were warmer, due to the potential impacts on river ecology within the context of impacts of future climate changes. In general cooler discharges of 3 degrees were considered much less of a concern. Rob had been reticent to provide guidance on overall temperature reduction limits to a stretch of river that would be considered benign (in order to derive indications on available discharge volume capacity).

Environmental permits and licences

03.15 In order that water can be withdrawn from the river, even for non-consumptive use, and discharge consented, an abstraction licence and environmental permit must be applied for. Recently the Environment Agency (EA) have combined the application paperwork required for surface water heat pumps[14].

An EA representative has advised that timescales for application for these permit and licences for a non-consumptive open source heat pump could vary. Typically applicants should allow about 5 months for a pre-application process and 13 weeks from 'duly made' (which is when the EA acknowledge your application is correct) to issue. Initial licenses are valid typically for 6-10 years, with longer periods possible after renewal.

03.16 If the scheme/application is non-standard and deemed complex this may involve the EA requiring a detailed environmental impact statement. Some industrial cases have taken up to 5 years but this had been considered unlikely for non-consumptive heat pump schemes for the Wensum with total cumulative non-consumptive abstraction < 1m^3/sec threshold.

03.17 Monitoring of abstraction/discharge flow, daily volumes and temperature are likely to be required. Alarms to warn operators of potential breach of any consented temperature limits have been specified.

Charges

1) **Pre-application** – Initial pre-application discussions with EA. 15 hours of advice is free of charge and if further advice is required after this charges can be levied at £125 per hour (under the Environment Act 1995 to charge for services provided).

2) **Formal Application** - Licence cost is £135 plus £500- £2000 advertisement costs may be charged if deemed necessary by the EA for ensuring public awareness following grant of licence.

The 15 hours and subsequent charge for pre-application advice does not relate to permits for discharges to water where *minimal pre-application advice can be provided because no charge is currently levied*[15].

Annual charge. For bespoke permits with discharge volumes between 1,000 and 10,000m^3 per day a subsistence factor of £1,026 may be applied. This has been derived from multiplying a fixed annual charge by the appropriate factors[16] for the volume, effluent content and receiving water.

Summary of ecological impact assessment against WFD objectives

03.18 Table 3 overleaf summarises the understanding and likelihood of WSHP impacts screened against the Water Framework status and objectives for the stretch of the Wensum (WFD site reference GB105034055882 'Wensum DS Norwich'). This is based on the results of a review which are documented in the appendix (page 73).

03.19 There is no formal guidance for carrying out WFD assessments for the freshwater environment in England, Wales and Scotland. The Northern Ireland Environment Agency has issued guidelines on WFD assessments for mandatory Environmental Impact Assessments (EIA's) of large infrastructure (Schedule I[17]) developments or other larger (Schedule 2[18]) developments deemed to need further assessment as of part of planning requirements. Being much larger, the kinds of developments listed

[14] Application for an environmental permit and full abstraction licence Part B8 – New ground source or surface water source heating and cooling scheme.
[15] Environmental Permitting Charging Scheme & Guidance Scheme effective from April 2014 Version 3 (Dec 2015)
[16] Schedule 4 of above.
[17] http://www.legislation.gov.uk/uksi/2011/1824/schedule/1/made
[18] http://www.legislation.gov.uk/uksi/2011/1824/schedule/2/made

would not appear to apply to WSHP applications. However, general principles of screening and scoping have been applied here and are outlined in the review in the Appendix.

Status of WFD elements **2015 Assessment** (2027 Objective)		**Impact of Water Source Heat Pump Discharges on WFD status and objectives of river Wensum study area**
Overall	**Moderate** (Good)	Overall there is limited scientific evidence and information on species in the study area to give indications of impacts of cooled water discharges of the specified heat pump system would prevent WFD objectives being reached.
Fish	**High** (Good)	Limited scientific research is available to substantiate impacts from localised 2°C reductions to river temperature in winter on cyprinid communities. The operation of the heat pump in winter periods does not coincide with more critical stages of cyprinid growth and reproduction in summer. Ambient level reduction in temperature for the scale of the St Anne's Quarter development is relatively small (0.05°C) so the likelihood of impact on fish community structure or population levels is considered to be low. Cumulative effects from more than one scheme could impact temperature and understanding these impacts would require further research. If localised cooler discharge plume causes avoidance behaviour this could displace the zone of influence for fish, but the area is not likely to restrict population of reduce habitat to impact communities significantly. A discharge diffuser would mitigate the extent of plume.
Invertebrates	**High** (Good)	High status is defined as *The level of diversity of invertebrate taxa shows no sign of alteration from undisturbed levels*. The likelihood that the higher scoring sensitive mayfly species present in upper reaches (Costessey) are common in this section of the Wensum is low. BMWP and ASPT appear to reflect this showing macro invertebrate species richness declining in the sample site. WFD status assessments apply revised metric (WHPT[19]) which may explain differences in BMWP indications and WFD class. Surveys for white clawed Crayfish and compressed mussels have not revealed the presence of these or other protected species near St Anne's Quarter.
Macrophytes	**Moderate** (Good)	Information available for a desk based study is restricted to national macrophyte survey database (JNCC). No surveys have been carried out in the study area. Unqualified observations indicate the river is not rich in species and abundance of macrophyte flora compared to higher reaches of the Wensum. Bank margins have been heavily modified and are unlikely to be restored to natural profiles and the river may be subject to dredging for navigation. Localised cool water discharges mostly during heating season are considered unlikely to prevent improvements for achieving good status. Studies on deep colder water releases from impoundments have improved some macrophyte communities in one study but there is not enough evidence to make general conclusions.
Hydro-morphological Supporting Elements	Supports Good	The abstraction and flow rates from pumped exchanger discharge is unlikely to impact hydro-morphological conditions in the study area in feasible deeper water sites. Siting is not considered likely in shallow sections due to winter temperature issues. Scouring or turbidity risks can be avoided through linear diffusers and sensible direction of discharge (away from river bed).
Specific pollutants	**High** (High)	No pollutants will contact river water in normal operating conditions and are unlikely to in abnormal operations given the heating network circuit (brine side) is a separate closed circuit and isolated from the pumping river open loop circuit via heat exchangers.
Hydrological Regime	Does Not Support Good	The WFD assessment appears to indicate that the river flow is not supportive of Good status. The open loop water source heat pump system is non-consumptive so the likelihood of the WSHP impact net flow status of the river is very low.
Temperature	**High** (Good)	The removal of 2°C of heat from 172 m^3 of water per hour (maximum) and at a low (Q95) winter river flow of 1.9 m^3/sec[20] is a theoretical equivalent to cooling the whole the river water volume flowing past by 0.05°C assuming immediate and perfect equilibrium of heat dispersion through the mixed water bodies. For Q70 winter flows the temperature reduction would be less than half this value.

Table 3 Screening/scoping of WSHP impacts against the river Wensum's WFD status and objectives

[19] Whalley, Hawkes, Paisley &Trigg (WHPT) metric in WFD River Invertebrate Classification

[20] This is a Wensum flow rate that is exceeded 95% of the time between October and March. It has been derived from combining flow archive data 1995 -2014 for the river Wensum and river Tudd (a tributary).

Concluding remarks

03.20 Surveys suggest that there are unlikely to be any protected species of crustaceans or molluscs present at the Carrow /Riverside area in the lower reaches of the Wensum. Limited evidence suggests that these species would not be impacted by ambient reduction in the river temperature of a magnitude likely to result from discharges from water source heat pump heat exchangers.

03.21 Acute exposure to a cooler water plume from the heat pump discharge could impact individual species of fish, however temperature differentials of 2 or even 3°C would likely trigger avoidance behaviour. The likelihood that exposure would result in fish mortality or significant sub-lethal impacts is considered to be small.

03.22 There have been few relevant scientific studies to enable any assessment of the impacts and thresholds for significance of impacts caused by a colder water discharge plume into the river Wensum on wider natural ecological communities of macroinvertebrates.

03.23 Given the paucity of scientific evidence on cold water impacts it is not possible to make practical judgements against criteria in the Water Framework Directive for WSHP impact on this stretch of the river Wensum's current ecological status and, importantly preventing achieving 2021 and 2027 objectives for good ecological and overall status.

03.24 A recent review of literature on studies in ecological regime shift and thresholds in freshwater river systems[21] indicates there are few sources of evidence to understand these changes in general. This makes it difficult to conclude whether water source heat pump discharge activity will impact Water Frame Work directive status and objectives.

03.25 In view of this, pre-application advice from the Environment Agency was sought. A precautionary limit to reducing the discharge water temperature to no greater than 2°C from the abstracted river water temperature has been suggested[22]. This partly follows the discharge consent permitted for the only other river water source heat pump development (Kingston Heights, Kingston-upon-Thames) which has a 3°C differential limit.

03.26 No limits on maximum or relative discharge volumes or ambient temperature reductions could be advised by the Environment Agency. Therefore precautionary limits to heat removal have not been substantiated. Representatives of DECC's Heat Network Development Unit advised, at an interim meeting, to reframe the project by basing water volume requirements on development heat demand first, given the limited evidence or regulatory support to ascertain environmental constraints.

03.27 Therefore the maximum temperature gradient between the river water and the point of discharge 2°C has been used in the following sections to base a conceptual heat pump system for the chosen case studies and the required volumes will be driven by building demand and this temperature differential rather than through determination from ecological constraints.

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[21] Samantha J. Capon, A. Jasmyn J. Lynch, Nick Bond, Bruce C. Chessman, Jenny Davis, Nick Davidson, Max Finlayson, Peter A. Gell, David Hohnberg, Chris Humphrey, Richard T. Kingsford, Daryl Nielsen, James R. Thomson, Keith Ward, Ralph Mac Nally, Regime shifts, thresholds and multiple stable states in freshwater ecosystems; a critical appraisal of the evidence, Science of The Total Environment, Volume 534, 15 November 2015, Pages 122-130

[22] Personal communication (07 January 2016) with Steven Oates, Senior Advisor at the Environment Agency and Technical lead for wider deployment of water source heating systems, supporting Department of Energy and Climate Change Heat Networks Unit.

Amenity constraints

03.28 Recent consultation by the river Wensum strategy partnership[23] indicates there is a diverse set of public interests taking a stake in the amenity value of the navigational part of the river flowing through Norwich. Boat owners and users, canoeists, cyclists along with anglers all have interests in maintaining and improving their access to the river in different ways.

03.29 Correspondence with the Broads Authority's senior navigation engineer[24] highlights a number of key restrictions for installation of water source heat pump pipework, intakes or discharge manifolds. The navigable part of the river Wensum begins down river from New Mills Yard and is subject to siltation, and potentially requires access to dredging. This affects the majority of river length/study area considered in this feasibility assessment.

03.30 Any pipework or intake unit sited on the river bed (as has been achieved by the Kingston Heights design) is unsuitable for the Wensum due to the requirement for dredging and therefore excludes closed loop heat pump designs and siting of filters or submersible pumps in the river. Secondly any installation that may risk impediment to mooring or an obstacle to boating traffic is unlikely to be approved by the Broads Authority[25]. This is a key constraint which demands a different design approach to that of Kingston Heights in-river filtration.

Cultural heritage constraints

03.31 St Anne's Wharf has been chosen to represent a case study for water source heat pump in this feasibility study but being in close proximity to a number of historic sites (Table 4) it is a good example of heritage related restrictions likely to face heat network installations.

03.32 Like much of the central part of the city the Wensum flows through, St. Anne's Wharf site has evidence of human activity at least since Saxon times. In 1270's onwards it had been the site of an Augustinian Priory which was later dissolved during the reformation in 1538.

03.33 In the 17th century the site was bought by Henry Howard, Duke of Norfolk. At the westerly limit of the site boundary (furthest from the river) stands Howard's House, a grade II listed 17th century building. It is not open to the public and has been on the English Heritage "At Risk Register" because of its very poor state of repair

Table 4 Sites of historical significance in the study area

The Old Barge	Grade I listed (623548.785, 308184.15184)
Howards House	Grade II listed (623468, 308307.36084
St. Anne's Chapel	No existing remains
13th Century Augustinian Priory	No existing remains

03.34 Since the development of St Anne's Quarter has already commenced with planning permissions granted, processes have been put in place to preserve the archaeologically important remains after archaeological surveys. The site works proposed for the new residential development such as foundation pilings and excavation for pipe services have taken account of the need to preserve archaeological remains beneath the site in situ.

03.35 Since civils and services have already been planned it is assumed for purposes of this feasibility study that the heat network installation would not be prevented by archaeological reasons. The extent and depths of pipe laying operations will be similar. Some economy could also be achieved by allowing civils and HN pipework to be laid at the same time sharing some of the excavation cost. This should be explored further at the design level stages for WSHP in new developments.

[23] https://www.norwich.gov.uk/downloads/file/2841/report_summarising_the_consultation_responses

[25] Personal communication, Tom Hunter Rivers Engineer, The Broads Authority 17/12/15

04 Technical feasibility

04.1 This section outlines a technical assessment of how water source heat pumps can supply the heat demand estimated for the main case study St Anne's Quarter development outlined in section 2 through a heat network.

04.2 The section also considers the feasibility of retrofitting water source heat pumps to smaller existing residential developments that are a more common size for older properties in the river corridor through the centre of Norwich using heat loads derived from an existing social residential building (30 flats) owned by Norwich City Council.

04.3 The technical feasibility has been broken down into several sub tasks with the main aim of providing recommendations for a suitable system design and associated costs.

Case Study 1 - new development St Anne's Quarter

Proposed layout of heat network and energy centre

04.4 A river side site has been proposed for the energy centre,(Fig 11) housing all the heating plant as well as the abstraction of river water since the location is also reasonably close to the proposed buildings and takes advantage of an existing revetment for siting the intake screen. The image below can be seen in the bottom left of the proposed heat network layouts (Fig 12 and Fig 13).

04.5 The proposed energy centre plant room will be built approximately 10 metres away from the river bank, it will be placed below ground level (bunker) and will have a surface of approximately 100 m^2 (14x7 m)

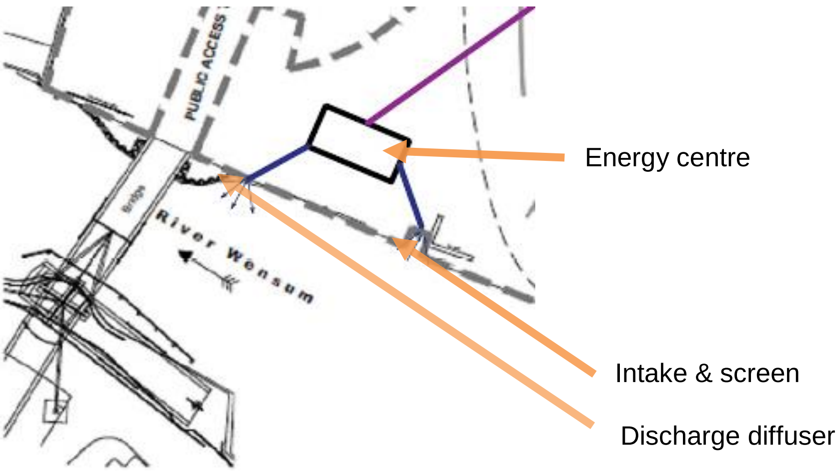
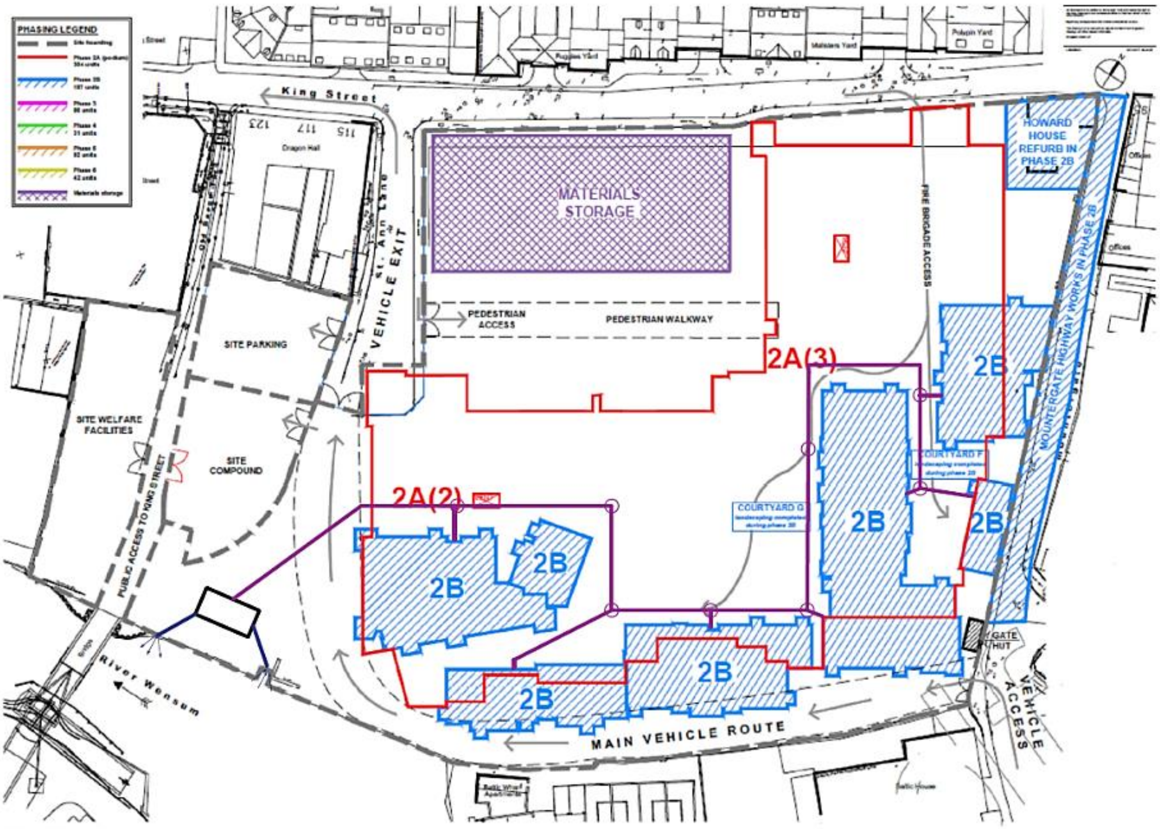


Fig 11 Location of the energy centre and abstraction and discharge points

04.6 Heat distribution from the heating plant will be reasonably uncomplicated with only one existing roadway to be crossed. The development is planned to be built in phases. The figures overleaf (Fig 12 and Fig 13) show how the HN is proposed to allow for this.

04.7 Connections to an electricity grid supply would be required in a protected services cable run. Given the development will also require connection from a transformer on site cabling will be required from this transformer to the energy centre. The cost of the transformer are assumed to be absorbed by the larger building development. Costs for connection fees are included in the financial information in section 06

Fig 12 Initial phases of St. Anne's Quarter's development. *A heat network distribution point is specified for each block to allow for balancing and distribution to individual properties within each block (purple line). (Images from Orbit Housing's public domain promotional document).*



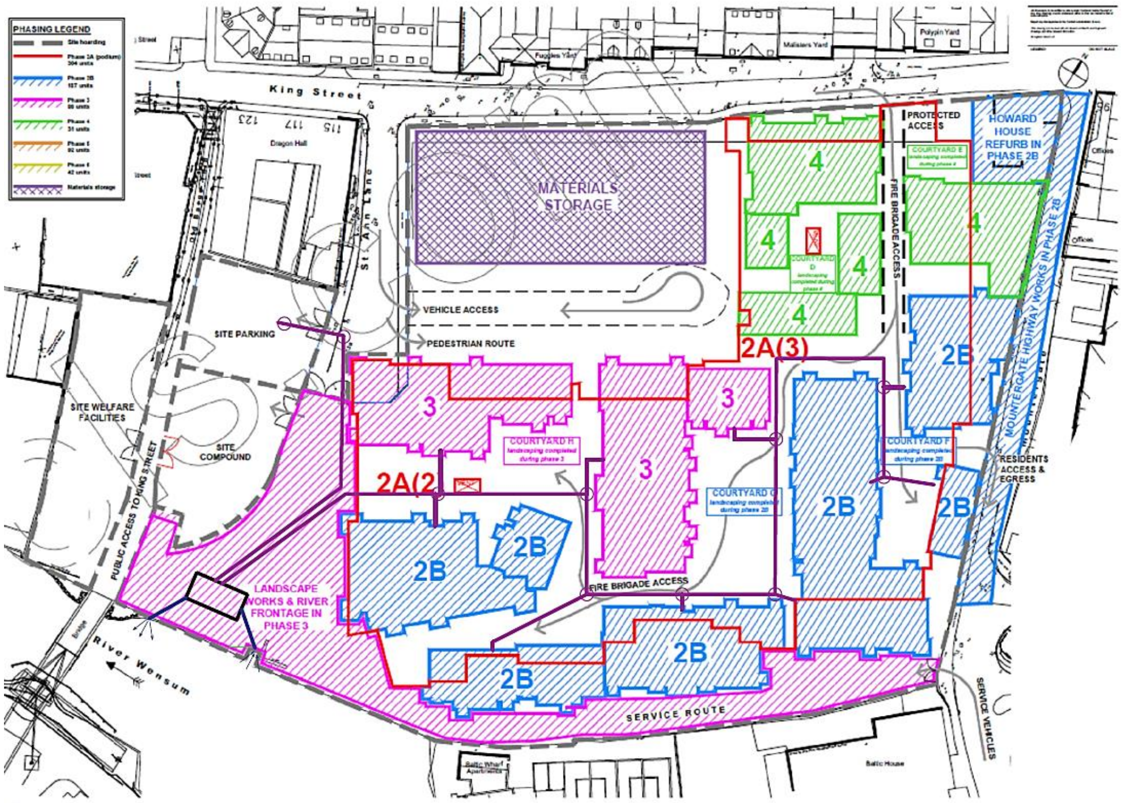
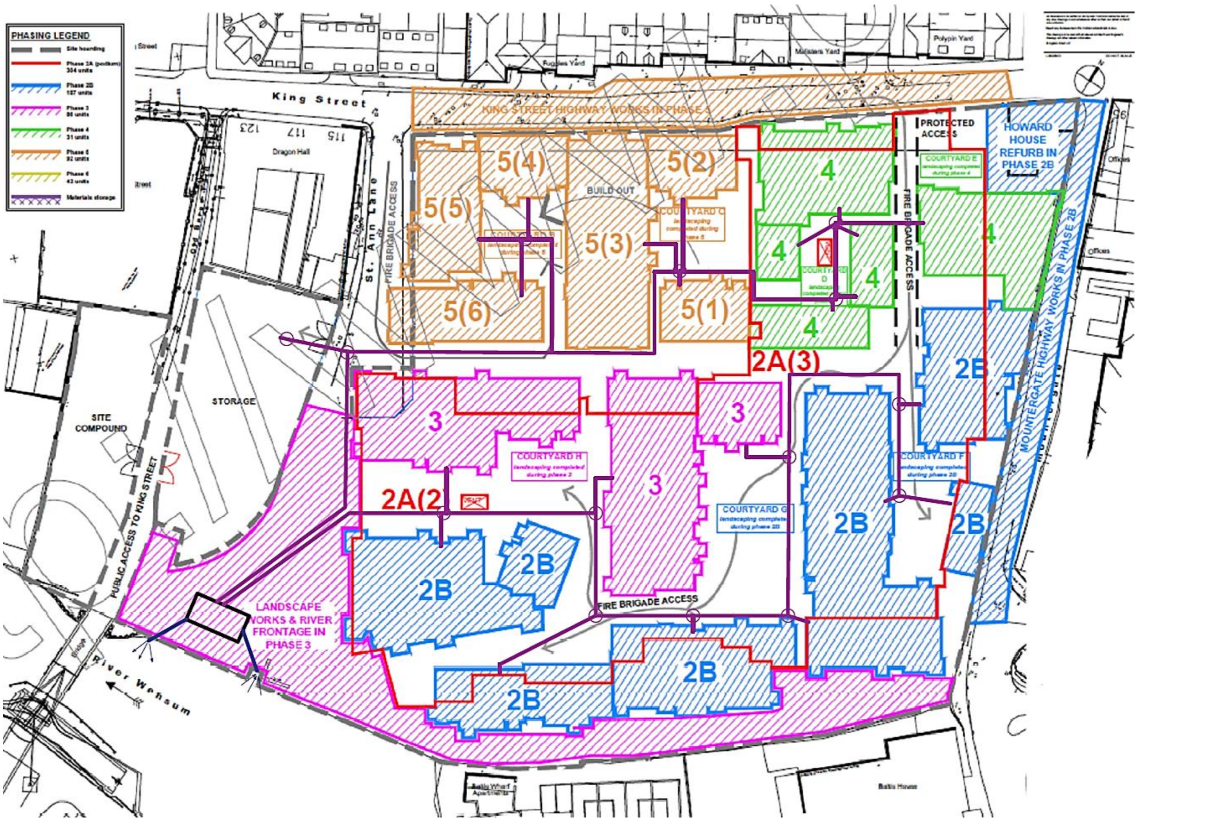
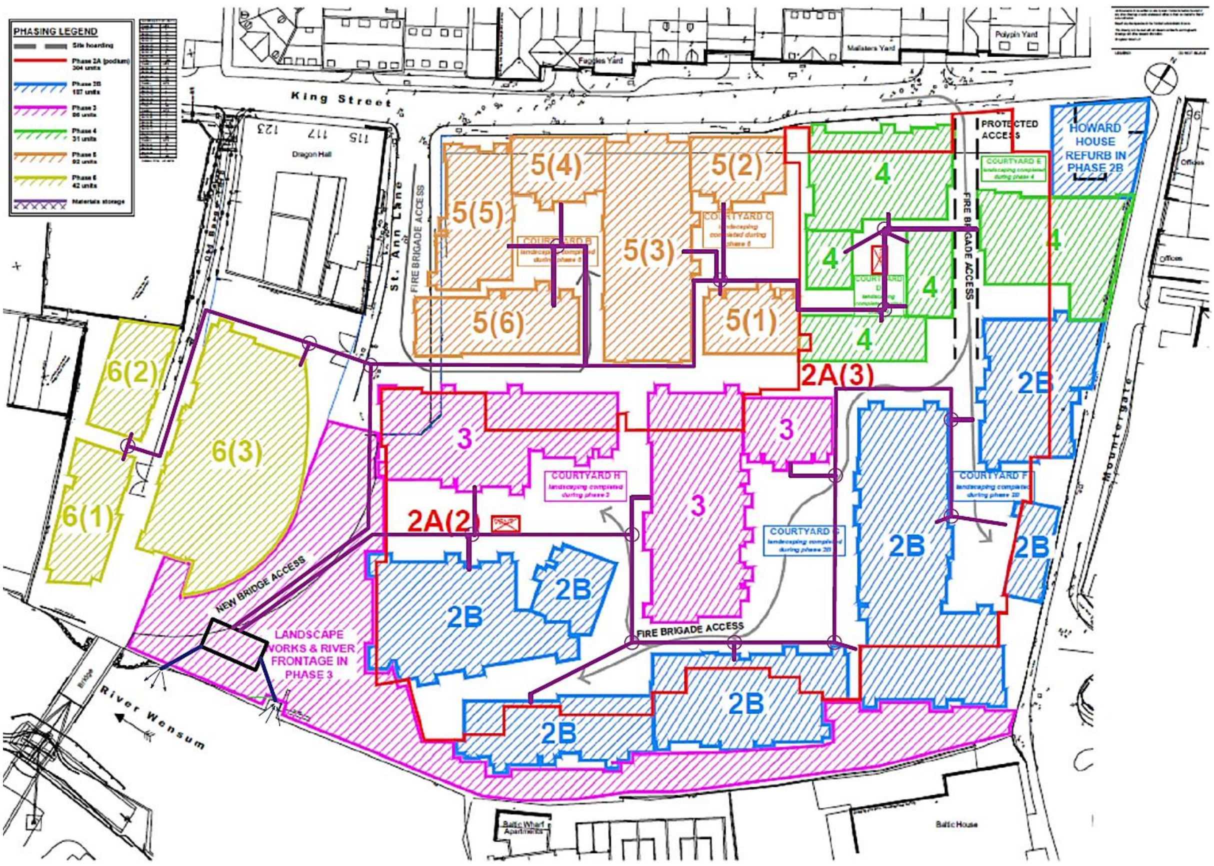


Fig 13 Later phases of St. Anne's Quarter development *Heat network extension is proposed as shown by the purple line (Images from Orbit Housing's public domain promotional document)*





System design and distribution overview

04.8 The WSHP system has been designed to accommodate available river heat in view of river water temperature data and the heat loads and space heating demand profile for the St Anne's Quarter development outlined in section 02. St. Anne's Quarter will have 437 units (flats and studios) with a total floor area of 25,650 m^2; the minimum external design temperature for the heat pump system is minus 2°C.

04.9 Total heating and domestic hot water load covering peak demand has been calculated at 589 kW using heat load data from the building. To cover this capacity a system is proposed using 11 water to water heat pumps each having a capacity of 55 kW, (maximum nominal total system capacity 605 kW).

04.10 The WSHP system design for St. Anne's Quarter based on a 2 °C differential from the river requires eleven 60kW Mitsubishi Ecodan CRHV-P600YA heat pumps[26] . Each heat pump will extract heat from river water via individual heat exchangers fed via a single pipe and filtering system. River water is pumped through 22 heat exchangers (2 per heat pump) transferring heat to an ethylene glycol and water closed loops flowing at 14.6m^3/hour which transfers the heat to each heat pump.

04.11 Each heat pump incorporates a charge of 9 kg of non-ozone depleting refrigerant R401-a[27] hermetically sealed in the unit. Through compression cycle via two compressors each heat pump transfers heat to the hot water heat network closed circuit reservoir.

04.12 The whole bank of heat pumps then supply heat to two insulated buffering vessels of 5,000 litres each to maintain a constant feed temperature of 55°C for water pumped through the network to each dwelling's heat interface unit (HIU).

04.13 The heat pumps' duty is to maintain this water at a constant 55 °C whilst it is pumped through the heat network transferring heat to HIU's in each property. These then exchange heat to each flat's space heating circuits and for hot water supply.

04.14 The advantage of 11 heat pumps each with two compressors is that a stepped modulation output can be achieved to allow for multiple variances with heat demand. As heat demand increases more heat pumps will come on line to support peak loads.

Heat network options

04.15 The heat will be delivered to the buildings using a district heating network. The piping system proposed is Uponor Ecoflex pre-insulated Pex-A. We have proposed two distribution options (Table 5).

Heating Network Option 1 Cost: **£1,223,936**	Heating Network Option 2 Cost: **£1,194,183**
A branched system with one main section of pipe and multiple secondary branches to connect with the buildings as the project evolves.	Two main sections of pipe which will split the development in two halves
Uponor EcoFlex Thermo 110/200 x 900m	Uponor EcoFlex Thermo 125/200 x 450m
EcoFlex Chamber x 15	Uponor EcoFlex Thermo 110/200 x 200m
Uponor EcoFlex Thermo 90/200 x 400m	EcoFlex Chamber x 15
Uponor EcoFlex Thermo 2 x63/200 x 1000m	Uponor EcoFlex Thermo 90/200 x 400m

[26] https://heating.mitsubishielectric.co.uk/ProductsGroundSourceHeatPumps/Documents/CRHV-P600YA-HPB%20PI%20Sheet.pdf

[27] R401a is a substitute of R22 or Freon which has been phased out by the Montreal protocol on Ozone depleting substances. It is a mixture of R-125 (pentafluoroethane (CHF_2CF_3), and R-32 (difluoromethane CH_2F_2) with a global warming potential over 1,700 times that of CO2.

	Uponor EcoFlex Thermo 2 x63/200 x 1000m
Civil works - pipe laying @£60/m	Civil works - pipe laying @£60/m
HIU x 437	HIU x 437
HIU installation	HIU installation
Heat meters x 437	Heat meters x 437
Data logger 256 entries and GPRS modem x 25	Data logger 256 entries and GPRS modem x 25

Table 5 Specifications and cost of two heat network options for St. Anne's Quarter

04.16 In Option 2 one of the sections will supply heat to the buildings that will be built in phases 2b & 3 (Fig 12 a and b) representing 57% of the whole heating capacity. The second section will be used to supply heat to the buildings developed in the following 3 phases (4, 5 & 6 (Fig 13) representing 43% of the whole heating capacity.

04.17 The technical advantage of using Option 2 is that after the first two phases are occupied, the distribution system will be hydraulically balanced, therefore no further intervention will be required.

04.18 A further advantage would be that in the case of failure/leakage with Option 1, the whole heating network will be affected; with Option 2 having two main circuits, the chance of having failure/leakage on both of them in the same time is unlikely; therefore if a failure were to take place only half of the heating network would be affected.

04.19 Option 1 is more conventional. For the financial assessment, Option 1 has been used since this is more likely to be implemented.

Heating interface units (HIU's)

04.20 The heating network will deliver the heat to each dwelling via heating interface units (HIU's). They contain two heat exchangers – one for the heating system and the other one for the production of hot water. Heat meters and balancing valves are contained in these units.

04.21 HIU's allow automated metering of heat used by each dwelling. This enables occupiers to be charged efficiently and fairly for the heat they use but also allows record submissions for the Government's Renewable Heat Incentive scheme (RHI) compliance.

Hot water demand

04.22 Domestic hot water (DHW) demand is the most likely factor to cause peaking of the system. BS 8558/BS EN 806-3 states the designer is free to use a nationally approved detailed calculation method for pipe sizing but does not recommend a specific method.

04.23 Here the Danish Standard DS 439[28] has been used to calculate the DHW peak demand. Experience from continental schemes indicates that the BS 6700 (BSI, 2009a) factors are too conservative and Danish Standard DS 439: 2009 'diversity' or 'coincidence factors' are recommended for sizing DHW supplies to multiple dwellings by CIBSE (AM12:2013).

04.24 Other guidance, such as *A technical guide to district heating* (BRE, 2014) and the *Heat Networks: Code of Practice for the UK* (ADE/CIBSE, 2015 - draft at time of writing) advocate the use of the Danish Standard DS 439 for application of an appropriate coincidence/diversity factor.

[28] Dansk Standard https://webshop.ds.dk/Files/Files/Products/M231064_attachPV.pdf

04.25 Therefore 0.08 coincidence or diversity factor has been used for DHW heat load estimates for the whole of St Anne's Quarter's developments by extrapolation from DS 439 (Fig 14). The results and calculation steps are shown in Table 6.

Peaking or backup boilers

04.26 As a backup solution we have proposed gas condensing boilers. A cascade of 5 high efficiency condensing units having 120 kW each which will ensure the functionality of the system for the situations when the external temperatures drop below -2°C and/or whenever the river temperature drops below 5°C.

04.27 The seasonal efficiency has been estimated at 90% for the peaking boilers although the nominal seasonal efficiency for the condensing boilers specified is higher (98%). This is to allow for the fact that peaking boilers will not run continuously and additional start-ups will impact efficiency.

04.28 For the counterfactual scenario the same condensing gas boilers are expected to achieve the nominal 98% efficiency so this value has been used to estimate gas consumption and carbon emissions presented in the financial model.

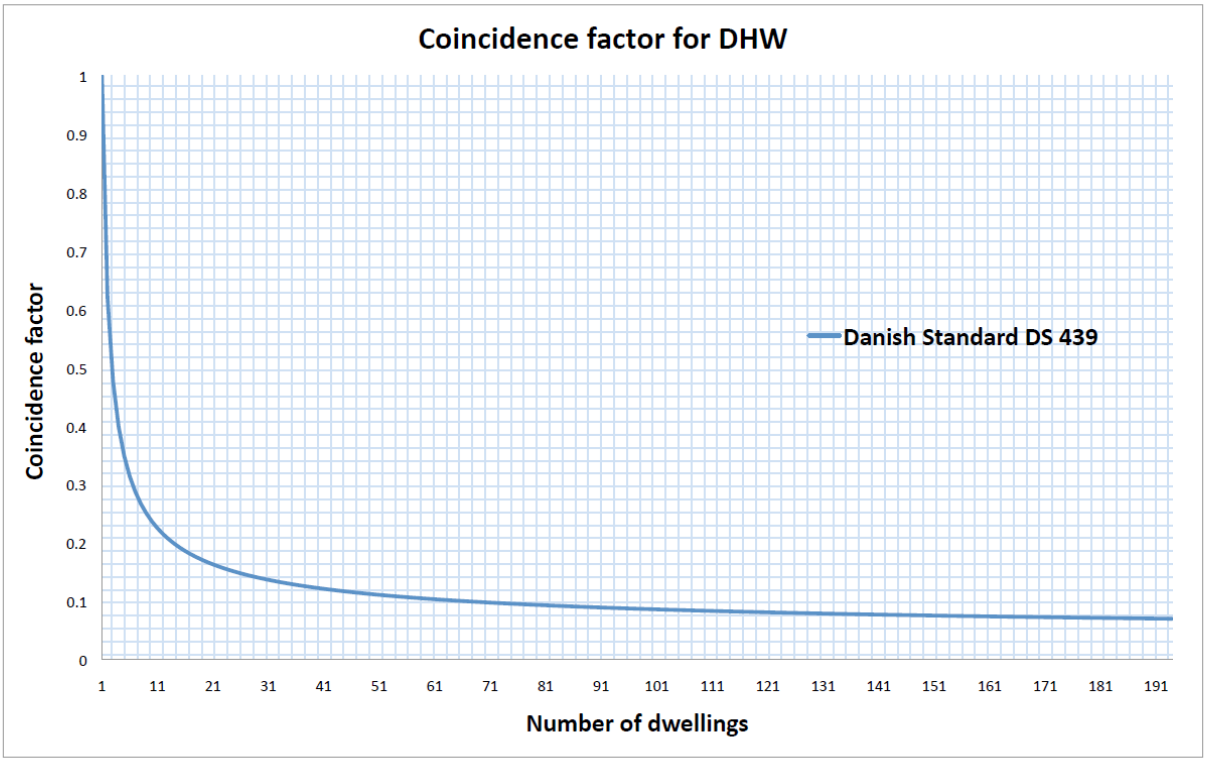


Fig 14 Coincidence factors for no. of dwellings for hot water peak demand calculations. *This has been taken from the Danish standard DS 439 (see text or glossary for explanation).*

DHW	Instantaneous
No. of Flats -	437
Delivered Temperature °C	50
Cold Feed Temperature °C	10
Temperature Raise °K	40
DHW volume l/day/flat	200
Flow Rate l/min/flat	10
Selected Diversity	0.08
District Loop DHW ΔT	20
Peak DHW Duration- mins	10
Peak DHW Usage Profile -times/day	2
TOTAL LOAD -kW	**973.3**
Energy Usage/Day/Flat kWh	9.28
DHW energy usage MWh /day	4.055
DHW energy usage MWh /year	1,476.15

Table 6 St. Anne's Quarter hot water demand estimates and heat requirements assumptions. *These have been used for sizing buffer vessels with respect to heat pump capacity.*

Intake screening

04.29 Due to the restrictions preventing placement of filters in the river channel (see 03.30 Amenity constraints) abstraction of river water would require an inlet channel from the river bank. The distance from the abstraction point to the plant room is approximately 10m with a difference in level of approximately 5m. The water depth in the inlet shall be required to allow for abstraction from an intake at sufficient depth below the surface to allow for tidal changes in river depth (2 m is proposed).

04.30 It had been suggested for St. Anne's Quarter that 1st stage filters could be placed in the river by extending the timber bridge abutments with fender posts, as seen on the opposite bank (Fig 15). This would solve the problem of the need for an additional channel and intake screening. This would require detailed negotiations with the Broads Authority due to channel siltation concerns and navigational requirements. In addition, this approach may not be possible for areas of the river that are not in close proximity to bridges.

04.31 Therefore a rotary disc screen is proposed to prevent ingress or debris and fauna into the channel ends (Fig 16). Working examples of these have been developed by Mono Pumps Ltd[29]. They are based on a series of plastic, stainless steel or high impact glass-reinforced polypropylene discs stacked in a column with spacing between the discs suitable for its specific usage. This will be required to be set in line with the river banks steel piling to ensure it will not be considered a navigation obstacle by the Broads Authority.

04.32 The discs within each column rotate in the same direction with adjacent columns interleaving. The discs are driven via motors with the direction of rotation matching that of the direction of water flow. Debris will be passed from one column to another until carried away by the flow. The annual cost in electricity of this operation is considered to be at least as economical as the equivalent manual cleaning costs that would be required due to debris blockage and fouling of passive screens.

Fig 15 Timber bridge fenders on the opposite bank from St. Anne's Quarter. *Photo © Joe Rutland (with permission).*

[29] http://www.mono-pumps.com/en-uk/webfm_send/2845 Documented in the Screening for Intake and Outfalls: a best practice guide Science Report SC030231 – Environment Agency 2005.

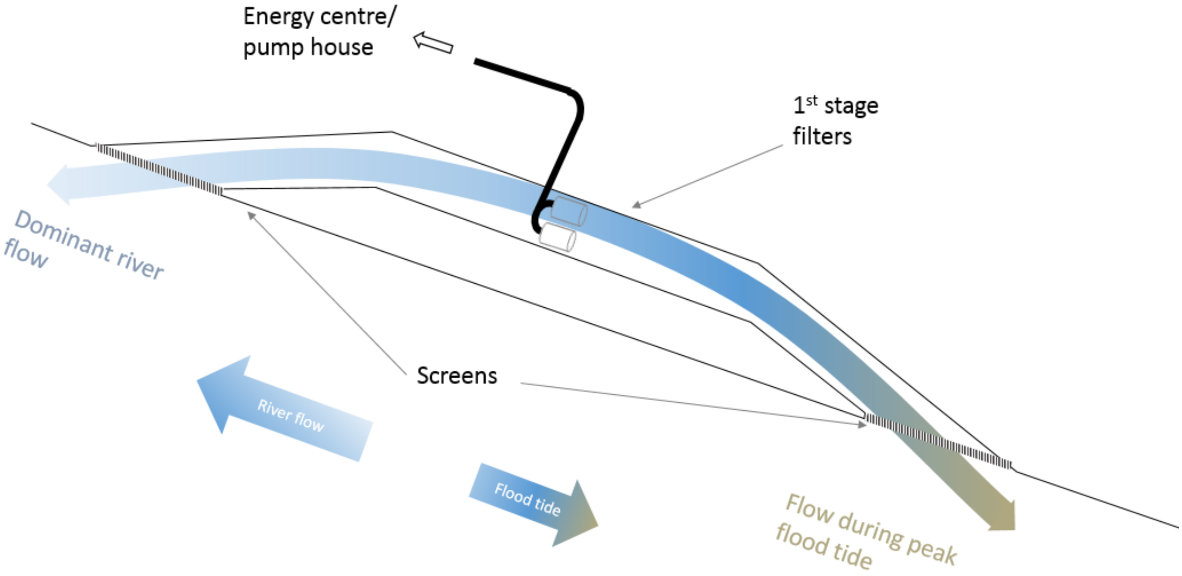


Fig 16 A conceptual diagram of the inlet required for filtering water abstraction. *The inlet allows through flow of water during normal river flow and at flood tide when the river flow reverses. This will need more detailed modelling but is suggested this way to allow adequate flow for removal of silt in the channel that may otherwise build up from backwash of the 1st stage filters. More detailed design stage modelling may mean that the screens may not be necessary if sufficient through flow is possible to prevent debris build up within the inlet.*

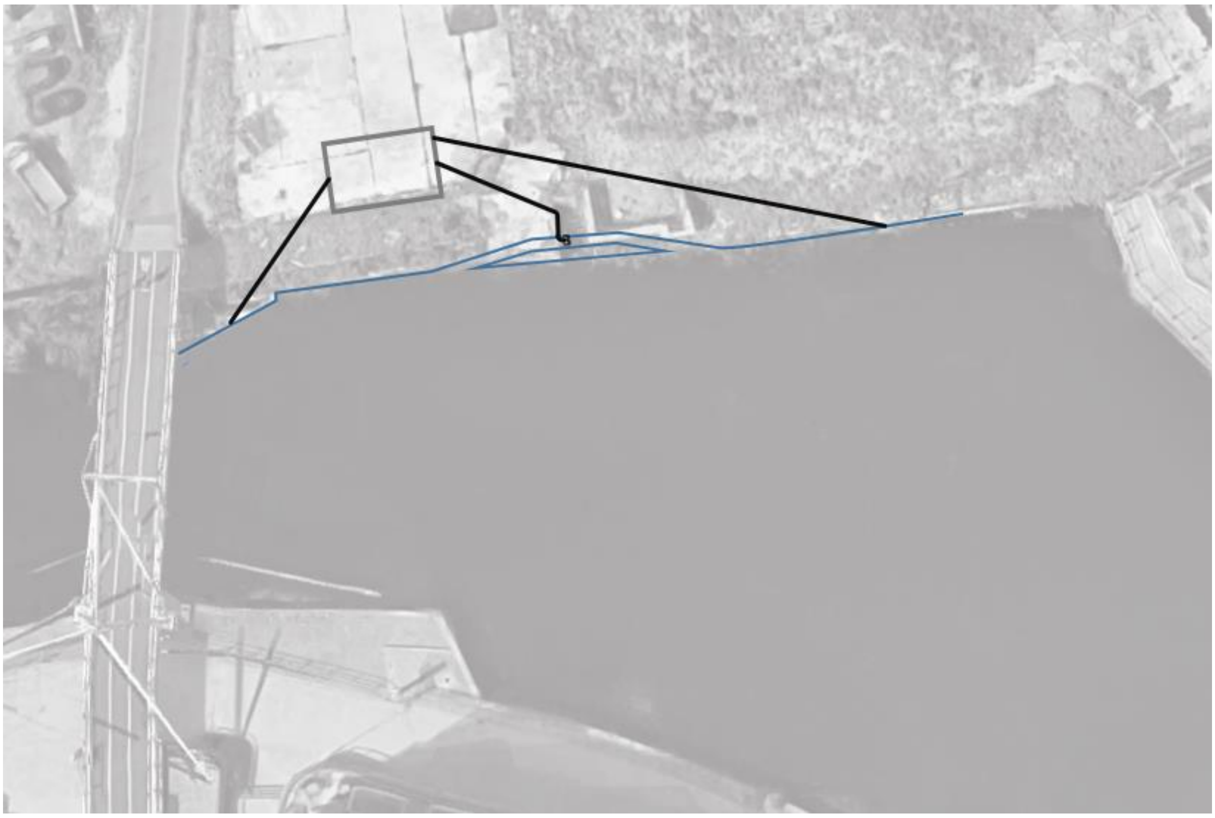


Fig 17 Location of the conceptual inlet and filters with respect to the proposed energy centre *(not to scale). Due to flood tide periods reversing river flow direction an alternative discharge point (longer pipeline on the right) may be required during these periods to prevent risk of crossover flow (cooler discharge water being abstracted by pumps).* ***Photo background image: Google Imagery © 2016 and Google Map data © 2016.***

Filtration

04.33 From research into the filtration requirements of the WSHP system employed at Kingston Heights[30] two stages of filtration are required to prevent biofouling and fines compromising the effectiveness of the heat exchangers. The indicative costs and specification have been obtained from the same company that supplied Kingston Heights, but with regard to the pumping flows specified for this assessment.

04.34 The filtration will take place in two stages with the first stage placed in the existing inlet. A channel is proposed that will allow flow from the existing inlet to secondary screens of the 1st stage filtering. Two drum filters are proposed that will screen to EA regulations and are self-cleaning via a pumped recycling configuration (Fig 18).

04.35 The second stage filtering (Fig 19) will be positioned in the plant room. This will also be self-cleaning with a drain required to return backwash water to the river. This filter will remove debris down to 200 microns ensuring a sufficient level of protection to the plate heat exchangers positioned within the plant room. This is essential for prevention of premature fouling heat of exchanger surfaces to maintain their effectiveness.

Pumping set

04.36 The water will be pumped via a booster set comprising of 4 centrifugal pumps having the configuration: duty/assist/assist/standby to supply a maximum design flow of 172 m^3 per hour at 25m head. The sets with on-board inverter have been designed and manufactured to meet the constant pressure requirements of modern system engineering solutions. The maximum daily abstraction is estimated to be 2,800 m^3 during times of highest demand (winter).

04.37 The constant pressure adjustment is a requirement as the heat pump system contains 22 compressors (2 for each unit) therefore the system has a modulation capacity starting from 4.54%. Differently from traditional fixed speed pumps, inverter driven pumps give the possibility to adapt the performance curve to the needs of the system.

04.38 In most cases, inverter driven pumps are used to maintain constant pressure in the system against variations in the requested flow rate, avoiding pressure fluctuations caused by small flow rate variations.

04.39 The discharge of the cooled water back into the river will require a linear diffuser placed below the water level to prevent freezing and also ensure high dispersal at low velocities. The design of this will need further agreement with the Environment Agency at the design/discharge application stage.

[30] http://www.cibse.org/knowledge/case-studies/cibse-case-study-kingston-heights

Fig 18 Example of 1st stage filtering configuration *(Image provided by Amiad Corp).*

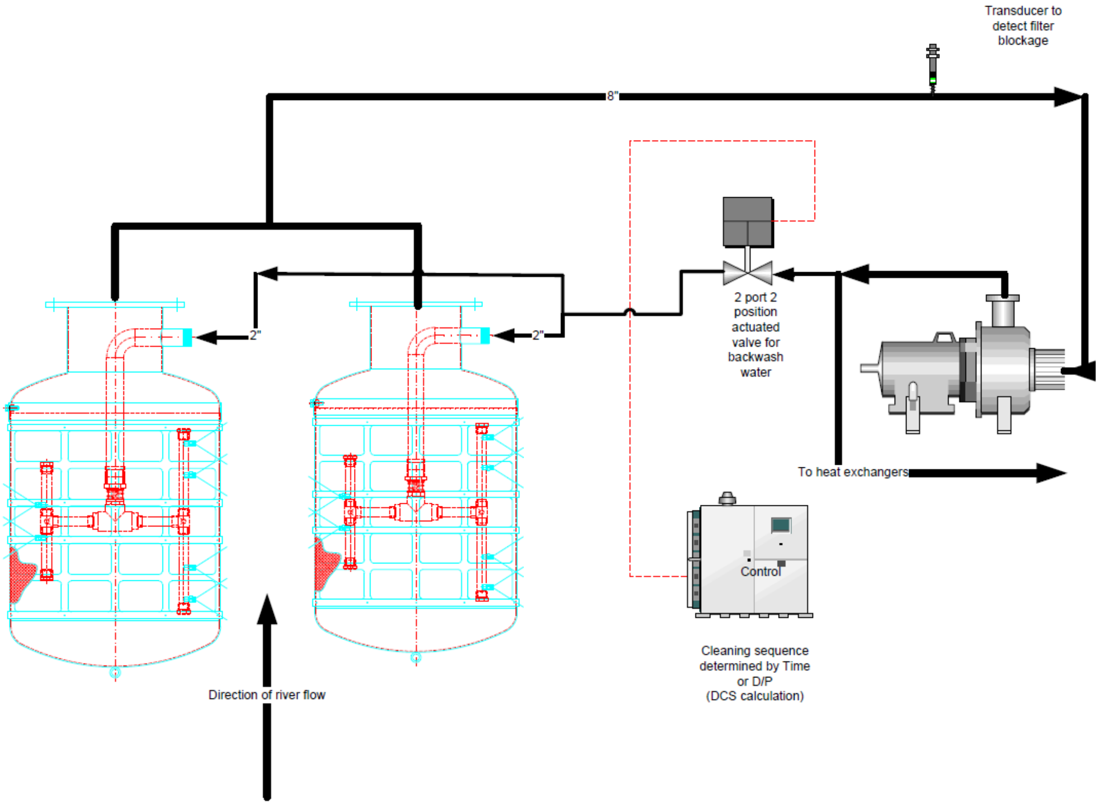


Fig 19 Example of the 2nd stage filter system *(image and text provided by Amiad Corp)*

How the SAF Filters work

General

The Amiad SAF Series are sophisticated, yet easy-to-operate, automatic filters, with a self-cleaning mechanism driven by an electric motor.
The "SAF" filters support flow-rates of up to 400 m³/h (1760 gpm), with various screens designed to cover a range of 800-10 micron filtration degree, and are available in inlet/outlet diameters of 2"-10".

The Filtering Process

Raw water enters the filter inlet (1) through the coarse screen (2) which protects the cleaning mechanism from large debris. The water passes through the fine screen (3), trapping dirt particles which accumulate inside the filter. Clean water flows through the filter outlet (4).
The gradual dirt buildup on the inner screen surface causes a filter cake to develop, with a corresponding increase in the pressure differential across the screen. A pressure differential switch senses the increased pressure differential and when it reaches a pre-set value, the cleaning process begins.

The Self-Cleaning Process

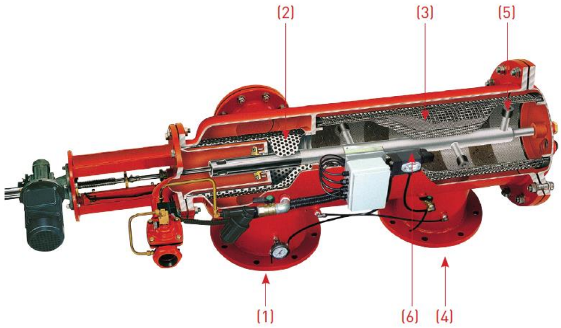
Cleaning of the filter is carried out by the suction scanner (5) which spirals across the screen; the open exhaust valve creates a high velocity suction stream at the nozzles tip which "vacuums" the filter cake from the screen. During the self-cleaning process, which takes between 20 to 40 seconds, filtered water continues to flow downstream.

The Control System

Two types of control boards are available for the SAF filters: PLC or Electro-Mechanical Relay and Timer.

The self-cleaning cycle begins under any one of the following conditions:
1. Receiving a signal from the Pressure Differential Switch (6)
2. Time interval parameter set at the control board
3. Manual Start

The control board also provides:
Optional continuous flush operation mode
Flush cycles counter
Alarm or an alternative reaction at malfunction mode; open a bypass, shut-off a pump, etc.



System efficiencies

04.40 The efficiency of the whole system will be a significant factor for revenue since the amount of energy lost from generation, storage and distribution is not eligible for RHI payment.

04.41 The conceptual system assumes the heat pumps operate with a coefficient of performance (COP) of 3.1 and a Seasonal Coefficient of performance (SCOP) of 2.85. This is based on water temperatures from the river of 5 °C with a 2 degrees water temperature differential between heat exchanger intake and discharge for a maximum flow of 172m^3 per hour.

04.42 If only lower volumes than 172 m^3 per hour can be consented for licence by regulatory authorities then the heat network would have to rely on the back up gas heating system to supplement the short fall. Further consultation with the Environment Agency will be required to ascertain acceptable extraction rates, whether these are an annual, daily or even seasonal.

04.43 The COP of heat pumps is directly affected by water temperatures, an increase in water temperatures will increase efficiency, but a drop in temperatures will stop the viability of heat pump use.

04.44 The system limit has been calculated based on a 5°C minimum water temperature and a 3°C discharge. This is due to the thermal limits of heat exchanger operation. This limit is also outlined in the Surface Water Source Heat Pumps Code of Practice[31].

04.45 With a centralised plant area and a distribution system that has been designed for flow temperatures of 55°C this also allows for other heat sources to be considered in the future.

Metering

04.46 The Renewable Heat Incentive (RHI) is a Government scheme providing additional tariffs for heat pump installations based on the amount of renewable heat generated and distributed.

04.47 The HIU approach allows RHI and heat sales revenue to be based on metering at each dwelling. Depending on government policy and OFGEM additional metering may be required at the heat pumps, gas boilers and the heat network delivery point to comply with, and obtain payments from, the renewable heat incentive scheme.

04.48 A metering scheme is at present the method used for payments. In the future this may be deemed, from property heat loads. The Government will be changing the scheme in the coming years and is currently undergoing a consultation on this with industry.

[31] Surface Water Source Heat Pumps: Code of Practice for the UK. Harnessing energy from the sea, rivers, canals and lakes. Chartered Institution of Building Services Engineers (CIBSE), the Heat Pump Association (HPA) and the Ground Source Heat Pump Association (GSHPA). www.cibse.org

Indicative costs

Capital costs

04.49 Capital outlay costs for the hardware have been obtained from suppliers (Table 7). As this is a conceptual feasibility study the figures are to be used as a guide only. The details of capital and maintenance costs are provided in the spreadsheet model that accompanies this report.

04.50 Some suppliers have based costs on guide specifications, others have provided quotes based on past installations, and others are expected costs which will need further consultation with contractors connected to the development.

Operation and maintenance costs

Maintenance costs are presented in Table 8. These figures are based on the system running with all residential blocks of flats in operation. The proposed build scheme is phased with different blocks of flats being completed and occupied at various stages. The operational costs are presented in section 06 Financial assessment and review of business models

04.51 The main equipment will be in operation from the time of commissioning and testing even if only one dwelling is occupied. It is therefore proposed that costs begin from the first day of operation. As the system ages, operational costs will increase. Therefore upgrades and system life expectancy for individual items have been accounted for with this in view.

04.52 There will undoubtedly be improvements to products which may decrease maintenance costs with any subsequent upgrade. No allowances for maintenance are included for individual dwellings as the heat network will finish at the heat interface unit positioned at each dwelling.

Simple paybacks on investment

04.53 Table 9 provides simple paybacks using two different examples of heat sale prices. District heat sales prices have been surveyed in a recent (2015) consumer report[32]. These varied from equivalent unit prices from 5.5 to just under 15 pence per kWh, with an average equivalent of 11 pence per kWh. These unit figures incorporate fixed charges (which were on average 38% of the total annual costs).

04.54 Table 9 shows an indicative example using LOW (best case) and HIGH (worst case) prices for public/commercial sector utility costs published by DECC for appraisal. The heat sales price (5.5 p/kWh) is used in the worst case example of a social heat network application such has a housing association scheme. The best case example uses the lower residential utility cost based on DECC's utility cost projections but with a more commercial heat sale price of 10p per kWh. A 10p/kWh unit price is considered by Which? to be competitive with the costs of installing, using and maintaining a modern gas condensing boiler in a modern two bedroom flat levelised over its lifetime and incorporated into the unit cost of heat used.

04.55 Automated screens had been specified to reduce the assumed likely higher costs of manual cleaning required for static screens, which can risk being overlooked and compromise the heat pump system. Further detailed specialist hydro engineers would be required to model the need for screening for the channel. To indicate the paybacks without the channel screening requirement their capital and running costs have been removed from Table 10 for comparison with Table 9. This shows an impact on the payback of around 0.1 - 0.5 years depending on electricity cost.

[32] November 2013 and March 2014 Which? collected price information on 51 community heat schemes representing 36,000 unmetered households and around 51,000 metered households. The networks were operated by 22 different heat suppliers and varied in age. Schemes were spread across the UK but with the majority (33) being in London. Around two thirds of the properties were social or affordable housing in addition to an increasing number of new build networks connected to private properties.

Table 7 Indicative WSHP capital costs from suppliers and expected estimates (St. Anne's Quarter)

Heat Pumps and heat exchange	Total	£291,342
Heat pumps	11 x CRHV-P600YA-HPB 60kw HP	£183,150
Heat exchangers	22 x Plex 322 - 40 (heat exchangers)	£39,292
Circulation pump	11 x wilo yonos maxo 50/0.5-9	£9,900
	Electrical Works for plant room	£24,000
	Labour	£25,000
	UKPN- Electrical main for HP Sys.	£10,000

Plant room ancillaries (HP + G)	Total	£42,037
Circulation pump	Wilo Stratos-D 80/1-12 1 phase twin head pump	£7,860
Hot water buffer vessels	2 x 5000l Buffers	£10,296
Expansion vessels	3 x 500l Expansion Vessels	£1,131
Lever valves	55 x 2" lever valve full bore	£2,750
	Materials & accessories	£20,000
	Labour	Included above

Screening (HP ONLY)	Total	£49,000
Self-cleaning rotary screen to prevent ingress from aquatic organisms and debris fouling water pump intake.	Rotary disc screen <2mm fish and aquatic debris barrier	£20,000
	Labour	£4,000
	Civil works	£25,000

Pumping + Filtering (HP ONLY)	Total	£120,649
Water pumps are a grouped set: (Duty/Assist/Assist/Standby). Pump design capacity 172 m³/h at 4 bar constant pressure. Metering for regulatory compliance. This includes diffuser for returned river water.	DAB 1 x 4 NKVE 45/3 T	£26,349
	1st and 2nd stage filtering	£80,000
	Cold water meter 6"	£1,300
	Materials & accessories	£10,000
	Labour	£3,000

Plant Room/Energy Centre (HP + G)	Total	£160,000
	Bunker- 100 sqm area (14mx7m)	£160,000

Gas boilers (HP + G)	Total	£68,265
Specified for the gas counterfactual and also as peaking plant for the heat pump system	5 x 120kW Vaillant Condensing Boilers	£18,265
	Materials & accessories	£15,000
	Gas Connection	£30,000
	Labour	£5,000

Heating Network Opt 1 (HP + G)	Total	£1,223,936
This is the option costed here for use in section 06	Uponor EcoFlex Thermo 110/200 x 900m	£105,561
	EcoFlex Chamber x 15	£17,520
	Uponor EcoFlex Thermo 90/200 x 400m	£39,396
	Uponor EcoFlex Thermo 2 x63/200 x 1000m	£103,050
	Civil @£60/m	£27,000
	HIU x 437	£623,424
	HIU installation	£131,100
	Heat meters x 437	£107,065
	Data logger 256 entries and GPRS modem x 25	£69,820

Table 8 Indicative maintenance frequencies and associated costs (annualised)

		Qty	Maintenance Frequency times/year	Price / unit		Annualised maintenance costs	
Heat pumps and exchangers	11 x CRHV-P600YA-HPB 60kw HP	11	1	£	200	£	2,200
	22 x Plex 322 - 40 (heat exchangers)	22	1	£	50	£	1,100
	11 x wilo yonos maxo 50/0.5-9	11	0.5	£	50	£	275
Plant room ancillaries	Wilo Stratos-D 80/1-12 1 phase twin head pump	1	1	£	100	£	100
	2 x 5000l Buffers	2	0.2	£	300	£	120
	3 x 500l Expansion Vessels	3	1	£	100	£	300
Pumping + Filtering	1 x 4 NKVE 45/3 T (DAB Pumping group) (Duty/Assist/Assist	1	2	£	250	£	500
	1st stage filtering	1	2	£	250	£	500
	2nd stage filtering	1	2	£	250	£	500
	Cold water meter 6"	1	0.5	£	100	£	50
Screening System	Rotary disc screen <2mm fish/debris barrier	1	2	£	450	£	900
Gas boilers	5 x 120kW Vaillant Condensing Boilers	5	1	£	150	£	750
Heating Network Opt 1	Uponor EcoFlex Thermo 110/200 x 900m	900	0			£	-
	EcoFlex Chamber x 15	15	0			£	-
	Uponor EcoFlex Thermo 90/200 x 400m	400	0			£	-
	Uponor EcoFlex Thermo 2 x63/200 x 1000m	1000	0			£	-
This is the option used in the financial model. Reasons are given for this in section 04 of the report.	HIU x 437	437	0.33	£	20	£	2,884
	Heat meters x 437	437	0			£	-
	Data loger 256 entries x 25	25	1	£	20	£	500
	GPRS MODEM for data logger x 25	25	1	£	10	£	250
Heating Network Opt 2	Uponor EcoFlex Thermo 125/200 x 450m	450	0	£	-	£	-
	Uponor EcoFlex Thermo 110/200 x 200m	200	0	£	-	£	-
	EcoFlex Chamber x 15	15	0	£	-	£	-
	Uponor EcoFlex Thermo 90/200 x 400m	400	0	£	-	£	-
	Uponor EcoFlex Thermo 2 x63/200 x 1000m	1000	0	£	-	£	-
	HIU x 437	437	0.33	£	20	£	2,884
	Heat meters x 437	437	0			£	-
	Data logger 256 entries x 25	25	1	£	20	£	500
	GPRS MODEM for data logger x25	25	1	£	10	£	250

Table 9 Simple paybacks for St. Anne's Quarter WSHP including the screening system

Water Source Heat Pump Heat Network			**Natural Gas Heat Network**	
Utility price and heat charge scenario:	**Best**	**Worse**	**Best**	**Worse**
Electricity price* /kWh	**£0.097**	**£0.118**	**£0.097**	**£0.118**
Gas price* /kWh	**£0.021**	**£0.031**	**£0.021**	**£0.031**
Example heat sale price /kWh	**£0.10**	**£0.055**	**£0.10**	**£0.055**
Heating plant capacity kW	605	605	600	600
Annual heating energy requirement of the property kWh	2,232,150	2,232,150	2,232,150	2,232,150
Heat network annual losses kWh	134,000	134,000	134,000	134,000
Seasonal COP/ efficiency	286%	286%	90%	90%
Annual electricity consumption of the heat pumps	763,280	763,280	-	-
Heat network parasitic electricity kWh	47,320	47,320	47,320	47,320
Annual electricity consumption of water pumps kWh	60,610	60,610	-	-
Annual electricity consumption of the screening system	9,640	9,640	-	-
Gas consumption kWh (HP - peak periods -10C to -2C)	148,460	148,460	2,629,060	2,629,060
Annual cost of electricity	-£85,350	-£103,890	-£4,580	-£5,580
Annual cost of natural gas	-£3,180	-£4,620	-£56,260	-£81,840
Annual RHI income (first 20 yrs only)	£105,960	£105,960	-	-
Heat sales income	£223,215	£122,768	£223,215	£122,768
OPEX levelised/yr	-£10,930	-£10,930	-£4,900	-£4,900
REPEX/yr levelised over 25 (40)yrs	*ignored*	*ignored*	*ignored*	*ignored*
Annual Net income	£229,715	£109,288	£157,475	£30,448
CAPEX	£1,955,230	£1,955,230	£1,494,238	£1,494,239
Simple payback	**8.5 years**	**17.9 years**	**9.5 years**	**49.1 years**

*DECC utility price projections for project appraisal Sept 2015.

Table 10 Simple payback of St. Anne's Quarter WSHP excluding the screening system

Water Source Heat Pump Heat Network			**Natural Gas Heat Network**	
Utility price and heat charge scenario:	**Best**	**Worse**	**Best**	**Worse**
Electricity price* /kWh	**£0.097**	**£0.118**	**£0.097**	**£0.118**
Gas price* /kWh	**£0.021**	**£0.031**	**£0.021**	**£0.031**
Example heat sale price /kWh	**£0.10**	**£0.055**	**£0.10**	**£0.055**
Heating plant capacity kW	605	605	600	600
Annual heating energy requirement of the property kWh	2,232,150	2,232,150	2,232,150	2,232,150
Heat network annual losses kWh	134,000	134,000	134,000	134,000
Seasonal COP/ efficiency	286%	286%	90%	90%
Annual electricity consumption of the heat pumps	763,280	763,280	-	-
Heat network parasitic electricity kWh	47,320	47,320	47,320	47,320
Annual electricity consumption of water pumps kWh	60,610	60,610	-	-
Annual electricity consumption of the screening system	-	-	-	-
Gas consumption kWh (HP - peak periods -10C to -2C)	148,460	148,460	2,629,060	2,629,060
Annual cost of electricity	-£84,410	-£102,750	-£4,580	-£5,580
Annual cost of natural gas	-£3,180	-£4,620	-£56,260	-£81,840
Annual RHI income (first 20 yrs only)	£105,960	£105,960	-	-
Heat sales income	£223,215	£122,768	£223,215	£122,768
OPEX levelised/yr	**-£10,030**	**-£10,030**	**-£4,900**	**-£4,900**
REPEX/yr levelised over 25 (40)yrs	*ignored*	*ignored*	*ignored*	*ignored*
Annual Net income	**£231,555**	**£111,328**	**£157,475**	**£30,448**
CAPEX	**£1,935,230**	**£1,935,230**	**£1,494,238**	**£1,494,239**
Simple payback	**8.4 years**	**17.4 years**	**9.5 years**	**49.1 years**

*2016 DECC utility price projections for project appraisal Sept 2015 (Latest publication at time of report).

Concluding remarks

04.56 Using the example combinations of utility costs and heat sale prices given in table 10 indicates that both the social and commercial heat sale prices from WSHP have a better simple payback than the counterfactual scenario using condensing gas boilers to supply a heat network, although the annual carbon emissions are marginally greater for WSHP due to 2015 grid electricity emissions being nearly three times that of gas per kWh.

04.57 The impact of the addition of screening, by comparing Table 9 and Table 10, indicates a loss in net income (differing with unit electricity costs used) of £1,700 - £2,400 due to annual maintenance and running costs. This reduces the simple payback by just under half a year. Also removing the electricity required for running the screens would make the annual carbon dioxide running emissions comparable to the gas boiler counterfactual scenario.

04.58 The simple paybacks shown in Table 9 and Table 10 are sensitive to the unit cost of electricity and gas and the heat sale unit price. Making conclusions on whether the WSHP system is feasible, or more competitive than the counterfactual is therefore highly dependent on these variables, and would reflect on whether investors would be able to access similar utility prices over the lifetime of the project, in addition to accessing the market for heat at these sales prices.

04.59 If commercial investors conduct energy procurement that accesses larger group framework purchase agreements to allow utilities to be bought at the price NCC has provided in combination with commercial heat sale prices of 10 pence per kWh (rather than the more social heat sales prices or 5.5 pence per kWh) then the WSHP simple payback period could be reduced further to 8 years.

04.60 The RHI income and utility cost are therefore key factors in making WSHP competitive with gas boilers in these scenarios. More detailed financial modelling of cash flows over longer project terms including the cost of replacing capital (REPEX) is given for St. Anne's Quarter in section 06. The model is not directly comparable with the heat sale prices used in these simple paybacks, since Section 06 has split out unit price and separate fixed service charge.

04.61 Increasing the allowable differential from 2°C to 3°C or more, for the same heat demand would theoretically allow a lower pumping volume of water required. As an example estimate, an increase in differential from 2 to 5°C may drop the water pumping duty by approximately 20%, which would reduce the river pumping electricity costs for the St. Anne's Quarter case study by 1.4% or around £1,000-£2,000 per year with minimal financial impact.

04.62 This estimate assumes reduced pumping duty can be applied during summer (weeks 18-40) when river water temperatures are likely to be >8°C to allow a 5°C differential. This coincides with hot water demand as the main heat pump duty. To estimate the potential for pumping duty reductions throughout the whole of the year would require further qualification through modelling and access to representative daily river water temperature data.

04.63 Increasing the differential for the St. Anne's Quarter case study without reducing the pumping volume would increase the available heat. However this would require additional investment in the number of heat pumps to cope with the increased capacity. This could allow an increase in the heat network capacity but plant room size and pumping would be required to be resized and reconfigured and re-costed accordingly in order to ascertain the difference in financial impact of expansion.

Case study 2 - retrofit of St James House

04.64 St James House was identified as a possible suitable case study with interest from NCC in applications for retrofitting to council owned social residential buildings. It is a building with 34 flats used as sheltered homes.

04.65 The former building heat load has been used as an example only for retrofit applied to existing building stock for a non-commercial application. The actual application of a surface water source heat pump to this particular building is considered unlikely given:

1. The property has been refurbished very recently, but largely cosmetically, décor and furnishings but this case study may not applicable for the building heat demand if significant changes are made to the thermal performance of the building fabric.

2. The property is located 375 metres from the river with much of this identified as private land. To route water pipework for river abstraction across multiple roads and asphalt areas would be cost prohibitive.

04.66 However, assuming the building is in close proximity to the river, it is a useful example for demonstrating the viability of a surface water heat pump for retrofit applications to older buildings, which typically have higher heat relative demands from inefficient fabric and social occupancy.

Heat loads

04.67 The heat load of this development has been estimated as approximately 80 kW with an additional hot water load of 63 kW.

04.68 Unlike the approach to case study 1 based on theoretical heat losses, the space heating load has been based on historical heating demands from 6 years of metered energy use assuming a fixed proportion for hot water demand, (based on occupancy).

Hot water

04.69 To provide heat in line with a 55°C supply and following methods for hot water diversity factors (as outlined for St Anne's Quarter) the capacity of the heat pump system has been calculated to be 165 kW.

Water pumps

04.70 The building heat demand would require a total maximum flow of 422 m^3/day (max 48m^3/hour).The parasitic pump loads for delivering river water the 375m distance would require annual electricity consumption of 12,940 kWh compared to 6,760 kWh following the assumptions that the development is within 10 metres of the river (at 10 p/kWh this is just over £600 per year). As mentioned the prohibitive costs would be the pipe laying civil costs.

04.71 The indicative costs provided for this for this case study (Table 11) assume the heat is distributed through the development by the existing internal wet heating system and there is room inside the building for the plant room housing heat pumps and pumping sets.

04.72 The simple payback based on CAPEX and the gross revenue stream from only the RHI payments is shown in Table 12.

Table 11 Indicative capital costs for the St James House retrofit case study. *St James House is a 30 flat single social residential block with no external heat network*

Heat pumps and heat exchange	3 x CRHV-P600YA-HPB 60kw HP	£	49,950
	6 x Plex 322 - 40 (heat exchangers)	£	10,716
	3 x wilo yonos maxo 50/0.5-9	£	2,700
	2 x VPB 1000 DHW Cylinder	£	8,348
	1 x 3" Heat Meter	£	3,500
	Electrical Works for plant room	£	6,000
	Labour	£	7,500
	UKPN- Electrical main supply for HP Sys. - No Allowance	**No allowance**	
	Total	**£**	**88,714**
Gas boilers	2 x 80kW Vaillant Condensing Boilers	£	5,804
	Materials & accessories	£	3,000
	Gas Connection- Probably available on site	£	-
	Labour	£	2,000
	Total	**£**	**10,804**
Plant room ancillaries	Wilo Stratos-60/1-9 1 phase twin head pump	£	2,150
	1 x 2000L Cordivari buffer vessel -Nuenta	£	1,982
	1 x 200l Expansion Vessels	£	377
	Materials & accessories	£	6,000
	Total	**£**	**10,509**
Screening	Screening System	£	12,000
	Labour	£	4,000
	Civil works	£	25,000
	Total	**£**	**41,000**
Pumping + Filtering	1 x HYDRO MULTI-E 3 CME15-01 (Grundfos Pumping Group) (Duty/Assist/Standby: 48 m3/h @ 2 bar)	£	11,600
	1st stage filtering 2nd stage filtering	£	20,000
	Cold water meter 4"	£	1,100
	Materials & accessories	£	5,000
	Labour	£	3,000
	Total	**£**	**40,700**
Construction of the Plant Room	NO ALLOWANCES- Assumes existing building utility space	**£**	**-**
	Grand total	**£**	**191,727**

Table 12 Simple payback estimate for St James House *This shows a comparison between a WSHP installation a) next to the river with no automated screening, b) with screening and pumping duty and indicative costs for laying pipeline to the river, and the counterfactual – replacing with modern condensing gas boilers.*

	Water Source Heat Pump System		**Natural Gas Boiler System**
	a) next to river	**b) actual distance**	
NCC Electricity price /kWh	**£0.105**	**£0.105**	**£0.105**
NCC Gas price /kWh	**£0.0143**	**£0.0143**	**£0.0143**
Heating capacity kW	165	165	165
Annual heating energy requirement of the property kWh	252,182	252,182	252,182
Seasonal COP/ efficiency	286%	286%	90%
Annual electricity consumption of the heat pumps	81,349	81,349	-
Annual electricity consumption of water pumps	6,760	12,940	-
Annual electricity consumption of the screening system	-	9,636	-
Gas consumption kWh (HP peak periods -10C to -2C)	32,391	32,391	280,202.55
Annual cost of electricity	**-£9,968**	**-£11,629**	*negligible*
Annual cost of Natural Gas	**-£463**	**-£463**	**-£4,007**
Annual RHI income	**£20,349**	**£20,349**	-
Annual Net income	**£9,918**	**£8,257**	-
CAPEX	**£191,730**	**£217,980**	**£10,804**
Old system efficiency	**65%**	**65%**	**65%**
Old annual energy cost	**£5,548**	**£5,548**	**£5,548**
Annual benefit from old system	**£15,466**	**£13,805**	£1,541
Simple payback years	**12 years**	**15.8 years**	**7 years**

Concluding remarks

04.73 The heating of buildings via retrofitting a WSHP is more feasible if several other criteria can be met.

1. Willingness to upgrade the building fabric.
2. Willingness to upgrade the building heating system to suit a lower supply temperature.
3. Diversifying the source for suppling primary heat to the heat pumps. This may be the river, or bore holes.

04.74 Considering the last point, where limited improvement can be made for certain buildings (heritage status, listed status, or planning restriction) more complex and novel applications for transfer of heat between seasons and media may be possible.

04.75 Heat can be extracted from the river or cooling duties from other sources during summer, stored in boreholes or more novel thermal stores[33] for re-extraction by heat pumps to supply winter demand. These are primarily applied to new developments.

04.76 However, older buildings have applied water source heat pump technology such as:

- 18th Century Plas Newydd (marine application), a National Trust property in Anglesey[34]
- 15th Century Blicking Hall (closed loop lake application – delayed in progress), also a National Trust property in Norfolk[35]
- 15/16th Century Aberglasney House (closed loop pool), in Carmarthenshire, West Wales. The 60kW WSHP replaced LPG heating. Aberglasney Trust is a registered charity[36].
- 19th Century buildings in Regents Park are employing heat pumps to store and retrieve heat from each season[37]

04.77 None of these examples are directly applicable to the open source heat network application proposed for the river Wensum but demonstrate that older buildings have made a financial case, or otherwise, to replace off grid LPG or oil fired heating by employing heat pump systems.

[33] See http://www.icax.co.uk/Borehole_Thermal_Energy_Storage.html and http://www.icax.co.uk/thermalbank.html

[34] http://www.nationaltrust.org.uk/features/plas-newydd-mansion

[35] https://www.nationaltrust.org.uk/blickling-estate/features/leading-the-way-in-renewable-energy

[36] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/348012/DECC_Aberglasney_House_NonDom_case_study.pdf

[37] http://www.icax.co.uk/Cambridge_Terrace_NW1.html

Passivhaus heating

04.78 It is feasible to use both heat pumps and heat network to supply heating and hot water using HIU units with a 55°C constant temperature supply to cover hot water production requirements of a Passivhaus standard scheme.

04.79 However, in Passivhaus standard buildings the space heating demand would be a relatively smaller component of heat demand affecting the revenue from heat sales and RHI tariff and attractiveness for commercial investment. Passivhaus would not reduce the hot water component of heat demand and therefore necessitate a 55°C flow temperature.

04.80 If hot water is produced at each dwelling via another source the RHI income will be lower still. Even then with low flows and reduced temperature lift possible to achieve a comfortable living environment it is unlikely that the scaling of pipe sizing of a heat network would reduce costs in proportion to the lower heat revenues.

04.81 As part of this study developers had been contacted regarding a proposed block of residential flats (Carrow Quay). The development planned had been reported to meet Passivhaus standards. Consideration had been reported to have been given to heat network options with renewable technology but an appraisal had shown this to be unviable.

04.82 The appraisal information was not shared but this anecdotally indicates that options for heat pump sourced heat networks for designs meeting low energy demand standards may not provide sufficient benefits to be attractive to developers for the additional capital outlay required for installing heat networks.

04.83 Detailed technical and financial modelling for specification of heat pumps dedicated to single buildings appropriate to the lower (temperature) heat demands of Passivhaus would be required to make any conclusions on how this would affect viability of river source heat pump applications for Passivhaus in general.

05 Connections to wider district heat networks

05.1 This task is to explore the feasibility of linking buildings onto a larger scale district heat network (DHN) in conjunction with using the river to supply heat pumps.

05.2 Appropriate heat exchangers can be specified for differences in temperatures and pressure between the two networks heat main flow to allow a city wide high grade heat network (such has proposed for the Generation Park development) to be utilised by smaller heat networks and heat pump systems defined in part 04 of this report. However there are a number of key constraints.

Key constraints

05.3 Larger heat networks typically would charge on a cost of connection on a per dwelling basis (see section 06). So the feasibility of linking to larger networks would be driven by cost of connections compared to the cost of an onsite dedicated heat source, how heat is sold to dwellings and how much profit is made.

05.4 The typical model of applying a cost of connection to a larger DHN, unless other atypical arrangements can be negotiated, could limit the financial case for connection if district heat was supplied to only cover a proportion of the demand for peaking, in the case where heat pumps were still used to cover the main heating duties. Access routes for pipes may be privately owned and there could be major roads to cross for a number of routing options.

05.5 Anchor loads, (substantial baseload demands), are critical to the development and routing of a larger scale district heating systems. So cost of connection would be likely be related to the proximity to DHN routes towards larger anchor loads.

05.6 If the issues of land ownership and financial constraints are overcome then several routes for connection to a larger district heat main could be envisaged. These are purely indicative and use the heat loads identified in the GIS mapping described for section 02 of this report. The detailed national heat map data described in section 02 was intended for this purpose and has been placed in a GIS for aiding this process.

05.7 Several potential routes are shown (Fig 20 to Fig 22) for linking St Anne's Quarter to a DHN from a large biomass CHP installation awaiting planning approval and investment on a site to the South East of the city. The DHN route had been proposed by Camco and Poyry in a 2011 study mapping heat loads for potential City wide DHN[38].

05.8 The blue route is much shorter distance but requires routing beneath the river which is likely to be costly and could be disruptive to the riverside complex. This would avoid issues with heritage sites on the West bank of the river, for that reason the green King St route avoids passing the Dragon Hall.

05.9 The justification to route district heating near to St Anne's would likely require that it is on route towards other anchor loads. The only key load following from either of the links indicated (Fig 22 blue and green lines) in the general north westerly direction is probably Castle Mall and then perhaps further west into St Stephens larger retailers and the Chapelfield shopping precinct.

05.10 However this route through King St. and disruption of busy roads toward the top end of Prince of Wales Road would probably prohibit these options. Camco's preferred route to the anchor loads in the West of the City accesses this via the side of the A147 but also with an under river crossing, partly justified by the potential heat load from the Deal ground development.

[38] Phillips, Bethan (2011) Norwich District Energy Study- Objective 1 Report: Heat Mapping and District Heating Viability. Camco & Pöyry Energy.

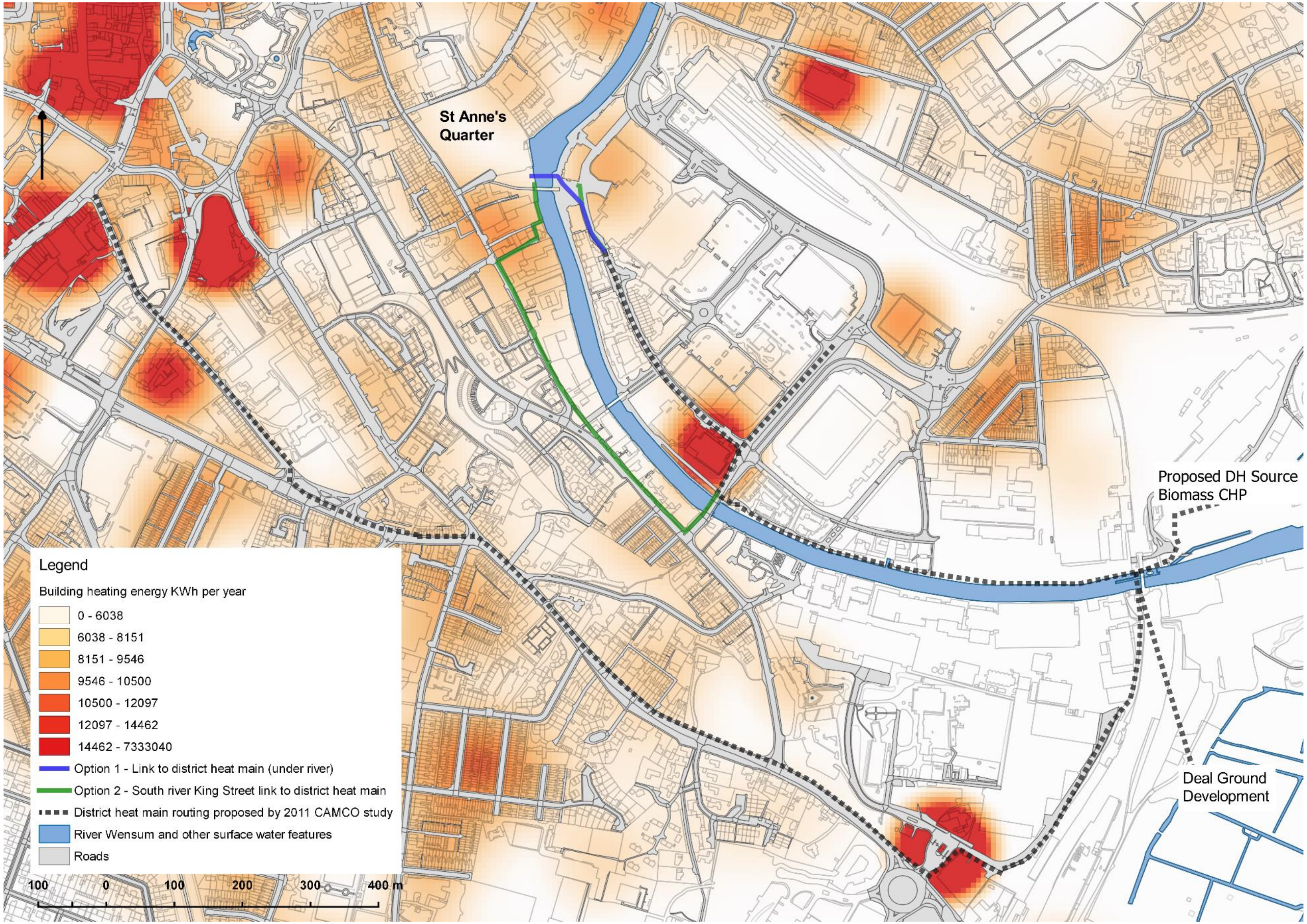


Fig 20 Heat map data for the area around St. Anne's Quarter showing links to DHN proposed by CAMCO.

There are a number of reasonably large apartment blocks and residential flats to parallel to King St bordering the river which could also be possible DHN customers.

The green route would require the DHN to cross the Carrow road bridge (A147) and then North West along King St

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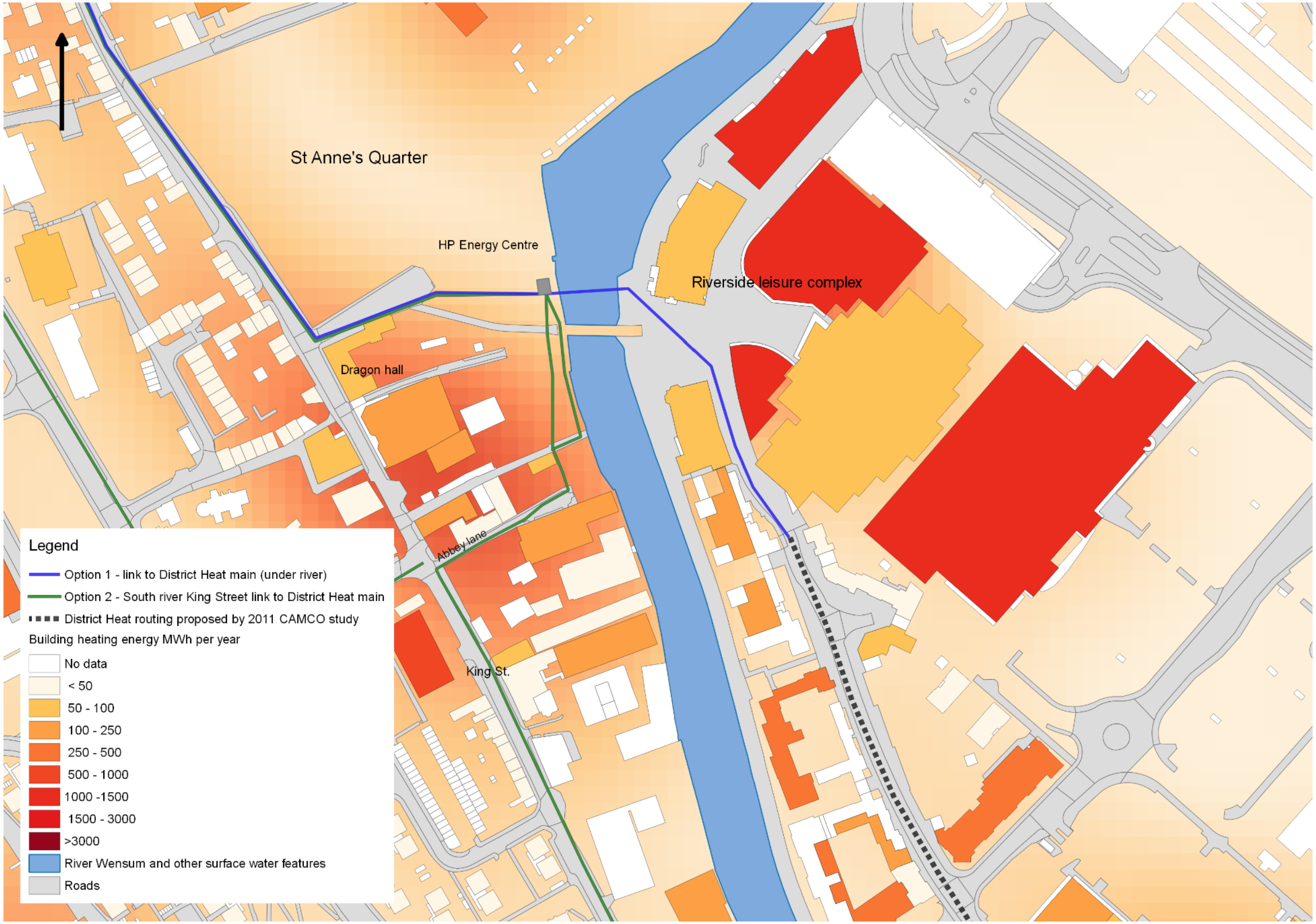


Fig 21 Larger scale exploration of DHN links to St. Anne's Quarter

The two routes from Abbey Lane are shown. One of these crosses a concrete apron which is used as a carpark for a car sales/garage business.

The other route avoids this but risks being routed under the bridge which may be restricted or unfeasible due to height limits or the bridge's engineering.

It maybe that reasonable measures can be taken to ensure no impacts to the Dragon Hall and Howards House will occur from installing and long term use DH pipework

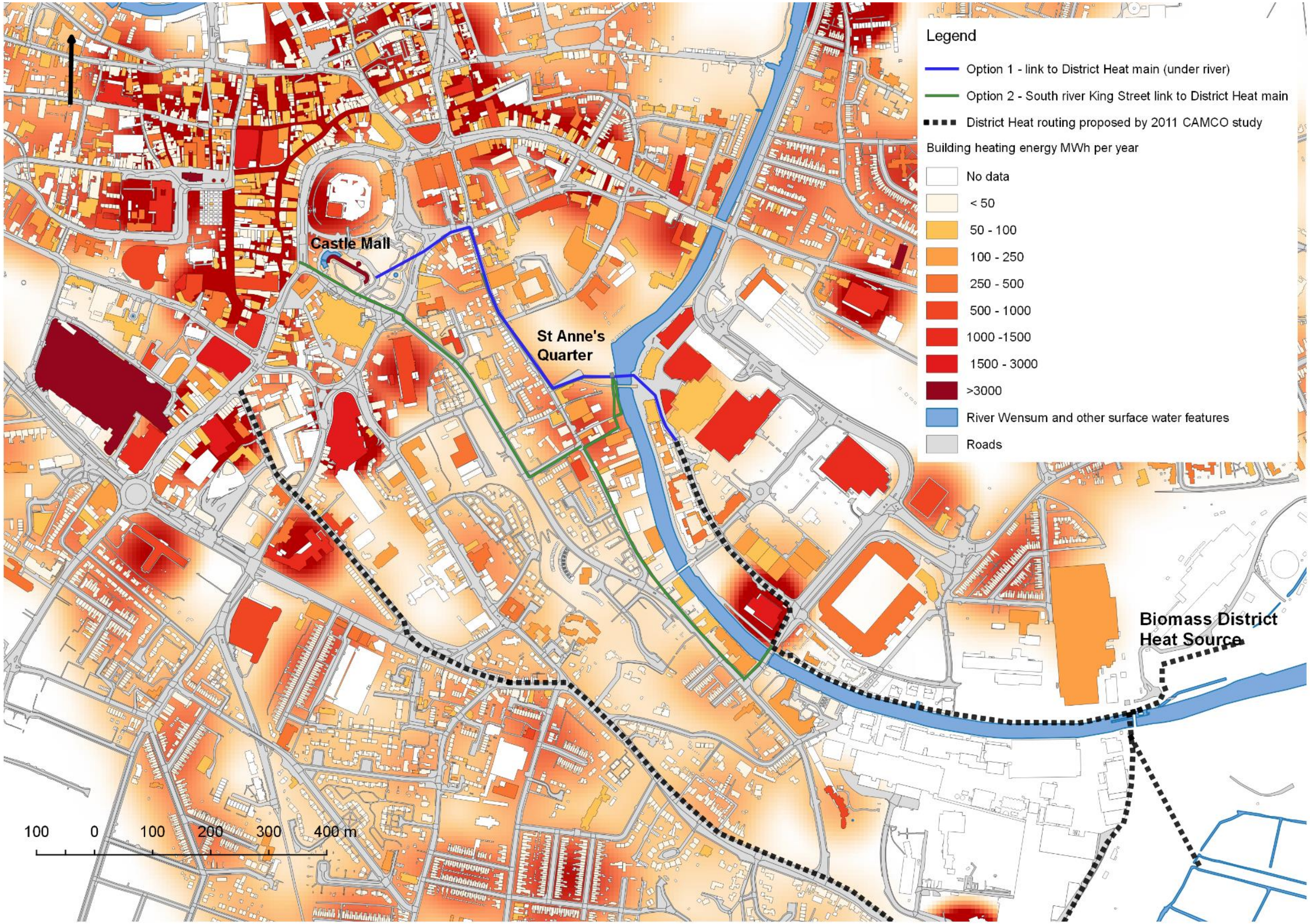
Fig 22 Smaller scale 1:8,500 view showing the broad direction of the (blue and green) routes explored.

The route can be observed with regards to other key 'anchor' heat loads in the City.

A more circuitous routing through high traffic roads is needed to link St Anne's Quarter with the Biomass DHN and then through to Castle Mall heat load and further West to other larger heat loads.

For the King St. route the key obstacles are the residences and a church to the on the West side of the road preventing any routing through to Rouen road and West to St Stephens St. and Chapelfield heat loads

The low heat loads along the routes explored also do not support this direction. Though the heat map data coverage is not considere to be of high quality.



Concluding remarks

05.11 Assuming that Camco's 2011 proposals are the most likely routes for a larger DHN from the biomass site to the heat anchor loads then it appears that linking to these from East under the river or as a new 1km spur taken from a crossing at Carrow Road Bridge would be very unlikely with regard to provision of heat for peaking loads. It is considered unlikely for supplying all of St Anne's Quarter's heat demand.

05.12 From a system perspective, if a larger heat capacity was available from the river via WSHP's to contribute to a DHN, greater efficiency gains would be achieved from heat being utilised where the lowest temperatures in the larger DHN are. These would likely be down river at the biomass power where the return temperatures to larger biomass DHN energy centre. This is because, in principle, at the lowest temperature lift the heat pump compressors would require the least work.

05.13 Contributing heat from a river source heat pump to a larger DHN, as was probably envisaged from the initial premise of the study question may now be constrained by regulatory uncertainty on the discharge temperature and volume limits *at the time of this assessment*.

05.14 As outlined in Section 01 the potential of 4MW exploitable heat capacity of the river outlined by the DECC surface water heat map could only be realised if the whole winter Q95 river flow could be lowered in temperature by an average of 0.5 degrees. At a 2°C differential approximately 25% of the Q95 winter flow would be required to be pumped through heat exchangers. At a 4°C differential the volume required would be halved but the winter river temperature may mean a 4 °C or greater differential is less available over the colder periods when peak heat demand occurs, impacting on the economic case. *In conclusion more river temperature data, representative of average winter conditions would be required to quantify this along with regulatory guidance on permitted discharge volumes.*

05.15 The greater discharge volumes and temperatures required to meet the 4MW capacity above are considered unlikely to be feasible given regulatory caution. This is reflected in the strict consent limits of 3 °C differential and discharge volume of 0.2% of the average river flow issued by the regulators for the only other river scheme in the UK on the Thames at Kingston. This stretch of the River Thames has an average river flow nearly 15 times that of the River Wensum. For comparison 0.2% of the River Wensum average flow is approximately 800 m^3/day, within the standard rules for heat exchanger permits.

05.16 If district heat was *supplied* to the WSHP scheme only to cover a proportion of the demand for peaking, in the case where heat pumps were still used to cover the main heating duties, connection charges typical for larger DHN schemes may make this unviable. However, if the WSHP scheme was developed by the operator of the city wide DHN, waiving connection costs, then this may be viable.

06 Financial assessment and review of business models

Financial model

06.1 A simple discounted cash flow financial model has been produced for St. Anne's Quarter, the larger of the two case studies. This has been used due to the quality of information and the requirement for this assessment at a conceptual level to be applicable to new developments.

06.2 The model costs are in real terms 2015/16 (no inflation) and net present value and internal rates of return are applied to revenue figures before tax. Capital outlay costs, projected life and replacement costs specified in section 04, have been used in the model. The heat network configuration for Option 1 has been used. This is considered the more conventional approach albeit at a slightly greater specified cost.

06.3 An example of the cash flow model is shown overleaf for a commercial scenario (Table 13**Error! Reference source not found.**).

Operational costs

06.4 The electricity demand for the heat pump system operation has been calculated based on the COP and the heat demand required from heat loads provided by the architects for St. Anne's Quarter in conjunction with the additional duty from estimated heat network losses. The cost of the proposed automated screening has been omitted since this was not mandatory, and its requirement uncertain.

06.5 The Government's Department for Energy and Climate Change's (DECC) November 2015 Central, Low and High projections for public and commercial sector utility prices (in real terms) over 40 years has been used[39]. Energy costs include the lower rate of VAT at 5% and also Climate Change Levy.

06.6 **It is important to note that utility costs will depend on an organisation's purchasing arrangements. Local Authorities and other large commercial organisations may have access to large framework agreements purchasing at lower costs than prices the DECC has projected.** The DECC price projections are consistent with DECC's marginal electricity carbon intensity projections used in the model, which DECC require to be used for this assessment. Due to this the model has been developed which allows a flat price or blanket adjustment to be applied across the whole DECC price projection dataset. In this sense the 'custom' price is simply a constant difference, so is 'indexed' to changes in DECC's pricing scenarios.

06.7 Maintenance costs from the heat pump specifications in section 04 have been included in the model. The smaller maintenance cost frequencies were annualised as a pragmatic step for a simple cash flow model (not a detailed investment level assessment) given these are a relatively small contribution and are only indicative.

Revenue

06.8 Revenue is provided by heat sales to the 437 flats and also from Renewable Heat Tariffs for the heat that is actually supplied at the point of use by the flats (i.e. excluding HN system losses and heat supplied by gas peaking plant). RHI tariff of £105,960 per year is received for WSHP heat supply to St. Anne's Quarter at full occupancy. The RHI is only available for the first 20 years of the heat pump operation based on tariffs 1 and 2 for published by OFGEM for WSHP installations in April 2016[40]

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

[40] Tier 1 tariff as of April 2016 is 8.95 p/kWh. This is applied following OFGEM guidance to the first 1314 hours of operation at the nominal maximum WSHP capacity 605kW (795 MWh). The tier 2 tariff of 2.67 p/kWh is applied to energy supplied by the WSHP to dwellings, less tier 1 nominal energy (795 MWh).

Table 13 Example scenario from the cash flow model accompanying this report *In this example the discount rate is set at 8% and DECC's central price projection for public and commercial utilities is selected. A fixed annual charge of £350 per dwelling and a unit charge of 8.5 p/kWh heat supplied are applied.* (Restricted to showing only 25 years of the 40 year period)

Heat Pump HN	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Heat source supplied MWh	0	558	1,116	1,674	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232
Heat sales income (gross)	£0	£47,430	£94,870	£142,300	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730
Service charges	£0	£38,238	£76,475	£114,713	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950
RHI Tier 1 eligible heat MWh	0	558	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795
RHI Tier 2 eligible heat MWh	0	0	321	879	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437
RHI income	£0	£49,940	£79,720	£94,620	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£109,520	£0	£0	£0	£0	£0
Total revenue	£0	£135,608	£251,065	£351,633	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£452,200	£342,680	£342,680	£342,680	£342,680	£342,680
Capital expenditure costs	-£1,955,229	£0	£0	£0	£0	£0	£0	£0	£0	-£44,792	£0	-£110,241	£0	£0	£0	£0	-£29,899	-£44,792	-£191,400	-£2,750	£0	-£359,991	£0	£0	£0	-£44,792
DECC pricing assumptions and emission factors																										
Electricity unit cost projection p/kWh	-	10.8	11.3	11.3	12.0	12.5	13.1	13.3	13.6	14.4	15.0	15.1	15.2	14.7	14.6	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
Gas unit cost projection p/kWh$_{gross}$	-	2.6	2.7	2.7	2.7	2.8	2.9	3.1	3.2	3.3	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Marginal electricity grid emissions kgCO_2eq/kWh		0.318	0.309	0.299	0.288	0.277	0.265	0.253	0.240	0.226	0.212	0.197	0.181	0.164	0.146	0.127	0.116	0.105	0.096	0.088	0.080	0.073	0.066	0.060	0.055	0.050
Back up/peak heating requirement MWh	0	33.4	66.8	100.2	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6	133.6
Operational electricity MWh	0	218	436	653	871	871	871	871	871	871	871	871	871	871	871	871	871	871	871	871	871	871	871	871	871	871
Electricity cost	£0	-£23,480	-£49,330	-£73,680	-£104,190	-£108,890	-£113,830	-£116,090	-£118,360	-£125,640	-£130,630	-£131,420	-£132,380	-£128,180	-£127,600	-£128,830	-£128,830	-£128,830	-£128,830	-£128,830	-£128,830	-£128,830	-£128,830	-£128,830	-£128,830	-£128,830
Gas cost - peak/back up plant	£0	-£980	-£1,990	-£3,000	-£4,020	-£4,210	-£4,370	-£4,540	-£4,700	-£4,860	-£5,030	-£5,110	-£5,110	-£5,110	-£5,120	-£5,110	-£5,110	-£5,110	-£5,110	-£5,110	-£5,110	-£5,110	-£5,110	-£5,110	-£5,110	-£5,110
Maintenance cost (planned)	£0	-£7,600	-£8,000	-£16,090	-£8,000	-£7,950	-£16,740	-£7,350	-£8,000	-£16,090	-£8,600	-£7,350	-£16,740	-£7,350	-£8,000	-£16,690	-£8,000	-£7,350	-£16,740	-£7,350	-£8,600	-£16,090	-£8,000	-£7,350	-£16,740	-£7,950
Total Operational cost	£0	-£32,060	-£59,320	-£92,770	-£116,210	-£121,050	-£134,940	-£127,980	-£131,060	-£146,590	-£144,260	-£143,880	-£154,230	-£140,640	-£140,720	-£150,630	-£141,940	-£141,290	-£150,680	-£141,290	-£142,540	-£150,030	-£141,940	-£141,290	-£150,680	-£141,890
Cash flow	-£1,955,230	£103,550	£191,750	£258,860	£335,990	£331,150	£317,260	£324,220	£321,140	£260,820	£307,940	£198,080	£297,970	£311,560	£311,480	£301,570	£280,360	£266,120	£110,120	£308,160	£309,660	-£167,340	£200,740	£201,390	£192,000	£156,000
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25
Heat source supplied MWh	0	558	1,116	1,674	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232	2,232
Heat sales income (gross)	£0	£47,430	£94,870	£142,300	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730	£189,730
Service charges	£0	£38,238	£76,475	£114,713	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950	£152,950
Total revenue	£0	£85,668	£171,345	£257,013	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680	£342,680
Gas boiler HN (Counterfactual)																										
Capital expenditure costs	-£1,494,238	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	-£9,791	£0	£0	£0	£0	£0	£0	£0	-£2,750	£0	-£235,541	£0	£0	£0	£0
Gas consumption MWh		657	1,315	1,972	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629	2,629
Operational electricity MWh (Heat network parasitic)		12	24	35	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Gas cost	£0	-£17,289	-£35,175	-£53,096	-£71,109	-£74,549	-£77,447	-£80,345	-£83,243	-£86,141	-£89,039	-£90,423	-£90,423	-£90,423	-£90,687	-£90,555	-£90,555	-£90,555	-£90,555	-£90,555	-£90,555	-£90,555	-£90,555	-£90,555	-£90,555	-£90,555
Electricity cost	£0	-£1,275	-£2,680	-£4,002	-£5,660	-£5,915	-£6,183	-£6,306	-£6,429	-£6,825	-£7,096	-£7,138	-£7,190	-£6,963	-£6,931	-£6,998	-£6,998	-£6,998	-£6,998	-£6,998	-£6,998	-£6,998	-£6,998	-£6,998	-£6,998	-£6,998
Maintenance cost	£0	-£1,900	-£1,650	-£10,390	-£1,650	-£2,250	-£10,390	-£1,650	-£1,650	-£10,390	-£2,250	-£1,650	-£10,390	-£1,650	-£1,650	-£10,990	-£1,650	-£1,650	-£10,390	-£1,650	-£2,250	-£10,390	-£1,650	-£1,650	-£10,390	-£2,250
Total Operational cost	£0	-£20,464	-£39,505	-£67,489	-£78,418	-£82,714	-£94,020	-£88,300	-£91,322	-£103,355	-£98,384	-£99,212	-£108,004	-£99,036	-£99,269	-£108,543	-£99,203	-£99,203	-£107,943	-£99,203	-£99,803	-£107,943	-£99,203	-£99,203	-£107,943	-£99,803
Cash flow	-£1,494,238	£65,203	£131,840	£189,524	£264,262	£259,966	£248,660	£254,380	£251,358	£239,325	£244,296	£233,677	£234,676	£243,644	£243,411	£234,137	£243,477	£243,477	£234,737	£240,727	£242,877	-£804	£243,477	£243,477	£234,737	£242,877
Change in greenhouse gas emissions compared to counterfactual tCO_2eq																										
Marginal electricity emissions for WSHP	0	66	127	185	237	228	219	208	198	186	175	162	149	135	120	105	95	87	79	72	66	60	55	50	45	41
Change in gas emissions for WSHP	0	-115	-230	-345	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460	-460
Net total difference (savings) tCO_2eq	**0**	**-50**	**-103**	**-161**	**-223**	**-232**	**-242**	**-252**	**-263**	**-274**	**-286**	**-298**	**-312**	**-325**	**-340**	**-356**	**-365**	**-373**	**-381**	**-388**	**-395**	**-400**	**-406**	**-410**	**-415**	**-419**

RESULTS

25 year period		**NPV**	**IRR**
WSHP	**£**	**692,360**	**12.2%**
Gas Counterfactual	**£**	**718,840**	**13.1%**
Cumulative CO_2eq saved*		**7,667**	**tonnes**

06.9 The charging revenue has two variables, a fixed standing charge and a unit rate of pence per kWh of heat (p//kWh) used by residents. Typical low £250 and high £350 fixed standing charge per dwelling per year is applied for DH supply. In addition sensitivity test is conducted on the unit charge with four prices from 4 to 10 pence in 2 pence increments.

Phasing of the development and heat network

06.10 IRR will improve if maximum revenue from heat sales and RHI payments is reached closer to the time that heat network CAPEX has been made. St. Anne's Quarter will be constructed in phases, indications suggests the first properties will be available after 1 year and all properties available 3 years after construction commences. Also not all flats will be occupied straight after their completion so there may be a time lag to the full heat demand calculated. Since details are not known on the exact time frames for each block and are likely to be determined by market interest in sale of flats an assumption of 3 years has been made with a linear increase (a third each year) to full occupancy (437 units) by year 4. The model allows this to be adjusted. In addition, to explore the sensitivity of IRR to a phased income, the model allows the capital cost of the heat network to also be phased (again, spread linearly) over a period *within* the timescale that has been proposed for achieving full occupancy.

Counterfactual case

The counterfactual is based on the five 120kW condensing gas boilers supplying the heat loads of the heat network substituting the heat pump contribution entirely. The manufacturer's declared seasonal efficiency is 96% but a 90% gross efficiency is applied as a lifetime average based on suggestions from DECC's Heat Network Development Unit. This has also been applied to the backup boiler in the WSHP system.

Carbon emissions

06.11 Marginal long term emission factors modelled by DECC for changes to grid electricity use projected for 40 years have been applied to estimate the carbon impact from changes in energy used by the WSHP compared to the counterfactual. A change in electricity demand is assumed to only impact the marginal grid generation source (the most likely to be modulated in response to changes in demand). The DECC modelled projections also assumes the marginal source will have increasingly lower carbon electricity generation compared to the average supply.

Cash flow model results

06.12 Table 14 and **Error! Reference source not found.** show the results of a sensitivity assessment using a cash flow model to calculate indicative internal rates of return (IRR) using different prices of unit heat sales with two different fixed annual charge of £250 and £350 per consumer. The heat sales reflect a linear increase to full occupancy after the first 3 years. The electricity costs and gas unit costs are taken from DECC's projections for low, central and high prices for the 40 year project life starting from 2016. Full occupancy (and heat revenue) is realised in year 4, (see 06.10).

Table 14 Simple cash flow IRR's for heat supply charges with a fixed standing charge of £250/year.

Occupancy phased over 3 years (100% capital expenditure assumed in year 0). *Values in bold exceed the minimum threshold for attracting ESCO investment over the respective time period.* **Bold figures** *indicate IRR's exceeding 11% over a 40 year period, the threshold considered to be attractive for ESCO investment. Highlighted figure indicates where WSHP is more competitive than the counterfactual.*

a) WSHP + peak gas boilers

£250 standing charge		Heat sale price							
	Utility cost scenario	4 p/kWh		6 p/kWh		8 p/kWh		10 p/kWh	
	(DECC)	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs
IRR	Low	4.3%	5.1%	7.6%	8.2%	10.1%	10.7%	12.4%	**12.8%**
	Central	3.3%	4.0%	6.8%	7.5%	9.5%	10.0%	11.8%	**12.2%**
	High	2.2%	2.9%	5.9%	6.7%	8.8%	9.4%	11.1%	**11.6%**

b) Counterfactual gas only

£250 standing charge		Heat sale price							
	Utility cost scenario	4 p/kWh		6 p/kWh		8 p/kWh		10 p/kWh	
	(DECC)	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs
IRR	Low	5.2%	6.8%	8.5%	9.6%	11.3%	**12.1%**	13.8%	**14.4%**
	Central	4.0%	5.1%	6.8%	8.1%	9.9%	10.8%	12.5%	**12.2%**
	High	-0.4%	2.6%	4.5%	6.2%	8.0%	9.2%	11.0%	**11.7%**

Table 15 Simple cash flow IRR's for heat supply charges with a fixed standing charge of £350/year.

Occupancy phased over 3 years *(100% capital expenditure assumed in year* 0).

a) WSHP + peak gas boilers

£350 standing charge		Heat sale price							
	Utility price scenario	4 p/kWh		6 p/kWh		8 p/kWh		10 p/kWh	
	(DECC)	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs
IRR	Low	7.5%	8.2%	10.1%	10.6%	12.3%	**12.7%**	14.3%	**16.1%**
	Central	6.7%	7.4%	9.4%	10.0%	11.7%	**12.2%**	13.8%	**14.1%**
	High	5.9%	6.6%	8.7%	9.3%	11.1%	**11.6%**	13.2%	**13.6%**

b) Counterfactual gas only

£350 standing charge		Heat sale price							
	Utility price scenario	4 p/kWh		6 p/kWh		8 p/kWh		10 p/kWh	
	(DECC)	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs
IRR	Low	8.4%	9.5%	11.3%	**12.0%**	13.8%	**14.3%**	16.1%	**16.5%**
	Central	6.7%	8.1%	9.8%	10.7%	12.5%	**13.1%**	14.9%	**15.3%**
	High	4.4%	6.2%	8.0%	9.1%	10.9%	**11.7%**	13.5%	**14.0%**

Heat charges required

06.13 IRR's of 11% to 15% are considered to be the typical range of what ESCO's aim to achieve for a 30 to 40 year term[41]. For the WSHP specified for St. Anne's Quarter, and DECC's central energy price projections, the cash flow model indicates that £250/year standing charges (Table 14a) and 10p/kWh unit charges would be required to produce 40 year IRR's that exceed 11% in each of DECC's utility price projection scenarios. Increasing the standing charge to £350/year, at the higher range for expected pricing, allows a lower respective unit charge of 8p/kWh to meet the 11% threshold (Table 14**Error! Reference source not found.**b). These charges are equivalent to 13.75p/kWh heat when rolled into a single unit charge.

06.14 Table 14**Error! Reference source not found.** indicates that the specified water source heat pump (WSHP) system network has a better IRR (in bold figures highlighted yellow) than the counterfactual with DECC's High utility pricing projections and a heat sale price of 10p/kWh, but only over a 25 year period . A higher standing charge of £350 (Table 15) with a heat sale price of 8p/kWh is also competitive, but again only over the shorter 25 year period.

Phased capital expenditure and utility price on required heat charge sensitivity

06.15 Table 16 and Table 17 show the improvement in IRRs due to phasing of the heat network CAPEX over 3 years, in line with the phased occupancy revenue. When standing charges are rolled into a single unit heat charge a threshold of 12.76 p/kWh heat is now required to meet the 11% IRR threshold over 40 years with DECC's central utility cost projection.

06.16 Setting Year 2016 utility costs in the model similarly to those provided by Norwich City Council to represent their public energy procurement contracts (10.5p/kWh for electricity and 1.6p/kWh for gas), would require 12.6p/kWh to achieve a 11% IRR for WSHP, rolling standing charges into a single unit heat charge. This assumes that the cost changes are indexed to DECC's price projections for the next 40 year period. The gas counterfactual would require 10.9p/kWh heat charge over 40 years. The 12.6p/kWh WSHP heat price required would not appear as favourable for consumers compared to indicative whole life unit cost between 9.55 and 11.60 p/kWh for heat supplied from individual gas-combi boilers estimated by *Which? However,* 12.6p/kWh is still within the overall price range of 5.5-14.94p/kWh observed for community heat schemes observed in the Which? survey[42]

Concluding remarks

06.17 The viability and competitiveness of the WSHP indicated for St. Anne's Quarter over the gas counterfactual is sensitive to the time it takes to achieve the planned heat sales, the charging strategy and future utility cost scenarios. The cash-flow model allows developers to test the impact of these variables indexed to DECC utility cost projections. Indications suggest that gas heating, from a centralised gas boilers (the counterfactual) and also from a standard combi boiler may be more economical for residents than WSHP.

06.18 Given the potential carbon savings of the WSHP are substantial, the WSHP heat network may be developed over the gas counterfactual if:

a) A 'green' lifestyle premium exists in the market for apartment residences in Norwich and can be a selling point, or

b) WSHP heat charges are not considered important in terms of affordability by prospective buyers or Council policy and the market for new riverside properties is strong enough that planning policy could

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[41] Personal communication Steve Marsh Ener-vate – former E.On communities DH specialist.

[42] This assumes typical cost of boiler, installation, and service life (11 years) for a two bedroom flat from consumer research. The lifetime fuel consumption is based on a 90% seasonal efficiency using a domestic residential fuel price of 5.5p/kWh. No initial connection costs are included in Which?'s estimate, but with discounts for multiple offtakes and civil works likely to already be covered in the building construction these are likely to be relatively minor contributions to lifetime costs. http://www.staticwhich.co.uk/documents/pdf/turning-up-the-heat-getting-a-fair-deal-for-district-heating-users---which-report-399546.pdf

require developers to meet additional costs of low carbon performance criteria (as the City of London has done) without impacting investment.

Table 16 Simple cash flow IRR's - phased heat network CAPEX, standing charge £250/year

Occupancy phased over 3 years (Heat network capital expenditure spread over 3 years). Values in bold exceed the assumed minimum threshold for attracting ESCO investment over the respective time period. **Bold figures** *indicate IRR's exceeding 11% over a 40 year period, the threshold considered to be attractive for ESCO investment. Highlighted figure indicates where WSHP is more competitive than the counterfactual.*

a) WSHP + peak gas boilers

£250 standing charge		Heat sale price							
	Utility cost scenario (DECC)	4 p/kWh		6 p/kWh		8 p/kWh		10 p/kWh	
		25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs
IRR	Low					11.4%	**11.9%**	14.0%	**14.4%**
	Central	<11%		<11%		10.6%	**11.2%**	13.3%	**13.7%**
	High					9.8%	10.4%	12.6%	**13.0%**

b) Counterfactual gas only

£250 standing charge		Heat sale price							
	Utility cost scenario (DECC)	4 p/kWh		6 p/kWh		8 p/kWh		10 p/kWh	
		25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs
IRR	Low					13.2%	**13.8%**	16.4%	**16.8%**
	Central	<11%		<11%		11.4%	**12.2%**	14.7%	**15.2%**
	High					9.3%	10.3%	12.8%	**13.5%**

Table 17 Simple cash flow IRR's - phased heat network CAPEX, standing charge £350/year.

Occupancy phased over 3 years (Heat network capital expenditure spread over 3 years). Values in bold exceed the assumed minimum threshold for attracting ESCO investment over the respective time period.

a) WSHP and peak gas boilers

£350 standing charge		Heat sale price							
	Utility price scenario (DECC)	4 p/kWh		6 p/kWh		8 p/kWh		10 p/kWh	
		25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs
IRR	Low			11.4%	**11.9%**	14.0%	**14.4%**	19.4%	**16.7%**
	Central	<11%		10.6%	**11.1%**	13.3%	**13.7%**	15.7%	**16.0%**
	High			9.8%	10.4%	12.5%	**13.0%**	15.0%	**15.4%**

b) Counterfactual gas only

£350 standing charge		Heat sale price							
	Utility price scenario (DECC)	4 p/kWh		6 p/kWh		8 p/kWh		10 p/kWh	
		25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs	25 yrs	40 yrs
IRR	Low			13.1%	**13.8%**	16.3%	**16.7%**	19.3%	**19.5%**
	Central	<11%		11.4%	**12.2%**	14.7%	**15.2%**	17.7%	**18.1%**
	High			9.2%	10.3%	12.7%	**13.4%**	16.0%	**16.4%**

Commercial Structures for a River Source Heat Network - Commercial Market Overview

06.20 The feasibility assessment cannot dictate or recommend specific roles and structures for delivery of a water source heat pump heat network at this feasibility stage. These depend on the source and driver of development funding and arrangement of ownership, in addition, the operation of the infrastructure and heat network can take a number of different approaches. Instead, we provide an overview of the common structures for delivery of a heat network and how these may evolve based on recent similar size heat network schemes.

Planning policy driven schemes

06.21 Commonly heat networks have been implemented through an Energy Services Company (ESCo). The ESCo structure will depend on the size of scheme and also the key drivers for the scheme. A market for ESCo / District Heating systems has primarily developed in London where planning policy stipulates higher carbon reduction targets than national building regulations. To meet these targets developers are mandated to upgrade building fabric and install various levels of renewable energy (solar, heat pumps etc.) beyond that required by Part L of the UK Building regulations.

06.22 ESCo's have provided a solution for developers to meet policy led carbon reduction targets with equal or lower costs in a single transaction, removing the burden of compliance from developers and transferring risks to the ESCo.

06.23 An initial barrier to adoption has been the developers' perception that fixing heat sales to a single long term supplier would not be welcomed by customers and therefore placing the sale of properties at risk. However, due to planning policy and the number of schemes in London, the approach of District Heating and ESCo's is now well-known and accepted amongst larger developers. Progressive developers and owners are beginning to also realise that ESCo's can also be a commercial business that can generate healthy returns and promote community engagement.

06.24 Local Authorities outside of London are starting to adopt similar approaches to ensure local energy generation can be capitalised upon. East Devon and Exeter City Council have adopted similar planning policies, which has resulted in one of the UK's largest new build ESCo developments – Cranbrook. This approach is now starting to become more widespread with developments in the North of the UK adopting ESCo structures.

ESCO structures

06.25 There are two common ESCo commercial structures that exist for new build developments; a connection fee model and a contribution model.

The connection fee model

- A third party owned ESCo is contracted to Fund, Design, Build, and Operate the heat generation plant and distribution network
- A full risk transfer approach – all risks are held by the ESCo
- Developer / owner pays a pre-negotiated price per property to connect to the network upon completion.
- Connection fees vary on a project by project basis, but typically range between £2,500 and £4,000 per unit.

06.26 The ESCo recovers a majority portion of its capital outlay from the developer or plot developers via the connection fees charged per property and then recovers the remaining investment and returns on the long term heat contracts with end users.

06.27 To attract a commercial ESCo to make an investment to deliver this kind of scheme, a threshold on the size of the development exists. This has typically been approximately 1,000 dwellings, however this threshold has been known to reduce to 750 dwellings for high density block of flats developments where the capital cost is relatively lower due smaller pipework requirements.

The main difference between the two is cash flow. The cost for the developer is spread throughout as each flat is built and can improve the results of the financial model.

The contribution model

06.28 This is typical for developments between 200 and 1,000 dwellings and is more appropriate to the heat available from the river water source heat pumps specified in the case study for St. Anne's Quarter.

- The ESCo (or a separate contractor) is paid by the developer / owner to Design and Build the scheme.
- The ESCo will typically contribute 20% of the capital cost (subject to individual project requirements).
- The ESCo gains in return the exclusive rights to charge for supplied heat for a long term period.
- The ESCo operates the scheme, or contracts the operation to third party.

06.29 In both cases outlined above, the majority of the capital cost of installation is born by the developer/owner. As referred to previously, this cost has typically been driven by the need to attain the standards of carbon reduction required by planning policy rather than commercial incentives. The heat network has therefore competed with the cost of alternative methods of attaining the standards. Installing District Heating Networks can outcompete building fabric improvement or PV installations to meet the policy standards in high density apartment projects. For lower density applications this may not be the case.

Typical ESCo Structure for developments with more than 250 dwellings

06.30 The opportunity for a heat network for St Anne's Quarter, or a similar sized development, if marketed as an entire development with concession for long term heat sales to 437 flats would be of interest to the current market (see examples listed at the end of this section) with standard commercial boiler technology. This would typically follow a contribution type model.

06.31 The attraction of this development would improve if the heat network had potential to expand the heat network. However this is unlikely given the regulatory uncertainty surrounding increased pumped discharge volumes and the precautionary stance likely to be taken by regulators on potential cumulative impacts.

06.32 An SPV (*special purpose vehicle)* 'ESCo' is typically created. This would most likely be owned 100% by a substantial entity such as a utility company, which undertakes the Design and Build (D&B) and ongoing Operations and Maintenance (O&M) / Customer Service functions, either via formal arms-length contracts with sister operations owned by the same company(fig 20) [43], or contractually 'wrapped' within the ESCo structure.

06.33 Under these typical structures the SPV is self-financed from the utility company's balance sheet capital investment. However, some of the main market leaders in delivering heat networks that are not utility based companies (see case study examples at the end of this section) have commercial finance structures that provide them with short term loans.

06.34 The key assets (such as Energy Centres) have later been re-financed and/or "sold" to major investors when the project has been de-risked (i.e. land rights purchased, all necessary consents approved and the scheme has been built and is operating successfully as planned).

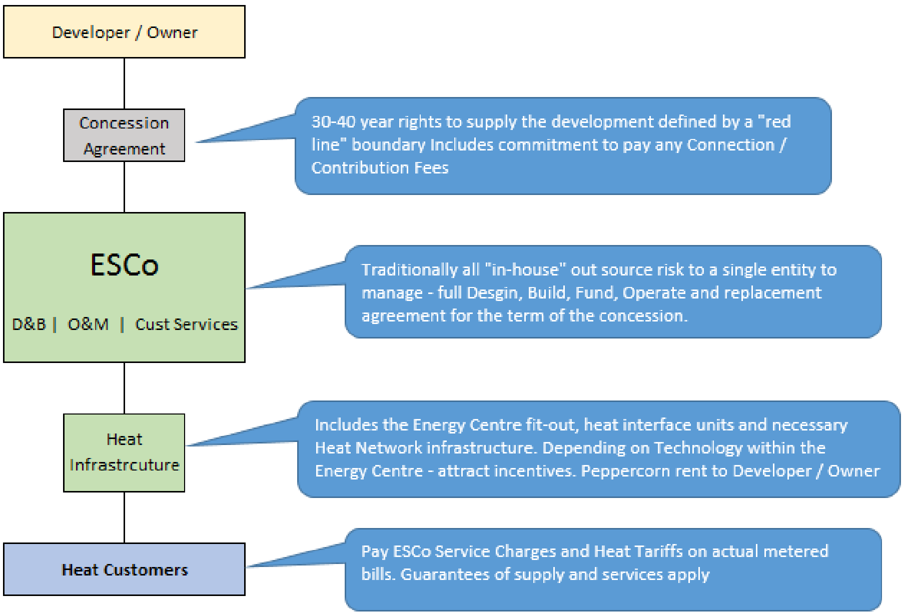

Fig 23 Typical ESCo structure and activity

[43] For example E.On PLC has different distinct operations that design and builds heat network schemes and other E.On concerns that operate community heat schemes and provide customer services.

ESCo role

06.35 The ESCo provider is the entity that contracts to provide space heating and hot water with individual tenants / occupiers of the properties. Most ESCo service (heat) providers will prefer to also carry out or directly control the Design and Build contract given they will carry the responsibility to provide cost effective long term heat, but it is not a requirement.

06.36 It is important to note that the ESCo entity and the Design and Build Contractor can also be totally separate. One reason for this is that the Developer/Owner may prefer to tender the Design and Build element to the market to ensure value for money. In this case the ESCo can lay down the criteria and standards of installation that it will accept via an Adoption Criteria to ensure that the installation meets their requirements. Many installations are carried out this way.

06.37 The ESCo entity will provide supply guarantees and standards of services to heat customers and ensure they design the Energy Centre with suitable technology to assure heat availability and operational resilience. The ESCo will need to demonstrate added value to customers through market comparisons, typically against a basket of traditional methods of heat provision.

Developer's Role

06.38 Following a contribution model the developer would provide over 80% of the capital cost in return for heat network connected to their development. Typically, under these structures, the Energy Centre building shell is built by the developer with a minimal or token rent charge to the ESCo provider.

ESCo Costs

06.39 Under this structure, upon completion of each flat and connection to the system, a Contribution Fee is payable by the ESCo to the developer / owner. This varies on a project by project basis, but typically can result in up to 20% of the Design and Build cost.

ESCo income

The main sources of income for the ESCo in this structure are: -

06.40 **Heat sales on a consumption basis**. The ESCo entity will enter into a Concession Agreement with the land / property owner / developer, typically for a term of 30-40 years – safeguarding the income stream from the retail of thermal energy (subject to compliance with industry practice and any future regulation). In many cases this is split between a Service Charge and a Tariff. There is some degree of flexibility on how this is split (see below).

06.41 The price review mechanism needs to be totally transparent to customers with clearly defined protocols on how to treat vulnerable customers. A variety of payment options are generally offered to accommodate all demographics (pre-pay, credit etc.) Heat Tariffs range between 5.8p and 7p/kWh consumed depending on location and comparison to credible market alternatives.

06.42 **Service Charges** range between £ 250 and £350 per annum per property. The Service Charge exists to principally recover replacement infrastructure (like individual Heat Interface Units). This can be a contentious area for ESCo entities when establishing the split between Service Charges and Heat Tariffs – in ensuring the levels of service.

06.43 As specified in the costs for the heat networks in this assessment, the heat is automatically metered on actual consumed levels (at the HIU) and is logged through a modem allowing remote meter monitoring and reading via the Customer Call Centre for billing purposes. The actual separated out delivery costs and charges for customer service and billing are not freely available but are likely to be a relatively low fraction of the service charge.

06.44 **Renewable Heat Incentives** for eligible heat generated by the heat pump technology employed within the Energy Centre the renewable heat tariff is guaranteed for 20 years and is index linked to inflation for eligible heat generated.

Evolving ESCo Structures

06.45 The approach to ESCo ownership has evolved recently. This has been led primarily by developers who have recognised that there is value in owning ESCo's. Whilst the principle commercial structure remains the same as the traditional models above, the ESCo entity seeks to appoint specialist sub-contractors to undertake the main elements of the service provision, Design and Build along with Operations and Maintenance (Fig 24).

06.46 The contractual arrangements employed allow risk to be deferred to contractors, reducing liability on the developer – or so called flowed down risk. Often the Customer Service / Billing is contained within the O&M contract – for reasons of continuity and acceptance of flowed down risk. However, in some cases this is broken out as the Developer / Owner may already have similar service provisions that could be adapted.

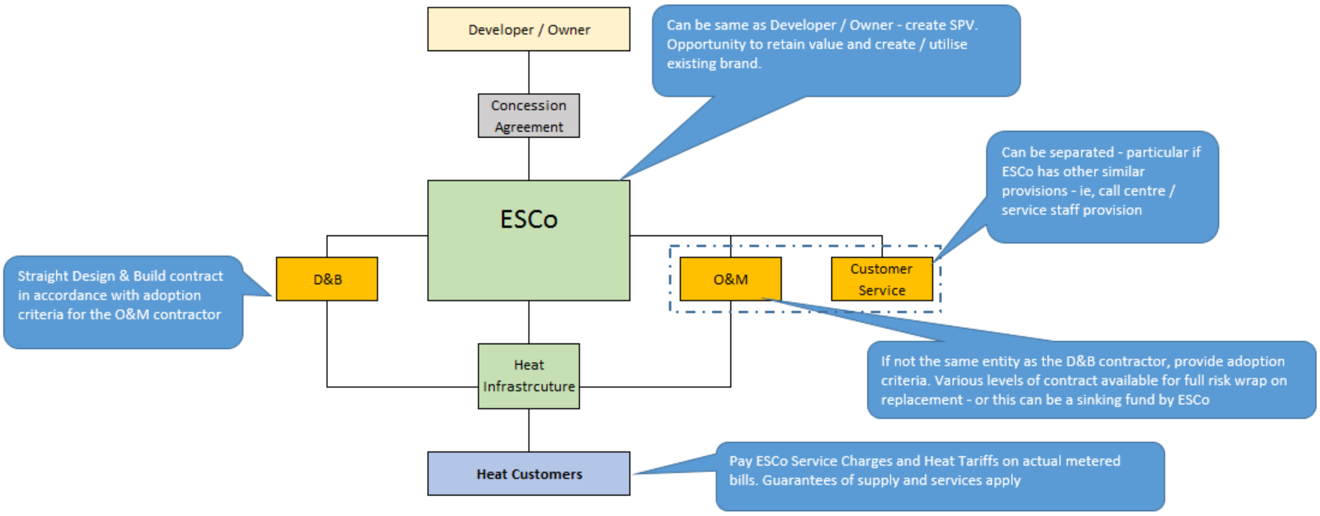

Fig 24 Evolving ESCo structures and roles

06.47 This recent adaptation is recognising that the creation of an ESCo holds social as well as commercial value. This provides a revenue stream from income that would have ordinarily been a 'sunk' cost (traditional utility connection costs for the provision of services) that can return a profit and, in some cases, be used to influence the levels of service charges and heat tariffs it chooses to charge customers.

06.48 Employing a third party ESCo under the traditional models described above are also considered sunk costs. Through the retention and ownership of the ESCo, what was once a sunk cost is now an investment which generates a return. This has value when considering the possible ownership of such an ESCo – be that private sale, private rented sector or registered social landlords ownership.

06.49 If the Developer / Owner has control over the charges, then they are in some degree influencing and creating unique differentiators in attracting sales / rental of their properties. Lower energy bills with service levels and guarantees can help safeguard the wider development interests by ensuring tenancy is very competitive and is consistently filled. Capital funding for the ESCo can also be considered within the main development construction costs.

06.50 This alternative structure is also scalable and could therefore be considered for smaller developments (individual blocks) similar to St Anne's Quarter or smaller. These smaller HN models are not commonplace within the commercial market due to the scale and appetite to invest. However, similar models to the above structure have been developed and in many ways are comparable to the retrofit of tower blocks from electric / gas fired system to Biomass solutions [44].

06.51 There are further adaptations of this approach that are in development phases. Some organisations are exploring a 'Community ESCo' structure, in some cases with support from the public sector / third sector[45]. Clearly the access and security of the source of funding for such a structure will require some careful consideration – the involvement of the public / third sectors here can perhaps provide some funding security and leverage.

Risks and mitigation

06.52 There are a number of key risks that ESCo's evaluate and seek to mitigate – some of which are within their control and others which are outside their control. Table 18 below shows a highlight of the key risks and mitigations of a traditional ESCo structure for this scale of development.

06.53 The risk profile for the evolved / alternative approach is broadly the same as the traditional route. However, the sub-contract position for the D&B, O&M and possible separation ('break out') of the Customer Services function to a further party means a greater level of project management is required – especially if the entity proposed for the services is different. The interfaces for what gets built and then operated are very important for how risk is distributed contractually amongst each entity.

06.54 The Energy Centre will require an adoption criterion or specification that the D&B contractor will be required to meet. The market testing / procurement for potential partners will therefore be critical to avoid a blame culture between the entities. A market testing exercise would need to be constructed in such a way that provides the ability to test the commercial value of separating these elements which needs to be balanced off with the risk. At the same time, the market respondents will be keen to enter into both contracts and therefore be keen on pricing as a combined package.

Table 18 risks and mitigation associated with commercial heat networks

Risk	Mitigation measures
Capex Over-run on Capex is critical risk to the commercial returns for ESCo's. Up front capital is often phased with stages of installation (and therefore phased revenue income). It's typical that D&B contracts operate with a 10% margin	Thorough appraisal of the design and installation costs required. Clear lines of responsibility between the developer and the ESCo of the scope of delivery. Adequate levels of contingency should be applied (typical 5-10% depending on technology and scale) Fixed cost contracts with DB providers Robust supply chain evaluation and selection process.
Opex The ESCo provision of O&M is either following its own installation through the D&B contract or following an installation by a 3rd Party. The ESCo needs to ensure that the physical installation of and the operation and lifetime expectancy of the installed	Ensure ESCo Adoption Criteria and standards are in place prior to D&B contract start Ensure sufficient local qualified staff are available to meet the service level agreements.

[44] £2m district heating system investment at Lancashire Hill, Stockport has building fabric efficiency improvements for 487 Priority 1 properties and heat delivered by 1MW biomass boiler backed up by three 1.4MW gas boilers. The installation was through a partnership between British Gas and Stockport Homes. This has been followed by a further £14m on subsequent DH schemes obtaining significant external funding from the Community Energy Saving Programme (CESP) obligation on large UK energy companies to deliver energy saving measures to low income households.

[45] Smart Klub in Leeds is one example. The SmartkKlub.org initiative is being run by former employees of E.On.

Risk	Mitigation measures
plant is of the required standard. Robust supply chain evaluation for the choice of equipment is essential. One of the main areas for high volume customer calls and engineer time is the Heat Interface Unit and associated meter reading accuracy. The design and operability of the Energy Centre is also essential, ensuring the technology choice performs to service level warranties and guarantees on efficiency, performance and availability. The ESCo is responsible for the supply of heat 24/7 365 – often with financial compensation to customers for failure to supply or remedy problems within a given time. Due care for the responsibilities for energy provision for vulnerable customers.	Appropriate planned and preventative maintenance regimes are in place. Back-off as much risk to suppliers of technology within warranties and guarantees Choice of quality apparatus (HIU's and generation assets) Utilisation of thermal storage to improve operational efficiency The design of the heat network has sufficient hydraulic breaks and valves for isolation. This is a fine balance with capital cost. However, the ability to limit the extent of any leakages / repairs can save in the long run. Ensure the design has system monitoring to detect leaks / issues in advance of failure.
Repex Replacement of the heat infrastructure over the term of the contract to maintain supply to customers. This means HIU's, heat mains and generation equipment	The treatment of Repex under this structure is absorbed within the total costs. HIU's should be replaced cyclically - allowances should be made within the model to accommodate this and all other limiting assets. The main heat network, subject to maintenance profile, is designed beyond 50 years.
Customer engagement, liaison and billing This is a customer journey and should be resourced and supported correctly. Many occupants will not be aware of DHN as it's a growing technology. How customer queries and problems are solved in a timely manner is very important. This is a monopoly position for an ESCo – whilst this is not yet a regulated sector, a Heat Trust of all major suppliers / ESCo's exists that provides a first stage approach to becoming regulated	Suitable tenant liaison at the point of rent / sale that explains the system, who the ESCo is and that this is a concession that is mandatory. An information pack should be developed and adapted to the development specific needs. Industry standard systems should be employed to automatically remotely read all meters – minimally monthly. The billing system should provide the ability for a variety of payment methods. In circumstances where tenants are regular and pro-longed non-payers (and not deemed vulnerable) provide suitable systems that can suspend supply. Many modern HIU's and systems can do this remotely to avoid the need to enter an individual property. The process for dealing with late / non-payment should be clear to occupiers when entering into the sale / rental agreement. Some modern systems provide usage profile data that can be used to be pro-active in advising customers of abnormal heat usage patterns – in the cases of increased usage above normal levels to check that there are no issues and avoid potential unexpected high bills for customers
Technology and availability Depending on the choice of generation technology within the Energy Centre – the availability and performance warranties / guarantees are important	Ensure that warranties and guarantees are strong with technology suppliers. Availability of renewable energy technology will impact on the usage of traditional resilience supply sources (gas) that will impact on the commercials.

Risk	Mitigation measures
	The Energy Centre layout should, where able, be designed in a modular format to future proof for new technology to be employed. In addition, a modular approach will provide greater efficient use of correctly sized plant to meet the projected daily, weekly and monthly profiles for demand.
Build risk & prelims A risk that is more apparent on larger scale developments – both high and low density. An ESCo profiles capital spend and revenues based on projected phased delivery of developments. If there is a delay, for whatever reason, this is typically a risk born by the ESCo.	Capital spend is planned on the basis of the proposed phased delivery schedule. Longer phased delivery plans carry with them larger prelims. One mitigation would be an agreement to compensate ESCo for "severe" delays in the phased delivery – which can be a mechanic that the ESCo repays the Developer / Owner once the delivery programme resumes. The main reason for such a mechanic is the recovery of spent capital with no income for the ESCo. For a development of scale <500 this is a smaller risk but needs consideration.
Customer bad debt risk The credit risk of heat customers is born by the ESCo.	This is a genuine risk for the ESCo that is very difficult to flow down. The possible mitigations are limited, however, as listed above, the selection of the employed technology can limit the exposure of this risk – i.e., ability to suspend or terminated supply until account resolution reached, modern pre-payment methods Typically, ESCo's set up a sinking fund to cover bad debt risk. This ranges and varies depending on the type and volume of customer types / demographic. Typically, this can range between £3 and £5 per customer per year.
Land ownership, easements and wayleaves A risk that is more apparent on larger scale developments – both high and low density. However, the location of the Energy Centre and routing for the network should consider land ownership.	Third party land ownership requires up-front scrutiny and negotiation to avoid land monopoly positions and ransom strips. Utility searches should also be undertaken to avoid greater capex risk exposure. This may include Canal & Rivers Trust, Broads Authority etc.

Current Market and Market Expectations

Traditional ESCo's

Below is a list of the key participants within the traditional ESCo structures market: -

- E.ON Community Energy
- Vital Energi
- GDF Cofely
- SSE Enterprises
- Brookfield Metropolitan
- Pinnacle Group

06.55 As explained earlier in this section, and as seen in the list above, the ESCo market is dominated by traditional utility companies. Under a traditional ESCo structure model, where the Developer / Owner seeks to employ or out-source the whole package, the typical returns ESCo's would be looking to achieve is in the region of 11% to 15% IRR based on a 30 to 40-year term. This will include the valuation of any profit for the D&B element of the project if a margin is taken by the ESCo. The traditional approach is a low risk option for the Developer / Owner – but equally doesn't provide much incentive.

Smaller emerging ESCo structures

06.56 The evolved and smaller ESCo structure is developing market space. Many of the same market participants listed above are engaged to some degree in this emerging market, however non-utility based businesses are likely to be more flexible and competitive with D&B and O&M contracts.

06.57 In some circumstances, under such smaller structures, co-development and ownership of the ESCo has been proposed through a Joint Venture – the partner for the D&B / O&M becoming a shareholder and co-investor in the ESCo. The advantage of a JV is that an owner developer as a partner may understand and maintain an element of control over the ESCo operations[46].

06.58 There isn't a single answer for such projects and the merits / needs' are required to be tailored and measured. The flexibility of the evolved, smaller structure, provides the ability to market test and adapt a structure that best fits the projects objectives and needs. These project structures are still capable of achieving acceptable returns between 9% and 12% IRR.

06.59 As described earlier, the developer / owner would ordinarily have a 'sunk' cost - whether employing an ESCo or through traditional utility connections to provide space heating and hot water. Becoming the ESCo themselves, this previously accepted "sunk" cost becomes an investment. This potential structure opens the opportunity for Public sector / Third sector input and investment given the stable and long term revenue streams.

06.60 These evolving structures can provide some control and flexibility to leverage profitable returns on investment as well as social benefits – creating advantages and differentials over other similar developments in competition. It's accepted that there is more risk with this approach, but with appropriate support, project management, contractual risk flow down and partner selection the rewards can be maximised.

[46] Keel holdings in Manchester is an example of where a property developer has a joint venture with an ESCo provider.

Case Study examples

06.61 The list below comprises developments of similar scale to St Anne's that have secured traditional ESCo structures. In most cases, these are Contribution models under a fully outsourced ESCo solution to a third party.

06.62 E.ON Community Energy – a market leading ESCo solutions provider for new build developers. E.ON have a framework agreement with Barratt Homes and many other major developers. Below is a list of the similar scale project to St Anne's.

- Barham Park - 335 residential units, a retail unit and a community facility
- Dalston Square - 244 residential and 9 commercial properties
- Blackhorse Lane - 476 residential units and small commercial
- Aldgate Place - 463 residential units, hotel, retail and office
- Altitude - 235 residential units
- Catford Green - 589 residential units
- East City Point - 143 Residential units
- Fulham Wharf - 472 Residential units, a supermarket, retail space, a training centre and crèche, and a gym
- Lincoln Plaza - 546 residential units
- Thursten Road - 406 residential units
- Waddon- 187 residential units, a leisure centre and children's education centre

Contact – Mr Tony Poole, Senior Business Development Manager tony.poole@eonenergy.com

06.63 Vital Energi are one of the market leading ESCo solutions providers. Vital are a private owned business and not from a traditional utility background. Vital Energi are considered by some to offer more flexible commercial solutions on a project-by-project basis than the established utility companies and are not tied to traditional delivery models.

06.64 Vital Energi are therefore likely to be at the forefront of the evolving ESCo market. Vital have been involved in a number of other ESCo's for Design & Build and / or Operations & Maintenance, some examples attached.

Example cases of Vital energy ESCo's are

- Oban Biomass Community Heating
- Parkdale
- Parkside
- The Movement
- Woodbrook Biomass Community Heating
- Yarn Street in Leeds

Contact – Mr Nick Gosling Group Sales and Strategy Director. Nick.Gosling@vitalenergi.co.uk

07 Concluding remarks

07.1 The river source heat pump scheme explored for St Anne's Quarter has been stymied somewhat by uncertainties associated with the regulatory position and lack of available guidance associated with the maximum limits for cooled water discharges. This is not to say that evidence is easily available to provide advice. There is limited scientific evidence to call upon to make judgements with regards to cold water impacts on river life.

07.2 A heat network of a scale similar to St Anne's can be attractive and deliverable within the current market under traditional commercial ESCO structures. However it has to be recognised, that this does come at a greater initial capital cost to the developer than traditional utility connection costs.

07.3 The counterfactual comparison indicates that for a large development like St Anne's Quarter the financial case would favour investment in centralised natural gas boilers rather than water source heat pumps. The likely higher cost of electricity contributes to this conclusion.

07.4 However the projected carbon savings for WSHP compared to the counterfactual are substantial, over 7000 tonnes CO_2 eq over 25 years and over 14,000 tonnes CO_2 eq over 40 years. These predictions are based on DECC's modelled long term marginal electricity supply carbon emission assumptions which predicts a continued trend in future reduction in carbon intensity based on a set of policies which could be subject to change.

07.5 Therefore unless there is a strong local low carbon planning policy and/or aspiration from the owner / developer/ home buyers this is less likely to be taken up. However, forward thinking developers / stakeholders can see community heat networks as an opportunity and it is starting to gather momentum within the market – creating a business from what would otherwise have been a "sunk" cost to connect to traditional utility infrastructure.

07.6 The indicative IRR's estimated for St. Anne's Quarter in section 06 are in the region of 11% to 15% that ESCOs are looking to achieve which supports this conclusion with regard to the commercial viability of heat networks from both WSHP's and gas boilers. However the IRR's are sensitive to utility cost and market heat price scenarios and more robust assessment of utility procurement options and potential heat market charges is recommended for any investment level decision. In addition the RHI income based on the current tariff available at the time of this report is critical in allowing WSHP's to compete with natural gas boilers. Therefore any conclusions made would also be subject to continued Government policy support for WSHP installations.

07.7 Each project should be fully explored to define what the aims and drivers are for delivering a heat network solution. The objectives (and utility costs/ and heat pricing) will, possibly, differ depending on the ownership / stakeholder interested. Once this is clear, a suitably prepared market engagement document should be initiated that seeks options for the required scheme from possible contractual packages from ESCo service providers and/or D&B and O&M contractors.

07.8 This market has provided opportunities for third party specialists to emerge, often with experience gained through community heat provision in larger utility companies. These specialists can offer services to prepare market engagement documents, broker and co-ordinate suitable schemes between developers and contractors, and advise on setting up tailored ESCo structures to meet the required project aims.

08 Glossary

Coefficient of performance	See COP
Coincidence factor	This is a statistically derived factor that represents the proportion of the maximum theoretical hot water demand from all dwellings to coincide at the same time – i.e. if all users turned hot water taps on at exactly the same time. The coincidence factor is related to the number of dwellings. This allows specification to the (lower) design hot water flows required in relation to the maximum theoretical hot water demand calculated. The accepted Danish Standard DS439 applies the following relationship: $P_{max} = 1.19N + 18.8N^{0.5} + 17.6$ (kW) Where: P_{max} is the total heat rate required for hot water production for the group of dwellings N is the number of dwellings
COP	Coefficient of performance relates to the ratio of amount of heat energy that is supplied by the heat pumps to that which is required to drive the heat pumps (electricity powering the compressors)
Degree days	Degree days are typically used in estimating the cooling and heating demands of buildings over time. The quantitative value is the difference in°C between a fixed base temperature and the daily outside average air temperature. The cumulative values over time are assumed to be proportional to the buildings cooling or heating requirement over the same time when a constant internal building temperature is maintained by a thermostat responsive heating or cooling system. For heating degree days the fixed baseline value is typically 15.5°C, (lower than 21°C room temperatures to account for influence of internal heat gains).
Differential (temperature)	Typically, within the context of WSHP's, this refers to change in temperature (due to removal of heat) between the abstracted and returned water from an open loop pumping circuit that transfers surface water heat to heat exchangers, which in turn transfers heat via a separated closed (typically water and glycol) loop to the heat pump.
Discount rate	Using a discount rate, a per cent reduction of the value of money per year, in future years, the accounts for the time value of money. This is because receiving a pound today is worth more than receiving a pound tomorrow. The value of the discount rate used will depend on the costs of borrowing or opportunity costs of using internal funds available which depends on the organisations financial and investment policies. These rates must be decided by the organisation interested in making the investment, and will affect the conclusions made from the financial modelling.

DHW Domestic hot water

Diversity factor See Coincidence factor

GHG Greenhouse gas – the units of for their combined global warming impact potential are given as the mass of (tonnes or kilograms) of carbon dioxide equivalents.

GSHP Ground source heat pump

IRR Internal rate of return is the interest or discount rate at which the **NPV** value of all cash flows over a project lifetime is zero. The higher the IRR value is above comparative interest rates or discount rates available the more lucrative the investment. Therefore threshold of what is considered a good IRR depends on the organisation's financial and investment policies. The Excel 2013 iterative IRR function is used to produce IRR values in this study for indicative purposes only. It is important to note the excel IRR calculation assumes cash generated over the project lifetime will be reinvested at the rate calculated by the IRR. If this is not the case the IRR calculation can overstate the financial benefits. Here it is used only for indicative feasibility purposes in comparison with a counterfactual, and is therefore not an investment level assessment. Excels MIRR function would be an improvement taking into account financing interest and reinvestment returns from cash flow surplus. This applies similar logic used in calculating Financial Management Rate of Return (FMRR).

Open loop Open loop refers to the abstraction and the discharge of surface water. Typically this is the same body of water, which is termed a non-consumptive abstraction when no net reduction in surface water volume or flow occurs.

NPV NPV or Net Present Value returns the net value of future cash flows over the lifetime of the project — represented in *today's money*. Using today's money accounts for the time value of money, because receiving a pound today is worth more than receiving a pound tomorrow. NPV calculates the present value for each year's net cash flows and adds them together to get the net present value. The Microsoft Excel 2013 NPV function is used for all calculations in this study and this uses a standard formula as set out below:

$$NPV = \sum_{i=0}^{n} (values)_i / (1 + r)_i$$

Where n is the number of annual values, and r is the interest or **discount rate**. The initial CAPEX investment value made in year zero is inserted into the function as a negative value (in keeping with the convention of the function)

Renewable Heat Incentive	The Renewable Heat Incentive (RHI) is a Government scheme providing additional income (tariffs) for heat pumps and other renewable heating installations based on the amount of renewable heat generated and distributed or deemed eligible heat output (EHO).
RHI	See **Renewable Heat Incentive**
SCOP	Seasonal coefficient of performance (SCOP), also referred to as a seasonal performance factor (SPF) in RHI guidance[47], accounts for the average efficiency over the operational range of the heat pumps likely to be encountered over a typical season. To be eligible for RHI, all heat pumps must have a minimum SPF value of 2.5. SCOP is calculated from standard testing methods given in BS EN 14825:2016[48]
Seasonal coefficient of performance	See SCOP
SPF	Seasonal performance factor – see SCOP
WSHP	Abbreviation for surface water heat pump. This is also referred to as SWSHP for surface water source heat pumps in other publications. The surface 'S' has been dropped in this report for convenience.
WFD	European Union Water Frame Work Directive.

[47] Different standards or methods may be used to derive SPF depending on whether the system is for space heating, water heating, process heating, or a combination. OFGEM RHI guidance Vol 1 (v7, 24/032016) suggests *possible standards that can be used are EN 14825 for space heating-focused systems and EN 16147 for hot water systems. EN 14825 refers to the 'Seasonal Coefficient of Performance' (SCOP), and the calculations are outlined for both the active mode SCOP (SCOPon) and the net SCOP (SCOPnet) as defined in that standard. For the purpose of the RHI, the calculation of the SCOPon or SCOPnet would satisfy the requirement for the design SPF calculation.*

[48] http://shop.bsigroup.com/ProductDetail?pid=000000000030323335

09 Appendix

Detailed review of the ecological impact potential of WSHP discharges

09.1 Modelling the extent and temperature gradient of the discharge plume has been suggested by the EA's senior adviser, though this suggestion was clearly aimed at the discharge permit application process post design level assessment. Modelling the zone of influence of temperature changes would be useful but only after establishing that it is possible to understand the effects of temperature reductions on biological communities.

09.2 Before any detailed fluvial modelling, baseline screening and scoping would require a preliminary ecological appraisal approach[49], in this respect the following questions would need to be answered first.

1) What protected biota and ecological communities are present or could be present with wider restoration objectives that could potentially be exposed to heat pump discharges (baseline).

2) Whether there is sufficient scientific evidence to determine what impacts of cooler water discharges can be on protected biota, and ecological communities. (screening risk of impact)

3) Whether that evidence can help establish if the worst case maximum temperature differences from the heat pump discharge are likely to be significant to these protected biota and the river's current and future WFD ecological status. (scoping the potential impact significance)

1-3 are documented in this appended section that follows

Ecological baseline and species potentially impacted

Protected Habitats

09.3 Much of the river Wensum is a designated a Site of Special Scientific Interest and also has Special Area of Conservation status. However, the designations boundary does not extend to the study area, and ends approximately 3 km up river from Dolphin Bridge (the boundary for this feasibility assessment) and approximately 7 km from St Anne's Quarter.

09.4 The majority of the length of the river Wensum flowing through Norwich city centre below New Mills Yard is largely through urban residential and industrial buildings within 0-10 meters of the banks. These stretches have been channelised and have modified river banks of brick, concrete and steel sheet piling for boat navigation. There are likely to be few areas of ecologically sensitive habitats and limited potential for improvement in these modified bank side areas in deeper sections.

Biological water quality indicators - macroinvertebrate surveys

09.5 Macroinvertebrate surveys have been conducted at New Mills Yard approximately 3 km upstream of St Anne's Quarter (fig 10) since the mid 1990's to determine changes in biological water quality. The site is below the sluice gates where water is likely to be more aerated and mixing will offer a more uniform temperature than slow moving stretches adjacent to St Anne's Quarter.

09.6 This single sample site restricts applying more general conclusions to the baseline water quality of the slower, deeper stretches of the river in the study area. The biotic indices ASPT (average score per taxon) and NST (number of scoring taxa) and Biological Monitoring Working Party (BMWP) are shown in fig 11.

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[49] CIEEM 2016 *Guidelines for ecological impact assessment in the UK and Ireland: terrestrial, freshwater and coastal*. Second edition January 2016. Chartered Institute of Ecology and Environmental Management (CIEEM).

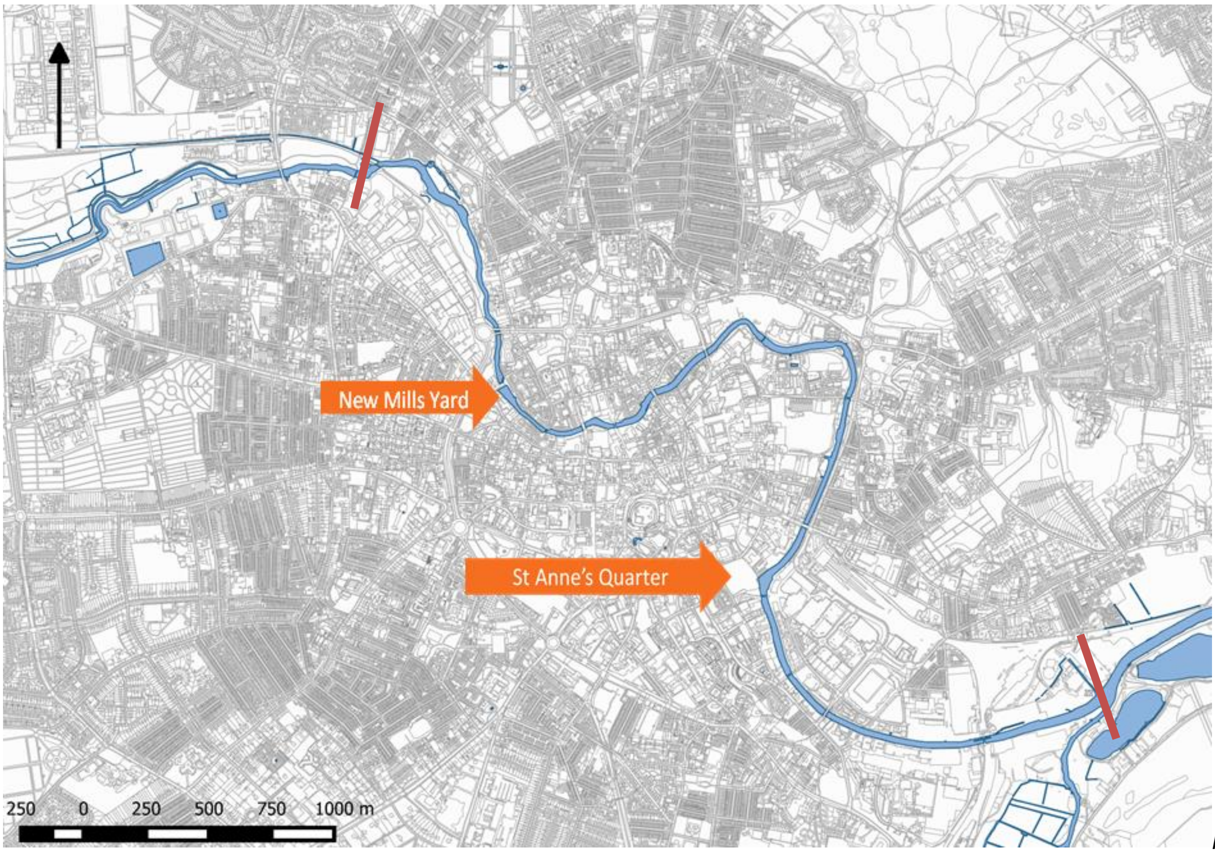

Fig 10. New Mills Yard sample site for macroinvertebrate survey results (fig 7) and Water Framework Directive assessment site location. Red bars indicate study boundary .map data: OS MasterMap®

09.7 As a metric of water quality for the sample site the average score per taxon (ASPT) indicates that the river water quality has declined from very good biological quality in the mid 1990's to poor biological quality after the turn of the century. The statistical significance of sample results cannot be verified. The lower BMWP score in more recent samples indicates a reduction of river water quality that has given rise to a greater abundance of more pollution tolerant macroinvertebrate species, with fewer different species being sampled.

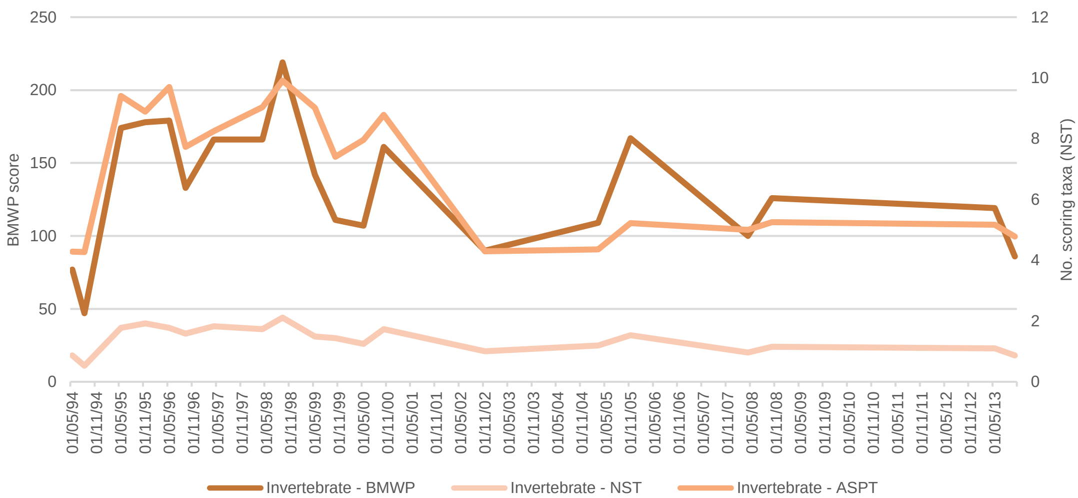

Fig 11 The biotic indices ASPT (average score per taxon) and NST (number of scoring taxa) and Biological Monitoring Working Party (BMWP) for the river Wensum, New Mills Yard. Samples taken between 1994 and 2013.

BMWP		ASPT	
BMWP Score	Biological Quality	ASPT	Water Quality
Over 100	A. Very Good Biological Quality	Over 7.0	Very Good (natural)
71 - 100	B. Good Biological Quality	6.0 – 6.9	Good
41 - 70	C. Fair Biological Quality	5.0 – 5.9	Fair
11 - 40	D. Poor Biological Quality	4.0 – 4.9	Poor
0 - 10	E. Very Poor Biological Quality	3.9 or less	Very Poor

Table 3 The BMWP score is the total score from all species of invertebrates found in a sample. Each species is scored based on their sensitivity/tolerance to pollutants. The higher the score the most sensitive/least tolerant the species are to polluted water. The number of species present is indicative of the habitat diversity.

Crustaceans and molluscs

09.8 Surveys have been conducted at St. Anne's Quarter for protected species (22/09/15)[50]. Previous field survey work was undertaken in 2008 by Norfolk Wildlife Services specifically for White Clawed Crayfish (Austropotamobius pallipes) and Compressed River Mussel (Pseudanodonta complanata). The survey found no evidence of these species or non-native crayfish in the River Wensum adjacent to the site.

09.9 The 2015 survey report does not clearly indicate whether attempts were made to actively survey for these species (capturing crayfish using traps or surveying mussels by grab sampling the river bed) but concludes that the likelihood of this species colonising this stretch of river is low.

Fish

09.10 Environment Agency fish surveys for the stretch of river Wensum are not published or available. The river Wensum in the study area has a characteristic lowland river cyprinid fish community. The presence of most of the common freshwater species such as roach, chub, bream, perch and pike are known to be present throughout the study area, down river from New Mills Yard. Carp and tench are known to have been caught by anglers in the slower moving water above New Mills Yard sluice.

09.11 Records indicate species such as brown trout, barbel, dace, stone loach, brook lamprey and bullhead are present in the river Wensum, but are only likely to be found outside of the study area in more lotic waters or clearer chalk stream habitats.

09.12 Brook lamprey and bullhead are protected species under the EU Habitats Directive, with distribution recorded in the river Wensum's designated Special Area of Conservation (SAC) upstream of the study area[51].The most endangered fish species that may be present is likely to be the freshwater eel[52] which has suffered a significant population decline in the past 30 years.

09.13 The eel's life history makes it vulnerable during the species early juvenile migration from the sea to rivers as glass eels transforming into silver and yellow forms. Eels have been surveyed in the higher reaches of the river Wensum so it is possible that the river Wensum may be used as a migratory route if not habitat for an adult population.

Other rare species

09.14 The survey by Norfolk Wildlife Services confirmed that no other protected or rare species such as aquatic snails, newts, water voles or otters were considered likely to occur on site or adjacent to the river bank in St Anne's Quarter. This is assumed to be reflective of most of the predominantly urban and heavily modified stretches of the river Wensum flowing through most of the study area.

09.15 Desmoulin's whorl snail, (Vertigo moulinsiana), is an air-breathing snail that inhabits fens and flowing waters with marshy or wetland margins, feeding on the sedges and reeds[53]. Though it is listed as a Protected species under the EU habitats directive and is present in the Wensum SAC designation (up river of the sites), it is unlikely to be present where there are few river margins likely to offer wetland sedges and reeds through the urbanised deeper sections of the lower Wensum flowing through the City.

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[50] The survey for sensitive species was conducted as part of planning requirements for improving the river-side piling. The compressed river mussel is known to be present below Carrow Bridge to the south of the site. It is a Red Data Book 3 Category rare species and is listed as a UK Biodiversity Action Plan Priority species.

[51] The current UK status and distribution of EC Habitats Directive interest features: Brook lamprey, Joint Nature Conservation Committee Website

[52] The Eel is on the IUCN's Redlist of threatened species classed as critically endangered (2014)

[53] Killeen, I J. (2003) Ecology of Desmoulin's Whorl Snail Conserving Natura 2000 Rivers EU LIFE. Ecology Series No. 6

Aquatic macrophytes and phytobenthos

09.16 Macrophytes inhabit the shallower sections of river where light is more available. With the exception of rotten timber stumps that have been colonised by small macrophytes (unidentifiable at distance) few aquatic macrophytes inhabit the canalised deeper stretches of the Wensum that are suitable for heat pump water abstractions.

09.17 The 2015 WFD assessment of this section of the river Wensum classifies the status of macrophytes in the study area as Moderate whereby: *The composition differs moderately from the type-specific communities and are significantly more distorted than those observed at good quality. Moderate changes in the average abundance are evident*[54].

09.18 A survey of aquatic flora is beyond the scope of this desk based feasibility study during winter so evidence is restricted to published and available data. The study area does not feature in the UK wide Joint Nature Conservation Committee River Macrophytes Database[55]. The nearest survey site is Hellesdon Mill so limited data is available on the presence of particular species.

Screening potential environmental impacts associated with open loop river WSHP installations

Construction and maintenance

09.19 Modification of the river bank within 10 meters from the river is required for construction of the energy centre bunker and laying pipework. This has a risk of increased sediment load from run off or minor oil/fuel spillage from ground works and plant operation. These are considered to both be temporary hazards with no irreversible impacts to the rivers ecological status.

09.20 Dredging/excavation of the inlet may be required to allow emplacement of abstraction intake screens in line with the sheet pilings of the river bank. This may risk causing temporary turbidity with the possible impact of a minor oxygen sag from organic loading. This should not constitute a significant constraint given there is existing provision for dredging operations in this section of the river for navigational reasons.

09.21 Maintenance of the filter screens, heat exchangers and pump sets would not constitute a risk to river pollution where these processes follow good working practices. In all cases, though recently withdrawn, it is assumed practices follow the principles from PPG5 pollution prevention guidelines for works or maintenance in or near water courses[56].

River water abstraction

09.22 A heat pump removes heat from the river water and discharges water that is cooler than the ambient river water temperature. The quantity utilised for water source heat pumps is unlikely to result in a depleted stretch of water due to the technical/economic limitations of pumping such a large quantity in any individual scheme.

09.23 Therefore, within reason, the non-consumptive abstraction of river for an open loop water source heat pump will not impact river water flow or water resources.

09.24 The key impacts that have been identified for non-consumptive water abstraction are the entrainment and uptake of sensitive river fauna such as juvenile species of fish.

Discharge of cooled water

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[54] See appendix for Table 1.2.1 text or p39 of the Water Framework Directive 2000/60/EC.

[55] River Macrophytes Database JNCC DEFRA.

[56] PPG 5 & PPG6 Pollution Prevention Guidelines: works and maintenance, [and] construction in or near water. Environment Agency 2007.

09.25 The cooled plume of water discharged back into the river has the potential to impact the ecology of the river in a number of ways:

1. An impact on the ambient average temperature of the river after mixing.
2. Exposure to abrupt temperature gradients between the plume and the mixing zone
3. A change in velocity where the plume direction is at a different angle to the river flow and/or at a different velocity to the river flow (scouring potential).

Ambient temperature impact

09.26 The removal of 2°C of heat from 172 m^3 of water per hour (maximum) and at a low (Q95) winter river flow of 1.9 m^3/sec[57] is a theoretical equivalent to cooling the whole the river water volume flowing past by 0.05°C assuming immediate and perfect equilibrium of heat dispersion through the mixed water bodies. For Q70 winter flows the temperature reduction would be less than half this value.

Localised temperature gradients

09.27 Since the cooler water temperature discharged to the river will not actually equilibrate to ambient temperatures immediately there will be a cooler plume of water. Diffusion and mixing will lower the gradient for each metre downstream of the discharge point until the temperature gradient reduces to more or less equilibrate with ambient river temperature.

[57] This is a Wensum flow rate that is exceeded 95% of the time between October and March. It has been derived from combining flow archive data 1995 -2014 for the river Wensum and river Tudd (a tributary).

Potential scope for ecological Impacts

Impacts on freshwater fish from acute (plume) cold water exposure

09.28 There are a number of non UK studies relating to thermal shock impacts where fish communities, acclimated to warmer discharges from industrial cooling installations, have been returned abruptly to cooler thermal regimes when facilities had been decommissioned. In addition cold weather fish kills have often occurred in extended sub-zero conditions, though reported primarily due to oxygen deficit due to ice cover.

09.29 Most scientific evidence of thermal tolerance for UK species, however, has been established using so called thermal polygon plots from laboratory experiments (table 4) where experimental conditions and experimental approaches differ[58]. Fish may be acclimated to various temperatures before being exposed to test temperatures at differing rates of temperature reduction.

09.30 Acclimation is conducted with various temperatures and timeframes from days to weeks. Therefore fish species lethal limits are influenced by these acclimation temperature regimes prior to conducting thermal limit tests. This indicates evidence of a potential lethal risk for fish species such as roach and chub acclimated to a warmer summer river temperature if an abrupt but sustained exposure to a much cooler plume (>10°C temperature difference) was likely.

09.31 The experimental data on fish response to low temperatures (table 4) is not directly applicable for assessing the likely sub-lethal or metabolic impacts of an ambient reduction in temperature. The laboratory experiments may not represent the much slower rate of temperature changes experienced by fish in the river environment or reflect longer term adaptation to cooler water regimes[59]. It is difficult to extrapolate these experimental exposure data to the sensitivity or adaptability of fish communities to cooler ambient water temperatures and its longer term implications.

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[58] Differences in experimental methods make a universal definition of lethal temperature limits difficult. Experiments may determine a Critical Thermal Maxima/Minima (CTM) or an Incipient Lethal Temperatures (ILT) for characterising the limits of fish species thermal stress. CTM is found where temperature is changed from acclimation temperature incrementally until death occurs, usually in 50 percent (LD50) of the test species. Increments vary though studies typically see 1-2 C per hour as an acceptable approach based on empirical sensitivity assessments. ILT is the temperature where certain stress related behaviour is produced by the fish species indicating proximity to death. The chosen acclimation temperature can alter the CTM and ILT. Acclimation time varies in experiments from days to a week. There may also be plasticity for tolerance to temperature extremes of the same species taken from populations that are exposed differing environmental temperature regimes.

[59] This is exemplified in the case of experimental data for roach for which the lethal temperature from acclimation at 23 ◦C was reported (table 4) as 7◦C. The river Wensum temperature has been recorded at 4◦C (fig 5) with no significant fish mortalities observed. Implications for metabolic response in winter are not clear from available scientific literature.

Table 4 Evidence for lower thermal tolerance of freshwater fish present or potentially present in the river Wensum

Fish Species present in the river Wensum	**Reported minimum temperatures**		**Description**	**References**[60]
	Adult	Juvenile		
Bream (*Abramis brama*)	No data	No data		
Brook lamprey† (*Lampetra planeris*)	No data	No data		
Bullhead† (*Cottus Gobio*)	1°C		ILT with acclimation at 7°C	Elliott & Elliott 1996
Chub (*Cephalus Leuciscus*)	8 °C	No data	*Extreme minimum*	Elliott, 1981; Alabaster & Lloyd,1982
Dace* (*Leuciscus leuciscus*)	4 °C	No data	Lower bound for *tolerated temperature*	Wüstemann & Kammerad (1995)
Eel (*Anguila anguila*)	3 °C <1°C		State of torpor from an acclimation to 29 and 23 °C respectively	Sadler, 1979
Gudgeon* (*Gobio gobio*)	No data	No data		
Minnow *(Phoxinus phoxinus*)	No data	No data		
Perch (*Perca fluviatilis*)	0.1 °C & 6 °C	No data	Lethal and lower boundary temperature.	Filon, 1972
Pike (*Esox lucius*)	4°C, & 0.1°C	No data	*'extended* [lower] *range'** *Lower lethal temperature* **	*Ginot et al., 1996: Rhone, France. **Casselman,1978: Ontario, Canada
Roach (*Rutilis rutilus*)	7 °C 7 °C	No data	Lower boundary temperature. Incipient Lethal Temperature of 7°C (ILT) with an acclimation at 23 °C	Mann, 1996; Noges & Jarvet, 2005 in Estonia, ILT reported by Cocking 1959
Rudd (*Scardinius erythrophthalmus*)				
Stone Loach* (*Noemacheilus barbatulus*)	No data	No data		
Three Spined Stickleback (*Gasterosteus aculeatus*)	No data	No data		

ILT –
Insipient Lethal Temperature58

† Likelihood of being present in the study site is considered to be low, but is included as a species in the Wensum SAC designation further up river.

**Likelihood of being present in the study site is considered to be low.*

Impacts on freshwater fish from changes in ambient temperature regimes

[60] Studies cited in Y. Souchon, L. Tissot. Synthesis of Thermal Tolerances of the Common Freshwater Fish Species in Large Western Europe Rivers. Knowledge and Management of Aquatic Ecosystems, 2012, 405 (3), 48 p.

09.32 Whilst there is scientific literature reviewing warming water impacts and summer water temperatures on cyprinid fish species[61] a review has not revealed any studies of cold water impacts on UK freshwater fish in their natural habitat.

09.33 Scientific studies in lakes and rivers do show that water temperatures are related to the variation in growth rate and reproduction cycles of freshwater fish species[62]. However these studies are largely concerned with summer temperatures and correlate impacts with river water temperatures greater than 12°C. This has been considered to be the minimum for cyprinid fish growth, which, for rivers in the UK, typically restricts the growth season from mid-April to October[63].

09.34 In addition mating, spawning and first period of growth for coarse fish occurs in that order from mid-March. Research suggests that warmer river temperatures (>12°C) and related river flow regime during the critical summer period are key factors explaining variation in successful recruitment years for cyprinid fish populations in lowland rivers[64]

Coldwater impacts on crayfish

09.35 Guidance for Natura 2000 published by Natural England suggests that minimum lethal temperatures are unavailable for crayfish though the 1–4°C that prevails under ice in winter is not usually lethal to cool-water crayfish. This suggests if white clawed crayfish were to recolonise the river near St Anne's Quarter, any 3°C winter discharges from water source heat pump discharges would be within their tolerance range. No studies were found to evidence any metabolic or life history impacts that could occur from reductions in water temperatures.

Impacts on aquatic plants

09.36 The shallower sections where macrophytes commonly occur are considered unsuitable for heat pump water abstraction due to likely near surface, cooler water temperatures in winter having been identified as less viable for WSHP's. The lower reaches of the study area are deeper and few plants are present in these stretches.

09.37 It is unlikely that shallowing or widening the river to allow colonisation by macrophytes in the area near St. Anne's Quarter would be possible in the foreseeable future due to the navigational requirements and riverside residential development that is very close to the steel piling river banks.

09.38 Few scientific studies on the impact of cooler water discharges were found. A number of studies suggest that water releases from the base of dams and impoundments, where water has been cooler relative to river water (due to stratified cooler hypolimnion), appears to enhance habitat conditions for macrophyte communities. However the impacts may affect habitats year round and therefore may not reflect the pattern of discharges typical to heat pumps.

Changes in flow and scouring

At the maximum flow rate of 172 m^3 per hour or 0.048 m3 per second. With a 150mm ID discharge pipe this could potentially lead to discharge velocities of up to 2.7 metres per second. At this velocity discharge flow directed at or near the river bed could risk scouring and entrain river bed sediment and silt. This could affect

[61] Nunn, AD, Cowx IG, Frear PA& Harvey, JP (2003). Is water temperature an adequate predictor of recruitment success in cyprinid fish populations in lowland rivers? Freshwater Biology, vol. 48, 579–588.

[62] For example in Roach: Grenouillet, G, Hugueny, B, Carrel, GA, Olivier, JM & Pont, D 2001. Large scale synchrony and inter-annual variability in roach recruitment in the Rhône River: the relative role of climatic factors and density dependent processes. Freshwater Biology vol. 46, 11-26; Gillet, C & Quétin, P 2006, Effect of temperature changes on the reproductive cycle of roach in Lake Geneva from 1983 to 2001 Journal of Fish Biology, vol.69, 518-534.

[63] J. R. Britton, (2007) Reference data for evaluating the growth of common riverine fishes in the UK. Journal of Applied Ichthyology. Volume 23, Issue 5, 555–560.

[64] Nunn, AD, Cowx IG, Frear PA, & Harvey, JP (2003). Is water temperature an adequate predictor of recruitment success in cyprinid fish populations in lowland rivers? "Freshwater Biology, vol. 48, 579–588.

water turbidity until finer sediment is scoured out and no longer risking disturbance to any macroinvertebrate community in the immediate vicinity and down river.

Localised temperature impacts (from plume and mixing boundary) and mitigation

09.39 The experimental research in table 3 only indicates the impacts on exposing fish acclimated to higher temperatures which are then exposed to relatively steep temperature gradients over hours and days, often to the point that response indicating mortality is imminent are observed[65].

09.40 The population of fish in the river Wensum are unlikely to be confined to discrete areas when river water temperature is less amenable. Fish are observed more frequently where cooler water occurs in shaded bank areas during summer. Conversely this behaviour is also likely to extend to avoidance behaviour for any cooler water plumes discharge during winter.

09.41 The impact of the discharge plume displacing fish from what was formerly their habitat is considered to be minimal. With the absolute minimum water source heat pump discharge temperature limited to 3°C, and a floating temperature reduction limit of 2°C lower than the ambient river temperature, it is unlikely that the influence of the plume on local water temperature would extend beyond tens of meters downstream from the point of discharge.

09.42 For the maximum 172 m^3 per hour flow when the heat pump specified for St Anne's Quarter is in operation, the exposure to the maximum 2°C temperature gradient would be partially ameliorated through enhanced mixing by employing a diffuser on the discharge pipe. Other options can be staged mixing pools to reduce the temperature gradient with river water before discharge.

Ambient temperature change impacts (after mixing of cooler water)

09.43 The maximum impacts on ambient water temperature from heat pump utilisation will primarily occur during the winter months when maximum heat demands are made. This is largely outside Cyprinid fish typical sensitive period identified for growth and spawning (April – October).

09.44 Therefore it is less likely that fish recruitment will be affected by winter heat pump operation and associated cooler water discharges. Conversely heat pump discharge impact will be considerably reduced during summer due to much lower heating demands meaning fewer system run hours.

Entrainment of juvenile fish from heat pump abstraction intake and mitigation

09.45 The pumped abstraction of river water for heat exchange at maximum of 48 litres per second (nominal) may entrain juvenile fish into the intake, causing damage and mortality. Glass eels, a migratory juvenile life stage of freshwater eels are especially vulnerable to entrainment into the systems river water abstraction intakes. The European freshwater Eel is an endangered species and has specific protection through the Eel Directive.

09.46 This is mitigated through the use of proprietary screens with mesh spaces of <2mm wide which are angled away from the water flow to prevent entrainment of juvenile fish (table 5). These also physically prevent detritus and aquatic flora and fauna entering the intake. Further filtering is involved but these are primarily for protecting the integrity of the pump and heat exchanger operation from bio-fouling and inert contaminant build up.

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[65] More recently fish biologists have observed that low temperature extremes have less distinctive thresholds than high temperatures do on fish mortality, and state that many freshwater fish species become torpid near 0°C so that mortality is often difficult to detect in experiments, with fish reviving with exposure to higher temperatures Matthews, W.J., (2012) Patterns in Freshwater Fish Ecology.

Life Stage	**Vulnerability**	**Timing**	**Physical screens mesh size/bar spacing for exclusion (mm)†**
Glass eel / elver	Migration – estuary to tidal limit	Spring	1-2
Yellow eel (14 cm)	Migration – active swimming upstream	All year round	3
Yellow / Silver eel (30cm)	Migration – active swimming up and downstream	All year round	9
Silver eel (50 cm)	Descending adults	All year round, but mainly autumn	15

Table 5 Screen mesh spacing required to prevent entrapment or injury to various life stages of eels (Source: Eel manual[66]). † Spacing is shown worst case screen angle ***Φ*** >20 deg though this doesn't alter recommended glass eel mesh size/spacing.

Flow disturbance turbidity and scouring

09.47 When the heat pump specified for St Anne's Quarter is in maximum operation a 172 m^3 per hour discharge flow is required. To mitigate the potentially high discharge velocity causing scouring or turbidity a linear diffuser has been specified which will retard and mix the discharge flow with river water.

[66] Screening at intakes and outfalls: measures to protect eel The Eel Manual – GEHO0411BTQD-E-E. Environment Agency

Also see Screening for Intake and Outfalls: a best practice guide. Environment Agency Science Report SC030231.(2005)

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