London Borough of Brent

Heat Pump Options Appraisal Report

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London Borough of Brent

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Executive summary

Background

The London Borough of Brent (LBB) appointed Anthesis (UK) ltd (AUK), to act as their technical consultant for the South Kilburn District Energy Network. AUK brief is to sufficiently develop a technical solution (incl. drawings, design detail and specifications) to RIBA stage 3; to support completion of the project commercialisation phase.

There are two key technical deliverables for AUK:

i. Design of the Energy Centre associated within the basement of the existing Gloucester & Durham Building.

ii. Design of the district heat network (DHN) for the development; primarily for the first phase being Gloucester & Durham, Hereford & Exeter, Carlton & Granville, and the Peel Development, allowing for subsequent phases of heat demand within the constraints of the existing Energy Centre.

As part of this work, LBB asked AUK to arrange several workshops to evaluate alternative low carbon technologies that could supplement the district energy network development (DEN) and help support the council's ambitions for carbon reduction.

AUK original programme assumed that the technical partner, commercial partner, and legal partner would be appointed by 05 May 2019, with project kick-off 17 June 2019. As part of this an innovation workshop was proposed for late June 2019.

Womble Bond Dickinson were appointed as legal consultant in October 2019, however LBB had difficulty appointing a commercial consultant for the project whilst delivering under the requirements of the DEEP framework. With assistance from BEIS/ HNDU; Teno Energy and Energy Direction were appointed to the project team, in February 2020.

A technology review of Fuel Cells took place on 30 Oct 2019 with Imperial College and Doosan (fuel cell manufacturer). Further discussions took place in November 2019 with 3rd parties who were considering or had installed fuel cells. e.g. Quadrant 3 (Regents Street), TFL Palestra (Southwark). From these discussions it became apparent that:

i. Gloucester & Durham could neither accommodate the size nor weight of an appropriate fuel cell,

ii. That the unit was not responsive in terms of load changes, needing both thermal and electrical storage to make it efficient.

iii. That the unit had specific maintenance requirements that if not met would severely limit the overall safety, efficiency, and operational life of the unit.

iv. That there were safety concerns about a system storing high pressure hydrogen given its possible location.

v. That the experience of current end users did not meet expectations with Quadrant, stating that they were planning to remove their system as it was not performing (10% efficient rather than 40%), and that financially it was loss making.

A technology review of Heat Pumps with ESBi (formerly Geothermal International) took place and concluded that a heat pump solution could be viable if considering either drawing heat from boreholes, air source systems, from sewers running under the site or from vented warm air; either from the proposed HS2 vent local to the Energy Centre, or Kilburn Park Tube Station to the North of the site.

Various scenarios were modelled and reported to LBB in December 2019, with summary outputs shown below:

Scenario	Annual Net Income	CO_2 Emissions (tonnes/yr.)
Scenario A - 1 no. 375kWth CHP	£ 120,131.00	1656
Scenario B - 1 no. 513kWth Fuel Cell	£ 148,080.00	1734
Scenario C - 1no. 375kWth CHP and 1no. 513kWth Fuel Cell	£ 163,824.00	1753
Scenario D - 2no. 284kWth Heat Pumps and 1no. 193kWth CHP	£ 189,446.00	1139
Scenario E - 2no. 30.4kWth Air Source Heat Pumps and 1no. 375kWth CHP	£ 121,371.00	1652

Outputs from the Energy Pro Modelling (Phase 1 Options - December 2019)

Based on this analysis, Scenario D was the preferred scenario, giving the highest net income at the lowest emissions by a reasonable margin. It was therefore recommended that further work be carried out through a desktop feasibility study.

On 02 April 2020, AUK was instructed by LBB and GLA to proceed with a desktop feasibility study using ESBi as a specialist subconsultant. The final report was scheduled to complete in July 2020 and conclusion in September 2020.

AUK and LBB proceeded to contact HS2 and Thames Water (TW) to extract useful infrastructure, temperature, and flow data to aid the desktop design of appropriate captive technologies. With assistance from LBB, AUK was able to contact HS2 and by late May 2020, had established through ESBi, opportunities for heat extraction from Ground Sources and the HS2 vent as follows:

- 6 no. 150m deep boreholes (Cambridge Gardens) and 14 no. 150m deep boreholes (Granville Road Play Area), capable of generating 130kW_{th} peak heat demand in heating only mode and 250,000kWh/year.
- Borehole and heat pump capacity increasing to 250kW_{th} and 380,000kWh/year by utilising waste heat to recharge the ground; increasing the heat pump coefficient of performance by ensuring the ground temperature is maintained, with the HS2 ventilation shaft to the north of the site acting as the main source of waste heat.
- An alternative to the HS2 shaft is Kilburn Park tube station, which itself has a ventilation shaft outlet above the station building. The station is much closer to the Cambridge Gardens site and may be a better option for heat rejection and ground recharging. No information was available on the air flows and temperatures from this source.

The quantum of available heat from these sources was thought to relatively small if compared with the overall development, and work continued on the basis that Thames Water would soon provide flow modelling data for local sewers, in the hope that this would represent a more significant contribution in waste heat available.

As this point the project was delayed with TW requiring a multi-party NDA to be signed before they would release information. TW issued their NDA on 08 June 2020. It took until 01 July 2020 to finalise the NDA between ESBi, AUK and TW and by 22 September 2020 between LBB, AUK and TW. This was compounded by the fact that TW altered the wording of their NDA mid process.

In July 2020, in an effort to move the project forward, AUK undertook an online document search and found drawings and details in the public domain that indicated that there were two large local drains, one at 14m deep for storm water relief and one at 28m deep for mixed sewerage storm water; and a conference paper based on flow modelling carried out by London Southbank University (LSBU) and Thames Water. This indicated that at least 750kW of heat could be abstracted from combined storm sewers if certain conditions were met. In this case the modelled sewer was significantly shallower and smaller in diameter than the sewers identified in the asset location search.

On 28 September 2020, TW provided flow data for the main Ranelagh trunk sewer running South along Kilburn Park Road. This indicates a peak flow of 600 l/s and a night flow of 210l/s. However, these are modelled flows, not measured; and lack measured temperature data.

AUK now have sufficient information from TW to complete the desktop feasibility study as instructed and presented within this report.

Approach

AUK was commissioned by the London Borough of Brent Council (LBB) to review the existing Brent Energy Centre design and look at alternative low-carbon heat generating technologies that could be integrated into the overall scheme.

Preliminary analysis via EnergyPro modelling and related workshops were consistent in agreeing heat pumps integrated into the current design could give benefit both financially and environmentally and if subjected to further feasibility analysis and techno-economic modelling; would determine the best-suited energy centre configuration to accommodate the additional design scope.

The Alternative Energy Workshop Report issued in December 2019, concluded that heat pumps used as a pre-heat on the district heating network prior to the flow into a CHP engine could be the most beneficial and feasible, to be integrated, delivering the best income for the lowest carbon contributions.

AUK recommended to LBB to commission a specialist to carry out a feasibility assessment to look further into which heat sources can be utilised for heat pumps (ground, water and/or air).

Based on this assessment, further additional engineering and updated technoeconomic modelling could be carried out to determine the final mix of technologies that might be integrated into the existing energy centre design.

ESBi were commissioned to review 4 basic aspects to the scheme:

- Ground/water Source heat
- Sewer source heat
- HS2 Vent source
- Respective capturing Technologies

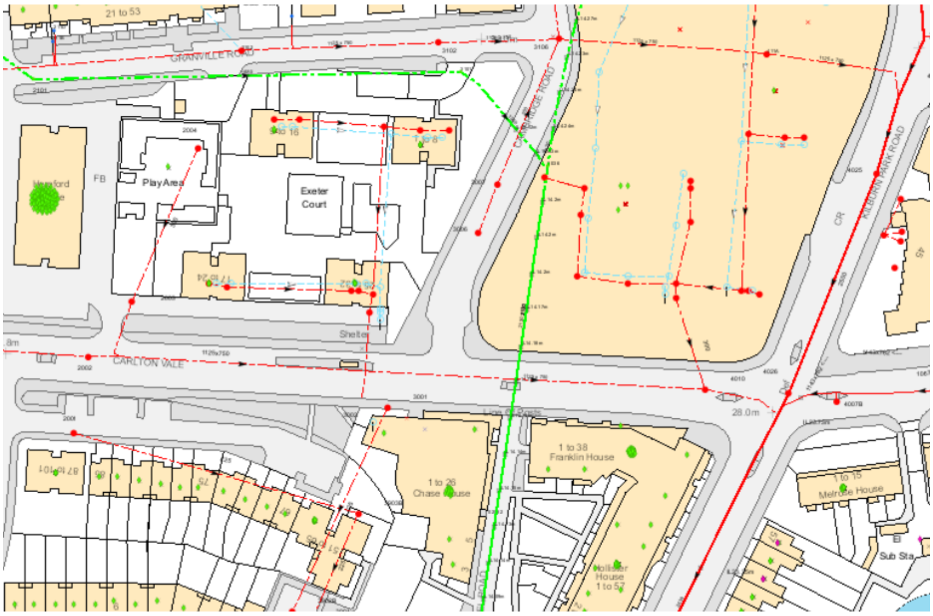
A desktop feasibility study was proposed that would include an assessment of each source and the potential quantity and quality available from each; to include outline Geotech considerations, and seek to engage with Thames Water in relation to the potential local sewer waste heat source.

From this ESBi would be able to establish the relative technologies to be used in each scenario, what potential heat capacity is available and the possible available technology to capture any available heat. Initial cost assessments would be provided for each option, and preliminary temperature provisions included.

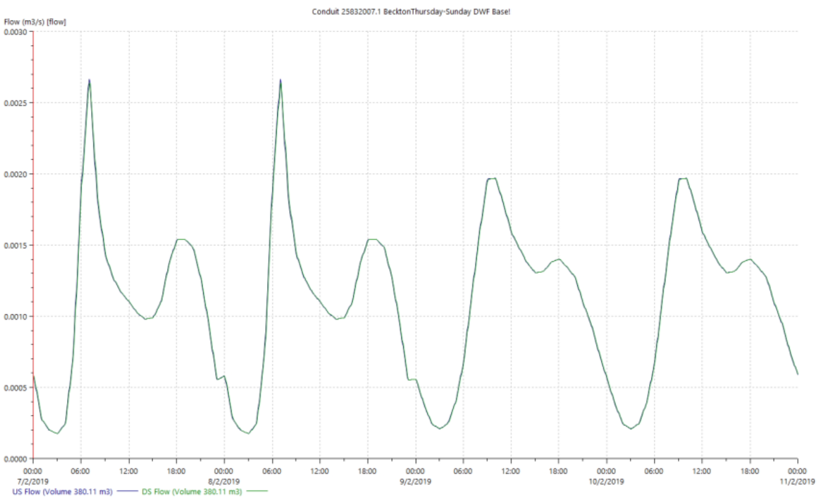
Focus on Sewer Waste Heat

There are two large sewers running South close to the Gloucester and Durham site. Referring to the sewer map location data reference TQ2583SW, the green coloured sewer running below Gloucester & Durham is a “storm water only” drain at c. 14m deep. From the available information the day-time flow peak is low (2.5 l/s) and of no practical use for heat recovery purposes.

The sewer running along Carlton Vale is a foul/combined line and carries dry weather flow. However, the second manhole identified in this area TQ25833036 is part of the storm relief network and will only carry storm flow. This storm relief network is shown in the green lines below:



Carlton Vale TQ25832002

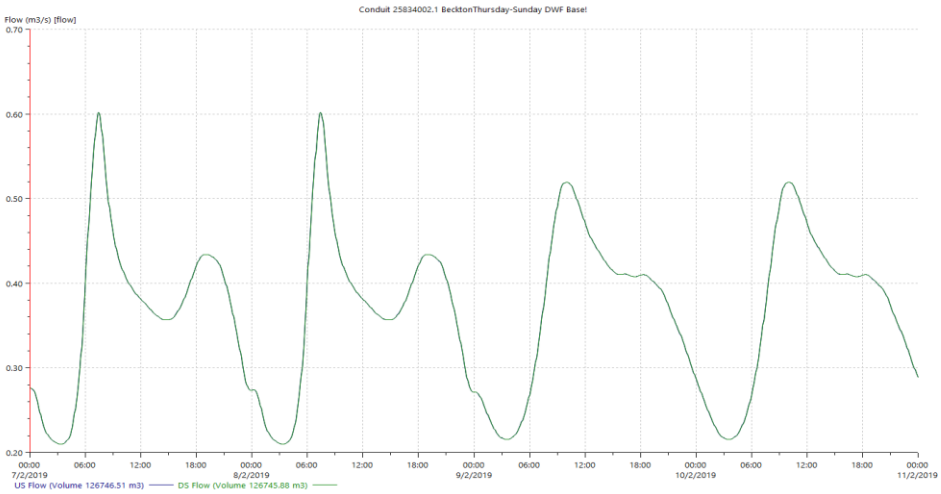


Flow data for Carlton Vale

The difference in the diurnal pattern between weekday and weekend is clearer at this point in the model. However, the flows are very low as this line only serves a small upstream catchment. Night-time flows are less than 0.5 l/s and the and the daytime peak is only around 2.5 l/s.

The Carlton Vale sewer connects to the top of the Ranelagh Trunk sewer just downstream of the selected location. The red coloured sewer to the east below Kilburn Park Road is a brick built ‘trunk’ combined sewerage and storm water drain at 28m depth and diameter 2.5m. By contrast, the Ranelagh serves a much greater part of the upper catchment and the flows are significantly higher. Night-time flows are around 210 l/s with peak weekday flows of 600 l/s and weekend peaks of 520 l/s.

This is much more significant than anything previously estimated by ESBi based on the LSBU paper and provides a good opportunity to further investigate options for waste heat recovery.



Flow data for Ranelagh Sewer

Model database used - M:\sewerage modelling\- New Projects\Beckton\#Latest Beckton Model\Beckton25-02-2019.icmm

Sewer map location data reference TQ2583SW

Summary of heat sources and capacity

Based on the information available, we believe that Thames Water would put a “floor” on heat abstraction from the sewer of 10˚C. Below that there is a risk that the sewage flow would solidify into a “fat-berg” and potentially impact downstream treatment.

Typical sewers run at 10 - 25°C but we have no specific data about the Ranelagh Sewer. However, based on the modelled flow, it is expected to be able to extract up to 3.7MW of heat via a heat exchanger and heat pump using XP10 (R513A GWP – 631) refrigerant with an estimated COP of 3.5.

Sewer Flow Rate (m^3/s)	Sewer Flow Rate (kg/s)	dT (K)	Available Heat from Sewage (kW)	Heat Pump Generation @CoP 3.5 (kW)
0.210	210	1	882	1,235
0.210	210	2	1,764	2.470
0.210	210	3	2,646	3,704

In terms of the system itself, typically it would have a macerator/pump that converts the sewage into a slurry that can be pumped mounted alongside the sewer as a side chamber. The sewage is then pumped to a heat exchanger at 10 - 25°C, where heat is extracted and fed into a heat pump. The heat pump increases the temperature of the available heat to c 50˚-55°C.

The SK-DEN area is short of available electrical power. UKPN advised that the area only has 750kWe available for the whole South Kilburn development. At a Coefficient of Performance of 3.5, the heat pump will require a power supply of c 1MW. To provide this power either the network will need to be reinforced or a gas fired CHP could be installed to provide this power. The waste heat from the CHP can then be fed back into the heat network.

In terms of other sources, the total amount of potential heat from the area surrounding the South Kilburn area is summarised below:

*Assumes sewage flow can be accessed 80% of the year

Heat Pump Source	Heat Pump Capacity (kW)	Annual Generation (kWh)
Ground Source	130	250,000
HS2 Waste Heat	120	130,000
Wastewater Heat Recovery	3,704	25,957,632*
Total	3,954	26,337,632

EnergyPro Modelling

The scenarios listed below assess the various heat pump options available which would be expected to meet the bulk of the annual heat loads as compared against a base case employing 6MW gas boiler plant and 260kWe/ 375kWth CHP (Base Case 1).

In Scenarios 3 & 4, the heat capacities of the proposed systems would allow a larger heat demand to be met. Therefore, a second base case (Base Case 2) was developed with increased boiler capacity (8MW) to allow a more realistic comparison of these scenarios.

The plant options and scenarios that were modelled are as follows:

Plant Options:

Base case 1: 2 no. 700kWth Boilers, 2 no. 2300kWth Boilers, 1 no. 375kWth CHP, 5 no. 10,000 litre Thermal Storage.

Base case 2: 3 no. 700kWth Boilers, 3 no. 2300kWth Boilers, 1 no. 375kWth CHP, 5 no. 10,000 litre Thermal Storage.

Option 1: 130kW Ground Source Heat Pump (GSHP)

Option 2: As Option 1, with 120kW Heat recovery from HS2, used as recharge for the GSHP, resulting in 250kW GSHP

Option 3: 6 no. 625kW Heat Pumps using waste heat from sewage water

Scenarios:

- Base case (BAU1): 2x 700kWth Boilers, 2x 2300kWth Boilers, 1x 375kWth CHP, 5x 10,000L Thermal Storage (6MW)
- Scenario 1: Base case + Option 1
- Scenario 2: Base case + Option 2
- Base case 2 (BAU2): 3x 700kWth Boilers, 3x 2300kWth Boilers, 1x 375kWth CHP, 5x 10,000L Thermal Storage (8MW)
- Scenario 3: Base case + Option 3, removing 2x 700kWth Boilers
- Scenario 4: Base case + Option 2 + Option 3, removing 2x 700kWth Boilers

Due to the current constraints in local power infrastructure; each of the options and scenarios were run in EnergyPro considering 3 different CHP operating regimes, dependant on the ability to import and/or export electricity with the following general assumptions:

1) Full Grid Import/ Export Capacity (Expanding current infrastructure)
2) Partial Grid Import/ Export Capacity (600kWe import, 263kWe export)
3) No Grid Import/ Export

General Assumptions:

- Flow/ Return temperatures of 55/50°C
- Wastewater flow/return temperatures of 12/9°C
- Components operating on a linear performance curve
- Boilers operating at 60% Utilisation
- Storage loss calculated using EnergyPro default values for insulation
- Thermal storage units not independent to specific components
- Gas price = 0.04 £/kWh
- Electricity price = 0.12 £/kWh
- Additional plant loads not considered

The base case (BAU) can be considered at varying heat demand, to highlight the implications of providing additional heat capacity where it exists. This is shown on the basis that there may be an opportunity to reduce installed boiler capacity whilst serving additional heat demand across the development; dependent upon which plant option, scenario and CHP operating regime fits best with the project success factors.

The EnergyPro results are summarised below:

Full Grid Import/ Export Capacity

Scenario	Annual Net Income (£)	CO_2 Emissions (tonnes/yr.)
BAU – 6MW	1,243,549	5,021
S1	1,278,691	4,784
S2	1,311,116	4,565
BAU – 8MW	1,853,319	7,156
S3	2,286,064	3,154
S4	2,262,732	2,994

This demonstrates the scenarios under the condition where additional infrastructure is installed to allow unlimited grid capacity.

Partial Grid Import/ Export Capacity (600kWe import, 263kWe export)

Scenario	Annual Net Income (£)	CO_2 Emissions (tonnes/yr.)
BAU – 6MW	1,243,549	5,021
S1	1,278,691	4,784
S2	1,311,116	4,565
BAU – 8MW	1,853,319	7,156
S3*	2,441,954	3,746
S4*	2,442,388	3,744

The first four scenarios run the same on partial and full grid capacity, but scenarios 3 and 4 could not be modelled, and for the purposes of approximate comparison were modelled on no grid capacity.

*No grid capacity

No Grid Import/ Export Capacity

Scenario	Annual Net Income (£)	CO_2 Emissions (tonnes/yr.)
BAU – 6MW*	1,243,549	5,021
S1*	1,278,691	4,784
S2*	1,311,116	4,565
BAU – 8MW*	1,853,319	7,156
S3	**2,441,954**	**3,746**
S4	2,442,388	3,744

*Denotes full/ partial grid capacity - these scenarios could not run under a strictly no grid capacity situation. The BAU cases require some way to export the electricity produced by the CHP, which could be fulfilled by plant loads. The minimum electricity load produced by the CHP is greater than the maximum load for the heat pumps in S1 and S2, this may also be alleviated by plant loads. Both of these solutions will require further analysis.

EnergyPro Conclusion

Scenario 3 offers the best opportunity for further analysis both in net revenue and carbon reduction whilst providing an opportunity to consider a wider peak load across the development; on the basis that the final heat demand is greater than the current 6MWth allowance constrained by the existing shell and core energy centre.

Summary Financials and Carbon Position

The following analysis is based on the options and costs extracted from ESBi inputs detailed in sections 2 and 3. The Energy summary is provided to show a comparison in heat pump (options) operating costs, O&M costs (whole life costs) and CO2 savings, compared against the equivalent sized gas boiler system.

	A(UK) Design 2018 (typical year - phase 1)		ESBi Model (Whole Scheme)		ESBi Sewer Based Model (Whole Scheme)	
Electric	£0.09	/kWh	£0.13	/kWh	0.13	/kWh
	0.41	/kWh	0.2332	/kWh	0.2332	/kWh
Gas	0.025	/kWh	£0.03	/kWh	0.03	/kWh
	0.1836	/kWh	0.1836	/kWh	0.1836	/kWh
Scope	CHP and Boilers		CHP and Boilers		Sewer Based System	
System Capacity	3,350	MWth	3.784	MWth	3.784	MWth
	0.26	MWe	0.26	MWe	0.26	MWe
Capex	£2,310,000		£1,890,000		6,136,000	
Electricity Generated	1701	MWh	1,971	MWh	7,577	MWh
Gas Used	5600	MWh	29,064	MWh	29,064	MWh
Heat Produced Boilers	1053	MWh	26,158	MWh	26,158	MWh
Heat Produced CHP	2009	MWh		MWh		MWh
Operational Costs	£51,086		£75,700		£75,700	
Energy Costs	-£13,090		£615,703		£985,010	
Carbon	1,028	T CO2e	5,336	T CO2e	1,767	T CO2e
Carbon Saving	155	T CO2e	98	T CO2e	3,569	T CO2e

The table above gives a comparison of the original AUK design, serving heat loads associated with Gloucester & Durham, Hereford & Exeter, Granville & Carlton and Peel (3.35MWth), against the ESBI base-case for the whole development limited to the peak capacity of the current energy centre (6MW) and the implications of changing to a WSHP system using the Thames Water Sewer, compared against the equivalent amount of heat being provided by Gas Boilers and CHP only.

Since 2018 the cost and carbon factors for gas have not changed much, but for electricity the carbon factor has gone down significantly, and the cost has risen by c 40%.

Therefore, the carbon savings under the ESBi model have reduced because the quantum of carbon that the CHP is displacing by on site generation has reduced by 40%.

The impact of switching out the Boilers and CHP for a sewer-based heat pump can be summarized as follows:

- The capital cost increases from c £2m to c £6m
- The cost to operate increase from £ 0.691m to £1.061m (53%)
  Comparing the cost to operate purely the CHP system is £0.872m vs. £0.985m for the heat pump, but this ignores saving in power generated by the CHP (£ 0.460m).
- There are significant savings in carbon (67%) due to the lower carbon factor in the electricity and the amplifying effect of the heat pump on energy.
- However, it also needs to be understood whether Thames Water would charge for the heat being extracted.

ESBi have also evaluated the benefit of extracting heat from thermal piles, HS2, without having established any quantum of heat from Kilburn Park Station. The quantum of heat available from GSHP combined with HS2 is 250kW/ 380MWh, which is significantly smaller than the total potential heat available from the Sewer based system.

On that basis these options may not merit further analysis at this point whilst the sewer-based system is focused on for the benefit of the techno-economic analysis. Thermal piles required to store the heat potential from HS2 may be reviewed in the future, to take advantage of them being able to act as heat storage to decouple generation from load. The value of heat storage available will not be understood until further additional engineering further work is carried out.

Summary Conclusions

Although the capital cost and economics of the Sewer based heat pump system are worse than a Boiler / CHP combination, the carbon emissions are considerably better.

AUK with inputs from the ESBi report have modelled scenarios in EnergyPro. The next step will be to develop the engineering and improve cost data to incorporate the preferred heat pump option into the scheme.

One of the key recommendations will be to verify the flow and temperature of effluent in the sewers in the area surrounding Gloucester & Durham. Thames Water could provide this service with an expected cost c.£10k-£20k, subject to agreement with all stakeholders. For this exercise TW would look to install flow and temperature loggers over a period; to gather and provide data to input to the next stage of the design process. TW should be approached by LBB to provide a quotation and programme for this service.

This report aims to evaluate combinations of Boilers/CHP/Heat Pumps considering uncertainty over constraints in the local grid capacity, the potential benefit that CHP could have in displacing expensive electricity with cheaper gas, if based on site generation and private wire export where available; as well as the potential to replace peak demand served by gas boilers and provide heat to a greater load across the development.

From a programme viewpoint, the heat network development can progress without delay as it will not be affected by the final energy source configuration, up to the point where installed gas boiler capacity does not meet peak demand, which is currently programmed to occur in late 2022

To finalise and develop a solution based on CHP/Boilers can happen relatively quickly and the energy centre is already configured, whilst allowing space to future proof the design to introduce low carbon alternatives

However, to develop the Sewer based heat pumps solution is going to take additional engineering resource and time in the programme for the following reasons:

i. There is a need to understand the measured flows & temperatures to have surety of performance.
ii. Detailed design work is required to work the system up to RIBA stage 3 to understand capital costs and OPEX, plus a more accurate view of carbon performance.
iii. We are veering away from the original brief of a boiler/CHP based system which impacts the terms of reference for the whole team.
iv. TW need to be engaged and we need to know if they will charge for heat. Other stakeholders internal and external to LBB need engaging (e.g. GLA, BEIS, HNDU).
v. Additional funding may be available either from HNIP or GLA, on the basis that low carbon alternatives for district networks are very much a part of the current strategy; However, this raises the “state aid” question and needs further consideration by the project team
vi. We will need to test the market to see if a DBOM contractor would be willing to take on such a system with the associated risks in design, build and operation
vii. The impact on “cost of heat” to residents needs to be understood
viii. Due to the advanced technology nature of the project, additional planning requirements and need to engage stakeholders, we would assess it would take c 2 years to adequately develop a project of this nature.
ix. A working group should be established as soon as possible have a specific session arranged to discuss the findings detailed in this report.

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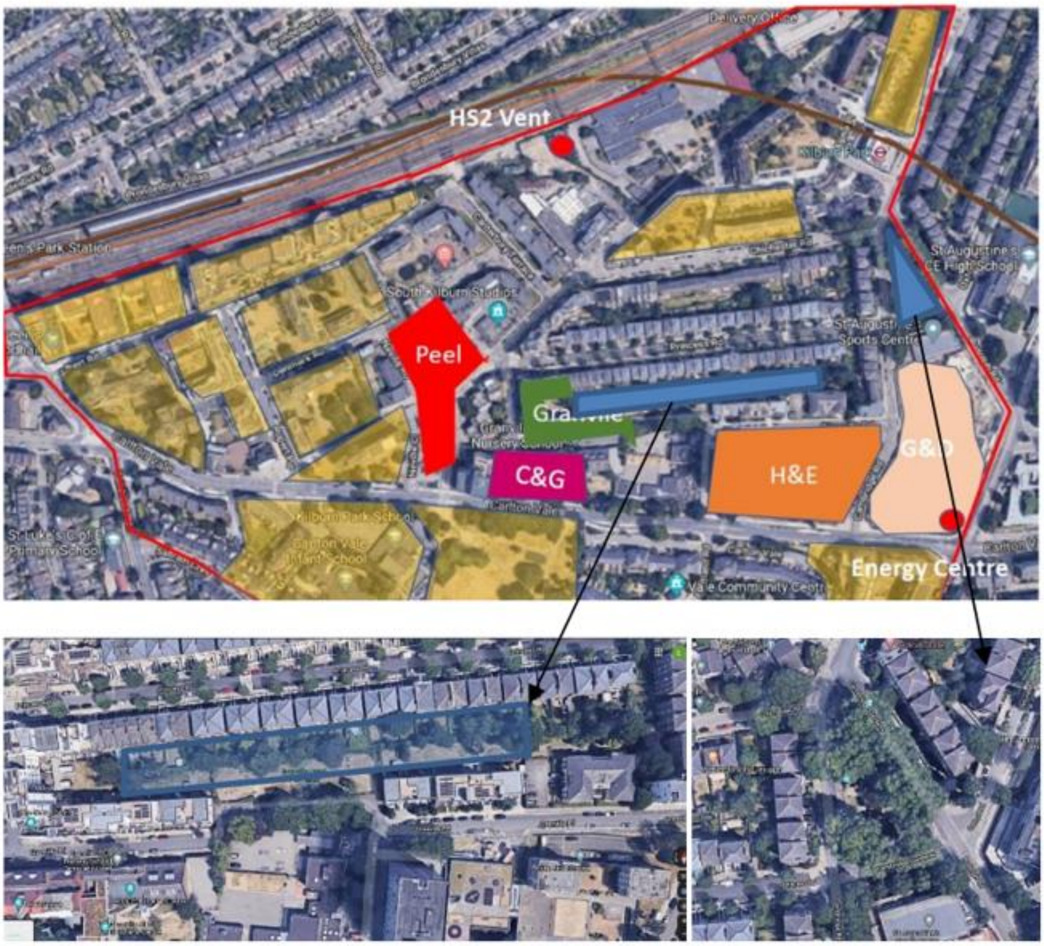
1 Introduction (ESBi Report)

The South Kilburn District Energy Network is a heat network & power scheme for the residential area south of Kilburn Park railway station, currently at the commercialisation phase of development. Much of the housing in the area is being replaced or refurbished. The base energy network is currently configured to comprise of a gas fuelled Combined Heat and Power Unit (CHP), Gas Boilers and Thermal Stores. This report aims to consider the inclusion of Ground Source Heat Pumps (GSHPs), HS2 vent, and use of Thames Water sewers; to provide alternative low carbon heat sources.

The peak heating demand for the development when complete is estimated to be in the region of 6MWth. The current plan is to utilise the heat produced by a 260kWe CHP engine, with gas boilers to supply the heating deficit.

To provide a low/zero carbon heating contribution, ESBi have been commissioned to investigate the use of a borehole array and associated GSHPs. Alternative nearby heat pumps sources are also being investigated, such as waste heat from a nearby HS2 ventilation shaft and wastewater from the Thames Water sewers.

The following diagram shows the general location of the DEN scheme, in relation to potential low carbon heat sources and existing shell and core energy centre:

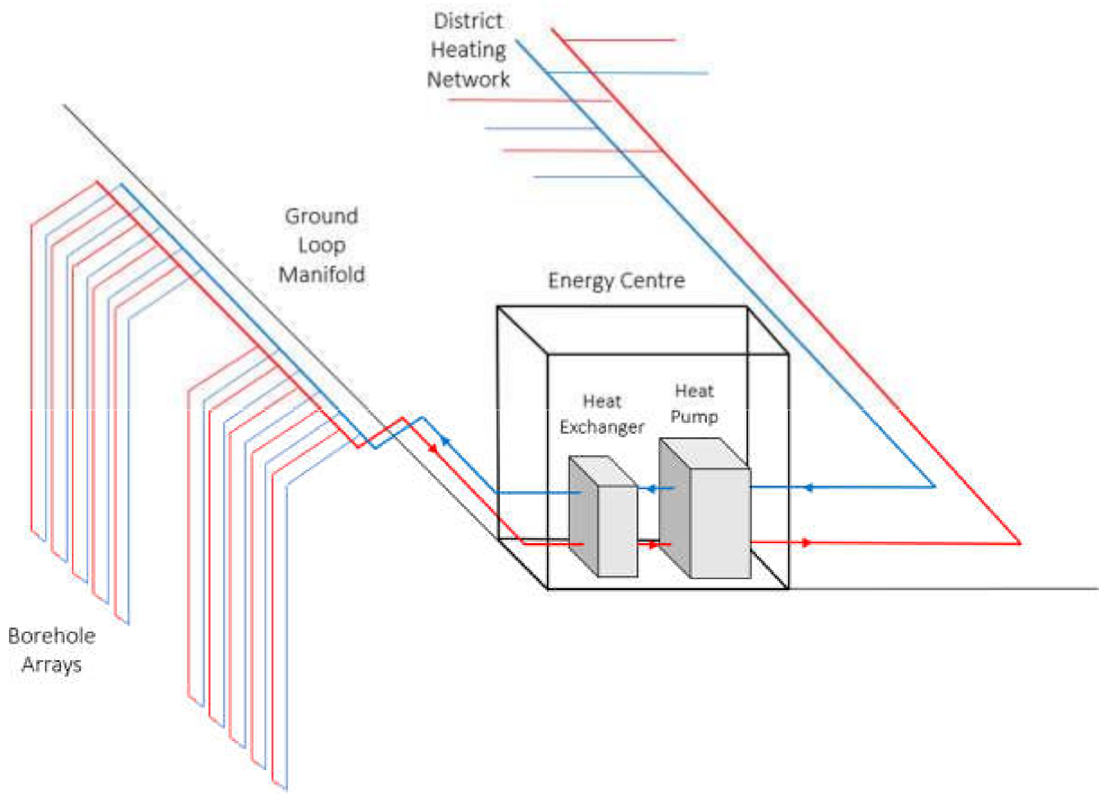


Phase 1 South Kilburn redevelopment areas. Bottom left: Granville Road Play Area. Bottom right: Cambridge Gardens

Ground Source Heat Pumps

Land has been provisionally assigned to the borehole array. Initial studies have shown that the triangular area north of Cambridge Gardens could encompass 6no. 150m deep boreholes, whilst the Play Area occupying the strip of land behind the homes on Granville Road could provide space for 14no. 150m deep boreholes.

When run in heating mode only, the 20no. boreholes could generate a peak heating contribution of 130kW, and a maximum of 250,000kWh/year. The boreholes would be connected via manifold to the GSHPs, which would be require space to be installed within the existing shell and core Energy Centre.



High level diagram of ground source system

HS2 Vent Waste Heat from Air

Borehole and heat pump capacity can be increased to 250kWth and 380,000kWh/year by utilising waste heat to recharge the ground; this has the added benefit of increasing the heat pump coefficient of performance by ensuring the ground temperature is maintained.

The main source of waste heat investigated to date is the HS2 ventilation shaft to the north of the site. The HS2 team has confirmed that the shaft contains two fans, which operate between midnight and 6am; the fans do not operate when the trains are running during the day and evening. When the fans do operate, they move between 100 – 200m3/s of air at temperatures between 26 - 32°C, depending on the time of year.

The maximum amount of energy that could be extracted from this air flow is 1600kW, which could be converted into useful energy either by utilising within a local air source heat pump or within an air-water heat exchanger to reject the heat to the aforementioned boreholes for recharge purposes; this effectively increases the borehole capacity as described.

The HS2 shaft is approximately 226m away from the play area boreholes and 282m away from the Cambridge Gardens boreholes as the crow flies. Pipework would need to be laid between the HS2 shaft and the two borehole arrays to transport the warm water between them.

An alternative to the HS2 shaft is Kilburn Park tube station, which itself has a ventilation shaft outlet above the station building. The station is much closer to the Cambridge Gardens site and may be a better option for heat rejection and ground recharging. No information has been received on the air flows and temperatures from this source.

Heat from Wastewater

One other area where investigations have started is the use of wastewater as a heat source, using the sewers beneath the roads, particularly close to the Energy Centre. Heat pumps can use wastewater as a direct source of heat (via specialist filtration equipment) so a system of this type would be in addition to the 250kW ground source and waste-heat heat pumps.

Wastewater heat capacity is directly related to sewage flow rates. Thames Water was approached to supply sewer maps for the area and modelled or actual flow rates for those sewers in the immediate area. Information on flow rates and depths of sewers has been received from Thames Water (TW) and has been incorporated into the analysis.

Sewers in the locality of the Energy Centres

Prior to the receipt of TW data, data from an academic paper ‘Determining the UK’s potential for heat recovery from wastewater using steady state and dynamic modelling – preliminary results’ by S. Farman Ali and A. Gillich at London South Bank University was used to provide an indication of the potential flow rates and heat capacity within a sewer of a given size and flow rate. There were limitations in this information as it is not possible to extrapolate data from a given sewer to another of a different diameter and location; and this is where this data needs to be provided by the water company.

With receipt of TW data, it was established though flow modelling data that the sewer close to the proposed Energy Centre will not meet the suggested criteria in the study as follows:

- Sewer should be in a densely populated up area corresponding to 15 – 30l/s dry weather flow rate
- Minimum sewer diameter should be 800mm
- Potential heat reclamation site should be in the proximity of heat consumers

With receipt of the flow rate, depth and diameter for the combined sewer running under Kilburn Park Road but within reasonable distance of the energy centre it can it was demonstrated that night-time flow rate is 210 l/s dry weather flow.

From Figure 2, the red (combined) sewers in the proximity are Ø2500mm - well in excess of the minimum diameter recommended in the paper. The sewer close to the energy centre on Kilburn Park Road is approximately 28m below the road surface.

Flow through a combined or foul sewer displays clear diurnal fluctuations with peak flow occurring in mid-morning and then later in the evening. This generally follows consumer behaviour of (typically) preparing for work in the morning and then using showers and hot water after work in the evening.

The potential heat capacity for this sewer is given in Table 1 below. Heat extraction is dependent on flow rate, as already mentioned, but also on the temperature difference between heat extracted from the sewer and heat rejected back to sewer. Water companies generally prefer to retain this temperature difference below 3K to avoid any impact on downstream water treatment processes, which can be affected by wastewater becoming too cold. A greater temperature differential drives heat generation. Table shows the heat capacity by given flow rate and increasing temperature differential from 1K to 3K.

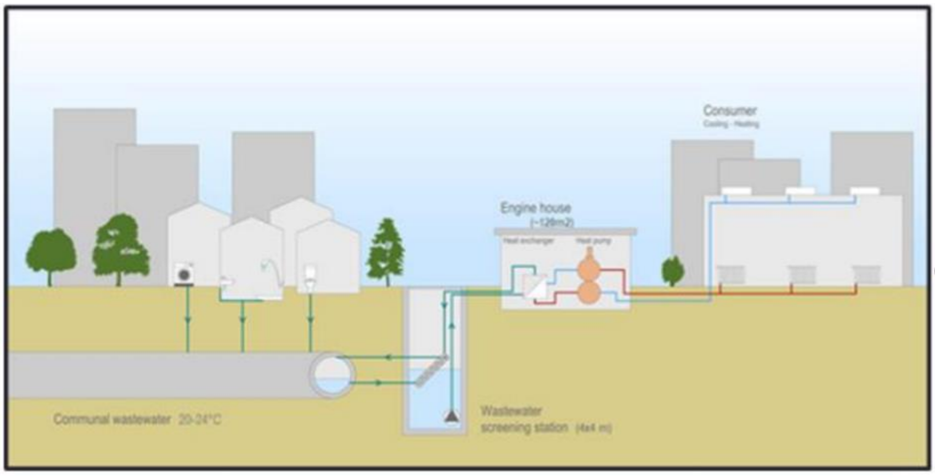
Sewer Flow Rate (m^3/s)	Sewer Flow Rate (kg/s)	dT (K)	Available Heat from Sewage (kW)	Heat Pump Generation @CoP 3.5 (kW)
0.210	210	1	882	1,235
0.210	210	2	1,764	2.470
0.210	210	3	2,646	3,704

Heat capacity from modelled sewer at various temperature differentials

The maximum heat generation from a heat pump using 0.210m3/s from the sewer is 3,704kWth.

The wastewater would be extracted directly from the sewer and the heat exchanged within a specialist heat exchanger mounted on the ground and within what is assumed to be a dedicated energy centre. Wastewater pumps will be required to pump wastewater from the sewer, through the heat exchanger and back to sewer. All plant and equipment would be located within the energy centre along with any additional filtration equipment required; the latter is dependent on the heat exchanger type used and water company requirements.

This same energy centre could also house the heat pumps, or the clean warmed water could be pumped to a separate energy centre some meters away housing the heat pumps, or if space permits, within the existing shell and core energy centre. The same heat pumps could then take heat from all or some of the sources described within this document.



High level diagram of wastewater heat recovery scheme showing sewer, extraction and screening station and ground-mounted heat pump in Energy Centre

In order to improve the accuracy of assumptions in the report, it is imperative that the dry weather flow rate in the Kilburn Park Road (Ranelagh) sewer, are measured and advised by Thames Water, which will confirm the figures put forward in Figure 4. Note that the use of sewage as a primary heat source results in a higher efficiency heat pump system due to the elevated temperatures found within the sewer; typical wastewater temperatures can range from 10 - 25°C depending on time of day and time of year.

The diagram below shows a typical system based on current market technology, and further work would need be carried out in the next phase of development to review the technologies available to the market and where exemplar case studies would enhance the development of the technical and economic case.

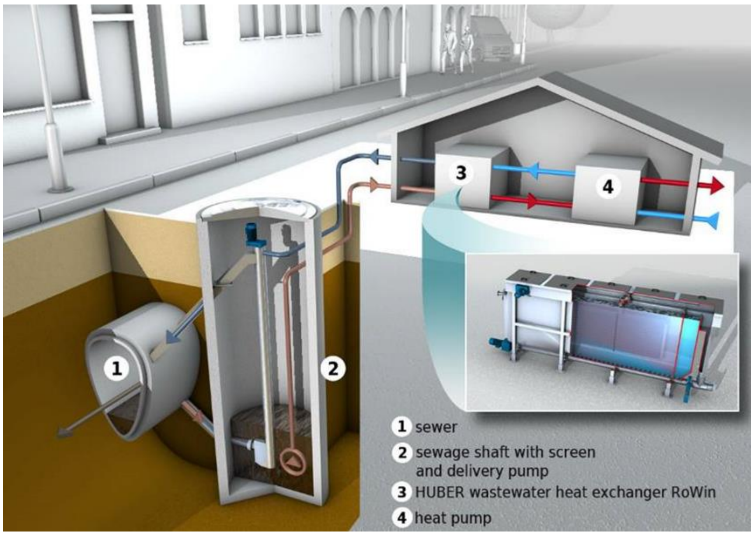


Diagram of Typical Wastewater Heat Recovery System https://www.huber.co.uk/products/energy-from-wastewater/huber-heat-exchanger-rowin.html

Waste Heat from Gas CHP

In a post-RHI world, waste heat from the gas CHP engines could also be used to recharge the boreholes mentioned earlier, which is another potential avenue of investigation, depending on when excess heat may be generated and the magnitude of the heat rejection energy.

External Infrastructure

The map extract below shows approximate location of heat sources in proximity to the existing shell and core energy centre, and possible utility routes for returning usable heat.

An additional source of potential waste heat is from tube station Kilburn Park ventilation shaft, subject to receipt of air flow and temperature data from Transport for London. Recent market engagement by Transport for London could provide a route to discussion with the relevant stakeholders.

Summary (heat sources and capacities)

The total amount of potential heat from the area surrounding the South Kilburn area is summarised below.

*Assumes sewage flow can be accessed 80% of the year

Heat Pump Source	Heat Pump Capacity (kW)	Annual Generation (kWh)
Ground Source	130	250,000
HS2 Waste Heat	120	130,000
Wastewater Heat Recovery	3,704	25,957,632*
Total	3,954	26,337,632

Technical Risk and Opportunity

The following are a list of early technical risks discussed with our specialist sub consultant on review of their report. Where opportunity has been identified we have attempted to consider in our assumptions as inputs to the EnergyPro Model. Further engineering is required to test opportunities discussed below:

Risk	Opportunity
When considering a comparison between gas fired boilers and the 3 heat pump options, what is potential impact of removing installed boiler capacity, in place of alternative sources.	In relation to the sewer heat peak contribution, operational risk is present in the event of sewer maintenance or lack of flow.
Opportunity to add heat pump peak(s) to the boiler current 6MW gas boiler peak and raise the overall system peak capacity; accordingly.	An opportunity to serve a wider load across the phasing of the DEN, subject to further design and analysis.
Raising the heat pump outlet temperature from c. 55°C to match the network supply temperature c. 85°C;	This would require ammonia heat pumps. Max. temperature for option 1 &2 using a R410a / R407 C or XP10 refrigerant would be 65 deg C. Using an ammonia heat pump for these options may not be economically viable and may require additional safety/ ventilation requirements for the energy centre.
The sewer design is to the night-time flow rate at 210 l/s. Could we consider median flow from the graph at around 400l/s.	Heat pump capacity being directly related to sewer flow, if the median is used in modelling heat capacity, there are times when the system will fall short. Experience shows the recorded flow rates have been considerably lower when completed actual flow tests on sewers, hence using the lower flow rate.

Basis of the equipment cost estimates.	The basis of equipment cost for the desktop study have had limited input from suppliers. Costs are based on previous projects and assumed technical considerations. Further engineering and market engagement will be required to improve accuracies.
RHI	Clarify if Tariff Guarantee 2 is to be applied for before March 2021, with system to be installed and commissioned before March 2022. In order to apply for TG2, the scheme would need to be funded with planning permission.
Option for 'containerised sewer source heat extraction system' to include heat exchanger and heat pump as a containerised solution.	The heat pumps could be housed in the main Energy Centre. The heat exchanger equipment to be housed in containerised plant room's adjacent to the sewers. Not recommended to pump raw sewage to the Energy Centre unless the Energy Centre is adjacent to the sewer.
Indicative temperature sources and their variability throughout the year for each of the options;	This would require measured flow data from TW.
Options for lower supply and return temperatures set at 55 – 65 deg.	Network temperatures could be lower, but this would impact selection of secondary side equipment.
Removal of heat when CHP runs with no export and excess power when heat demand is low.	This is not a scenario as even in low heat demand the CHP has been assumed to run. Further analysis is needed on plant and other side electrical loads.

2 ESBi Heat Pump Options Analysis

This section incorporates ESBi performance comparison against a boiler solution based on section 3 preliminary scope of works and estimates of defined meterage and linear metre costs for installation costs. The energy summary is provided as a comparison in heat pump operating costs, O&M costs, and CO2 savings, compared against the equivalent sized gas boiler system.

	A(UK) Design 2018 (typical year - phase 1)		ESBi Model (Whole Scheme)		ESBi Sewer Based Model (Whole Scheme)	
Electric	£0.09	/kWh	£0.13	/kWh	0.13	/kWh
	0.41	/kWh	0.2332	/kWh	0.2332	/kWh
Gas	0.025	/kWh	£0.03	/kWh	0.03	/kWh
	0.1836	/kWh	0.1836	/kWh	0.1836	/kWh
Scope	CHP and Boilers		CHP and Boilers		Sewer Based System	
System Capacity	3,350	MWth	3.784	MWth	3.784	MWth
	0.26	MWe	0.26	MWe	0.26	MWe
Capex	£2,310,000		£1,890,000		6,136,000	
Electricity Generated	1701	MWh	1,971	MWh	7,577	MWh
Gas Used	5600	MWh	29,064	MWh	29,064	MWh
Heat Produced Boilers	1053	MWh	26,158	MWh	26,158	MWh
Heat Produced CHP	2009	MWh		MWh		MWh
Operational Costs	£51,086		£75,700		£75,700	
Energy Costs	-£13,090		£615,703		£985,010	
Carbon	1,028	T CO2e	5,336	T CO2e	1,767	T CO2e
Carbon Saving	155	T CO2e	98	T CO2e	3,569	T CO2e

LZT Feasibility Results - Non Domestic

Project Name	Brent DHN
Job Number	UK

		Technology Matrix			Investment Costs			Annual Cost (Year 1)									Whole Life 25 yrs			
		GSHP	Gas Boiler	Grid Electricity																
	Option	Heating		Power	Capital Cost	System Life Span	Payback Captial Purchase	Run Costs	O&M Cost	CRC/CCL	RHI/FIT Rev	Total Costs	Cost Savings	CO_2 Produced	CO_2 Savings	Cost	Saving	Carbon	Saving
					£'000	Years	Years	£'000	£'000	£'000	£'000	£'000	%	tonnes	%	£'000	%	tonnes	%
0	Gas Boiler	-	130kW	-	£63	15	n/a	£11.8	£2.6	£0.8	£0.0	£15.1	0%	76.0 t	0%	£670.7	0%	1,899.6 t	0%
		-	250MWh	-															
1	Option 1 GSHP System providing 130kW heating at 50 to 55°. 20 x 150m Boreholes at 8m centres	130kW	-	-	£367	25	15.2	£8.6	£2.6	£0.6	(£13.6)	(£1.8)	112%	20.2 t	73%	£508.4	24%	292.2 t	85%
		250MWh	-	71MWh															

Item Description	Price +/- 20%	
Preliminaries, Design, and Project Management	£	24,056
Closed Loop Borehole Installation and Borefield Headering Works	£	217,370
Plant Room M&E Installation Works	£	102,254
System Testing & Commissioning of Energy Centre & Ground Loop	£	23,220
Total Ex VAT	£	366,900

Technical Data			
GSHP Heating - SPF	3.50		Design Point
Gas Boiler - Efficiency	0.85		CIBSE
GSHP Hours Capacity	8,760	hrs/annum	n/a
Gas CO2 Intensity	0.184	kg CO2/kWh	DEFRA
Electricity Carbon Intensity	0.283	kg CO2/kWh	DEFRA

Economic Data			
RHI Tier 1 Tariff	£ 0.0698	kWh	BEIS
RHI Tier 2 Tariff	£ 0.0208	kWh	BEIS
RHI Higher Rate Threshold	15.0%		BEIS
CPI Inflation	2.0%	per annum	BoE Target Rate
Energy Price Inflation	3.0%	per annum	BEIS

Customer Specific Data			
Gas Price	£ 0.0400	kWh	Assumed
Electricity Price	£ 0.1200	kWh	Assumed
Climate Change Agreement?	Yes		Assumed

Option 2 GSHP System & HS2 Vent heat extraction providing 250kW heating at 50 to 55°C

LZT Feasibility Results - Non Domestic

Project Name	Brent DHN
Job Number	UK

ESB Energy for generations

		Technology Matrix			Investment Costs			Annual Cost (Year 1)								Whole Life 25 yrs			
		GSHP	Gas Boiler	Grid Electricity															
	Option	Heating		Power	Capital Cost	System Life Span	Payback Captial Purchase	Run Costs	O&M Cost	CRC/CCL	RHI/FIT Rev	Total Costs	Cost Savings	CO_2 Produced	CO_2 Savings	Cost	Saving	Carbon	Saving
					£'000	Years	Years	£'000	£'000	£'000	£'000	£'000	%	tonnes	%	£'000	%	tonnes	%
0	Gas Boiler	- -	250kW 380MWh	- -	£123	15	n/a	£17.9	£5.0	£1.2	£0.0	£24.1	0%	115.5 t	0%	£1,099.1	0%	2,887.4 t	0%
1	GSHP System & HS2 Vent heat extraction providing 250kW heating at 50 to 55°C & 20 x 150m Boreholes at 8m centres	250kW 380MWh	- -	- 109MWh	£696	25	18.0	£13.0	£7.5	£0.9	(£24.0)	(£2.6)	111%	30.7 t	73%	£932.6	15%	444.2 t	85%

Item Description	Price +/- 20%	
Preliminaries, Design, and Project Management	£	34,863
Closed Loop Borehole Installation and Borefield Headering Works	£	220,340
Plant Room M&E Installation Works	£	417,915
System Testing & Commissioning of Energy Centre & Ground Loop	£	23,220
Total Ex VAT	£	696,339

Technical Data		
GSHP Heating - SPF	3.50	Design Point
Gas Boiler - Efficiency	0.85	CIBSE
GSHP Hours Capacity	8,760 hrs/annum	n/a
Gas CO2 Intensity	0.184 kg CO2/kWh	DEFRA
Electricity Carbon Intensity	0.283 kg CO2/kWh	DEFRA

Economic Data		
RHI Tier 1 Tariff	£ 0.0698 kWh	BEIS
RHI Tier 2 Tariff	£ 0.0208 kWh	BEIS
RHI Higher Rate Threshold	15.0%	BEIS
CPI Inflation	2.0% per annum	BoE Target Rate
Energy Price Inflation	3.0% per annum	BEIS

Customer Specific Data		
Gas Price	£ 0.0400 kWh	Assumed
Electricity Price	£ 0.1200 kWh	Assumed
Climate Change Agreement?	Yes	Assumed

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Option 3 TW Sewer Source systems abstracting 210l/s Providing 3,784kW heating at 50 to 55°C

LZT Feasibility Results - Non Domestic

Project Name	Brent DHN
Job Number	UK

Energy for generations

	Option	Heating (Technology Matrix) Sewer Source	Heating (Technology Matrix) Gas Boiler	Power (Technology Matrix) Grid Electricity	Investment Costs: Capital Cost	Investment Costs: System Life Span	Investment Costs: Payback Captial Purchase	Annual Cost (Year 1): Run Costs	Annual Cost (Year 1): O&M Cost	Annual Cost (Year 1): CRC/CCL	Annual Cost (Year 1): RHI/FIT Rev	Annual Cost (Year 1): Total Costs	Annual Cost (Year 1): Cost Savings	Annual Cost (Year 1): CO_2 Produced	Annual Cost (Year 1): CO_2 Savings	Whole Life 25 yrs: Cost	Whole Life 25 yrs: Saving	Whole Life 25 yrs: Carbon	Whole Life 25 yrs: Saving
					£'000	Years	Years	£'000	£'000	£'000	£'000	£'000	%	tonnes	%	£'000	%	tonnes	%
0	Gas Boiler	-	3,784kW	-	£1,890	15	n/a	£1,247.9	£75.7	£82.5	£0.0	£1,406.1	0%	8,060.0 t	0%	£56,342.6	0%	201,499.9 t	0%
		-	26,518MWh	-															
1	TW Sewer Source systems abstracting 210l/s Providing 3,784kW heating at 50 to 55°C	3,784kW	-	-	£6,136	25	3.6	£909.2	£75.7	£59.7	(£795.2)	£249.3	82%	2,144.7 t	73%	£29,028.6	48%	30,996.0 t	85%
		26,518MWh	-	7,577MWh															

Item Description	Price +/- 20%
Preliminaries, Design, and Project Management	£ 222,166
Closed Loop Borehole Installation and Borefield Headering Works	£ 4,149,560
Plant Room M&E Installation Works	£ 1,662,801
System Testing & Commissioning of Energy Centre & Ground Loop	£ 101,160
Total Ex VAT	**£ 6,135,687**

Technical Data			
GSHP Heating - SPF	3.50		Design Point
Gas Boiler - Efficiency	0.85		CIBSE
GSHP Hours Capacity	8,760	hrs/annum	n/a
Gas CO2 Intensity	0.184	kg CO2/kWh	DEFRA
Electricity Carbon Intensity	0.283	kg CO2/kWh	DEFRA

Economic Data			
RHI Tier 1 Tariff	£ 0.0698	kWh	BEIS
RHI Tier 2 Tariff	£ 0.0208	kWh	BEIS
RHI Higher Rate Threshold	15.0%		BEIS
CPI Inflation	2.0%	per annum	BoE Target Rate
Energy Price Inflation	3.0%	per annum	BEIS

Customer Specific Data			
Gas Price	£ 0.0400	kWh	Assumed
Electricity Price	£ 0.1200	kWh	Assumed
Climate Change Agreement?	Yes		Assumed

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3 Costs & Preliminary Scope of Works

To support their options analysis in Section 2, ESBi have provided interim costings for each proposal outlined. The costs are desktop estimates and subject to further engineering, market engagement and detailed survey and design. Outlined preliminary scope of works define meterage as indicated by linear metre costs for trenching backfilling etc.

System Overview for Option 1

Item	Description
Energy Source	20No. 150m Deep Closed Loop Boreholes
Annual Heating (kWh)	250,000
Peak Heating (kW)	130
Heat Pump	1No. 130kW water to water heat pump providing max 55◦C LTHW

Scope of Works Option 1

Preliminaries

- System design and engineering
- Design drawings and co-ordination
- Site supervision
- System testing & commissioning

External Ground Loop and Header Works

- Install 20 No 150m deep boreholes, at a separation of 8m, complete with a single 40mm HDPE loop. Spoil removal, ground protection, Hera's fencing, site welfare unit
- Install interconnecting headering pipework to the boreholes in zones to provide resilience and route back to prefabricated manifolds.

M&E works

- Supply & installation of 1No. 130kW rated water to water heat pump
- Provision of associated ancillary items (load / source side circulating pumps pressurisation units, D&A separators, valves, energy meters, LTHW thermal store)
- Provision of control & power panel for GSHP system, enabling remote monitoring
- Testing and commissioning and handing over

Commercial Overview

Item Description	Price +/- 20%
Preliminaries, Design, and Project Management	£ 24,056
Closed Loop Borehole Installation and Bore field Headering Works	£ 217,370
Plant Room M&E Installation Works	£ 102,254
System Testing & Commissioning of Energy Centre & Ground Loop	£ 23,220
Total Ex VAT	£ 366,900

Price Considerations

- CDM Responsibilities / Main contractor responsibilities
- Works terminate at buffer vessel in the energy centre
- Energy Centre construction & provision of utility connections
- Connection of bore field to Energy Centre (trench excavation and reinstatement)
- District heating network
- Planning requirements
- Road closures or works in the highway
- Service diversions
- Legal fees

Provisional Groundwork Rates

Description Items	Quantity	Unit	Rate +/- 20%
Hard Dig Areas: Excavate and lay 2 x 355mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£1,260
Excavate and lay 2 x 250mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£965
Excavate and lay 2 x 140mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£750

Excavate and lay 2 x 90mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£630
Excavate and lay 2 x 75mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£620

Additional Closed Loop Borehole Rates & Thermal Outputs

Item Description	Price +/- 20%	Approx. Heating kW output p/Borehole	Approx. Heating kWh p.a. output p/Borehole
1No. 150m Deep Borehole, headering of borehole & Testing and commissioning	£10,100	6.5	12,500
Total Ex VAT	£10,100		

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System Overview for Option 2

Item	Description
Energy Source	20No. 150m Deep Closed Loop Boreholes & HS2 Vent heat extraction
Annual Heating (kWh)	380,000
Peak Heating (kW)	250
Heat Pump	2No. 130kW brine to water heat pump providing max 55∘C LTHW

Scope of Works Option 2

Preliminaries

- System design and engineering
- Design drawings and co-ordination
- Site supervision
- System testing & commissioning

External Ground Loop and Header Works

- Install 20 No 150m deep boreholes, at a separation of 8m, complete with a single 40mm HDPE loop. Spoil removal, ground protection, Hera's fencing, site welfare unit
- Install interconnecting headering pipework to the boreholes in zones to provide resilience and route back to prefabricated manifolds.

M&E works

- Supply & installation of 2No. 130kW rated water to water heat pump
- Provision of associated ancillary items (load / source side circulating pumps pressurisation units, D&A separators, valves, energy meters, LTHW thermal store)
- Provision of 250kW rated air to water coil for heat extraction from ventilation shaft
- Provision of control & power panel for GSHP system, enabling remote monitoring
- Testing and commissioning and handing over

Commercial Overview

Item Description	Price +/- 20%
Preliminaries, Design, and Project Management	£ 34,863
Closed Loop Borehole Installation and Bore field Headering Works	£ 220,340
Plant Room M&E Installation Works	£ 417,915
System Testing & Commissioning of Energy Centre & Ground Loop	£ 23,220
Total Ex VAT	£ 696,339

Price Considerations

- CDM Responsibilities / Main contractor responsibilities
- Works terminate at buffer vessel in the energy centre
- Energy Centre construction & provision of utility connections
- Connection of bore field to Energy Centre (trench excavation and reinstatement)
- Connection of HS2 Vent to Energy Centre (trench excavation and reinstatement)
- District heating network
- Planning requirements
- Road closures or works in the highway
- Service diversions
- Legal fees

Provisional Groundwork Rates

Description Items	Quantity	Unit	Rate +/- 20%
Hard Dig Areas: Excavate and lay 2 x 355mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£1,260
Excavate and lay 2 x 250mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£965

Excavate and lay 2 x 140mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£750
Excavate and lay 2 x 90mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£630
Excavate and lay 2 x 75mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£620

Additional Closed Loop Borehole Rates & Thermal Outputs

Item Description	Price +/- 20%	Approx. Heating kW output p/Borehole	Approx. Heating kWh p.a. output p/Borehole
1No. 150m Deep Borehole, headering of borehole & Testing and commissioning	£10,100	12.5	19,000
Total Ex VAT	£10,100		

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System Overview for Option 3

The Ranelagh serves a much greater part of the upper catchment and the flows are significantly higher. Night-time flows are around 210 l/s with peak weekday flows of 600 l/s and weekend peaks of 520 l/s. At this stage of design process Option 3 has been designed to the "Night-Time" flow rate and using a delta of 3°C.

Flow Rate l/s	dT	Heat Pump COP	Heat Pump Output (kW)
210	1	3.5	1235
210	2	3.5	2470
210	3	3.5	3784

Item	Description
Energy Source	Sewer Source Heat Extraction & Discharge
Annual Heating (kWh)	26,518,270
Peak Heating (kW)	3,784
Heat Pump	6No. 625kW water to water heat pump providing max 55∘C LTHW

Scope of Works Option 3

Preliminaries

- System design and engineering
- Design drawings and co-ordination
- Site supervision
- System testing & commissioning

TW Sewer Source System

- Provision of heat exchangers and controls
- Provision of screen

- Testing & Commissioning
- Supply & Installation of sewage pumps in the wet well and on the return to the well
- Supply & Installation of electrical installation for heat exchangers and pumps in the wet well

M&E works

- Supply & installation of 6No.625kW rated water to water heat pump
- Provision of associated ancillary items (load / source side circulating pumps pressurisation units, D&A separators, valves, energy meters, LTHW thermal store)
- Provision of control & power panel for GSHP system, enabling remote monitoring
- Testing and commissioning and handing over

Commercial Overview

Item Description	Price +/- 20%
Preliminaries, Design, and Project Management	£ 222,166
Closed Loop Borehole Installation and Bore field Headering Works	£ 4,149,560
Plant Room M&E Installation Works	£ 1,662,801
System Testing & Commissioning of Energy Centre & Ground Loop	£ 101,160
Total Ex VAT	£ 6,135,687

Price Considerations

- CDM Responsibilities / Main contractor responsibilities
- Works terminate at buffer vessel in the energy centre
- Energy Centre construction & provision of utility connections
- Connection of Sewer source system to heat pump Energy Centre (trench excavation and reinstatement)
- District heating network
- Planning requirements
- Road closures or works in the highway
- Service diversions
- Legal fees
- Thames Water fees for sewer use and O&M.
- SI works for foundations for the sewage heat exchanger building(s)

Provisional Groundwork Rates

Description Items	Quantity	Unit	Rate +/- 20%
Hard Dig Areas: Excavate and lay 2 x 355mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£1,260
Excavate and lay 2 x 250mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£965
Excavate and lay 2 x 140mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£750
Excavate and lay 2 x 90mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£630
Excavate and lay 2 x 75mm OD PE SDR11 pipes and associated fittings including shingle bed and surround, backfilling with Type 1 material and reinstatement (Hard - Type 4 Flexible Road) at 1.200m nominal cover	1	m	£620

Additional Closed Loop Borehole Rates & Thermal Outputs

Item Description	Price +/- 20%	Approx. Heating kW output p/Borehole	Approx. Heating kWh p.a. output p/Borehole
1No. 150m Deep Borehole, headering of borehole & Testing and commissioning	£10,100	12.5	19,000
Total Ex VAT	£10,100		

ESBi Disclaimer

This proposal is an expression of ESB’s current interest only, is subject to certain assumptions and conditions, and is also subject to agreement on mutually acceptable terms and conditions (‘Contract’) and signing and execution of such Contract by you and ESB. Therefore, the proposal does not constitute a legal offer capable of acceptance by you or create any legal obligation or liability on the part of ESB or any related party, affiliate, or adviser. Nothing in this proposal amounts to a representation, statement or expression of opinion or warranty, express or implied, with respect to the proposed transaction, and nothing in this proposal shall have any legal effect unless expressly incorporated into the definitive sale and purchase agreement satisfactory to ESB.

4 EnergyPro Analysis Outputs

Full Grid Import/ Export Capacity

Emissions

Emissions (tCO2e)			
Scenario	Gas	Electricity	Total
BAU: 6MW	5,021	0	5,021
S1	4,784	0	4,784
S2	4,565	0	4,565
BAU: 8MW	7,156	0	7,156
S3	2,299	855	3,154
S4	1,967	1,027	2,994

Revenue and expenditure

Revenue and expenditure (£)				
Scenario	Revenue (£)	Operating Expenditure – Gas (£)	Operating Expenditure – Electricity (£)	Net Cash (£)
BAU: 6MW	2,229,557	986,008	0	1,243,549
S1	2,218,138	939,448	0	1,278,691
S2	2,207,606	896,490	0	1,311,116
BAU: 8MW	3,258,457	1,405,138	0	1,853,319
S3	3,177,600	451,517	440,019	2,286,064
S4	3,177,600	386,308	528,560	2,262,732

Heat and Electricity

Heat & Electricity						
Scenario	Heat Demands (MWh/Year)	Heat Productions (MWh/Year)	Peak Heat Demand (MW)	Peak Heat Production (MW)	Electricity Demands (MWh/Year)	Electricity Productions (MWh/Year)
BAU: 6MW	21,487	21,487	5.962	5.911	0	2,310
S1	21,487	21,487	5.962	6.041	326	2,310
S2	21,487	21,487	5.962	6.161	627	2,310
BAU: 8MW	31,776	31,757	8.597	8.679	0	2,310
S3	31,776	31,758	8.597	9.196	7,217	3,550
S4	31,776	31,765	8.597	9.446	7,513	3,109

EnergyPro Graphs

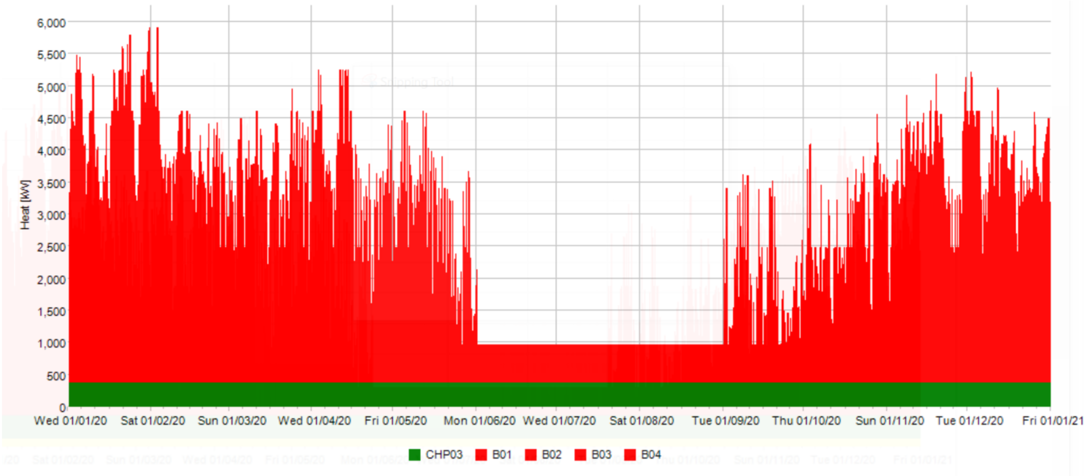


Figure 2. BAU

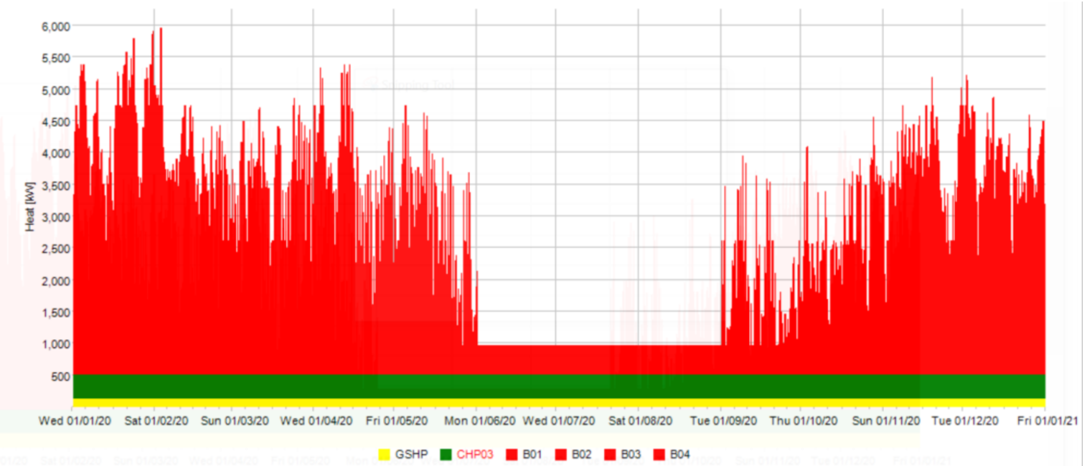


Figure 1. S1

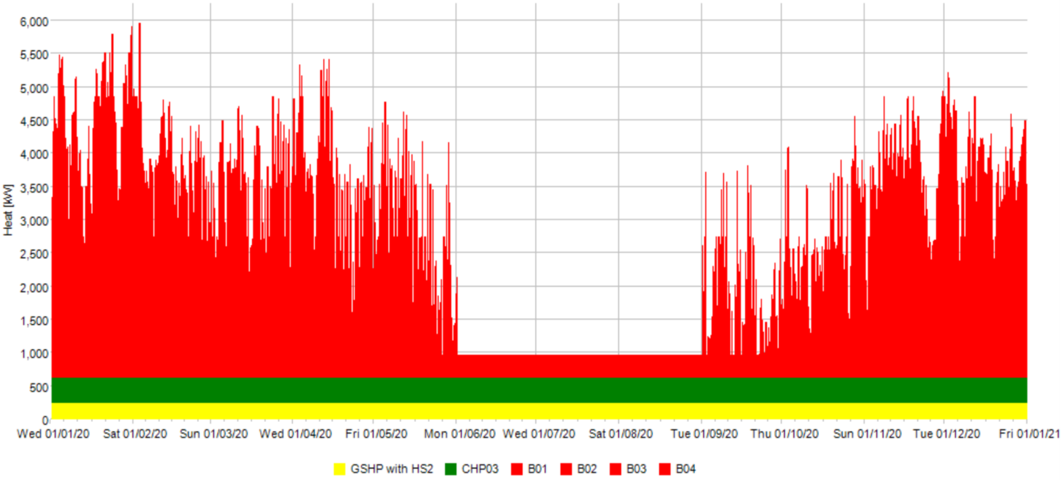


Figure 4. S2

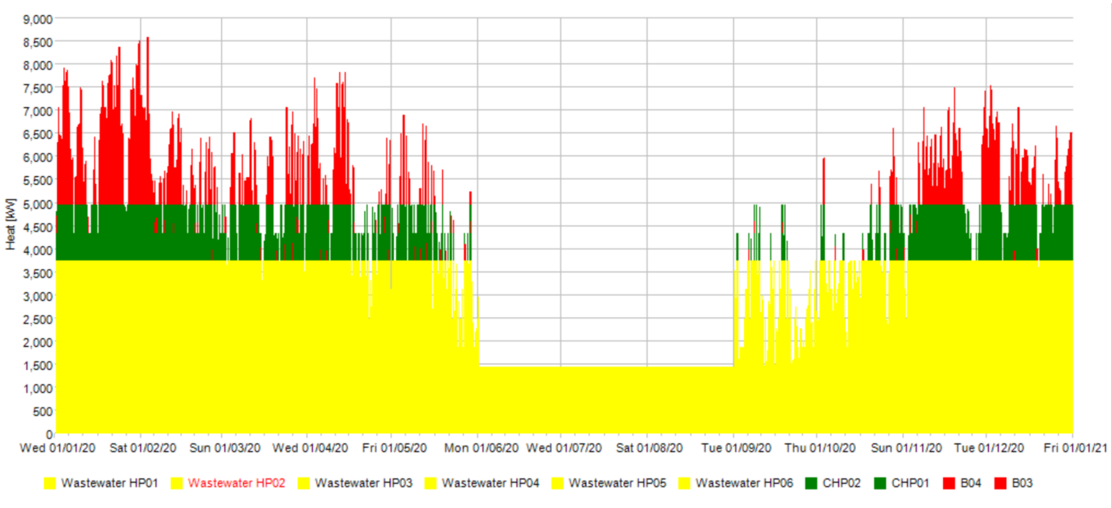
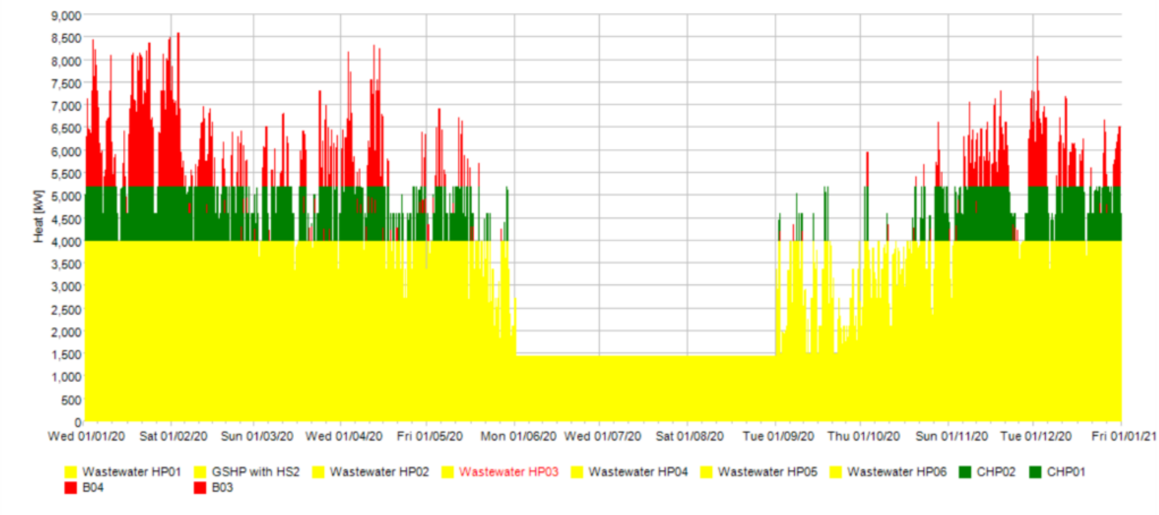


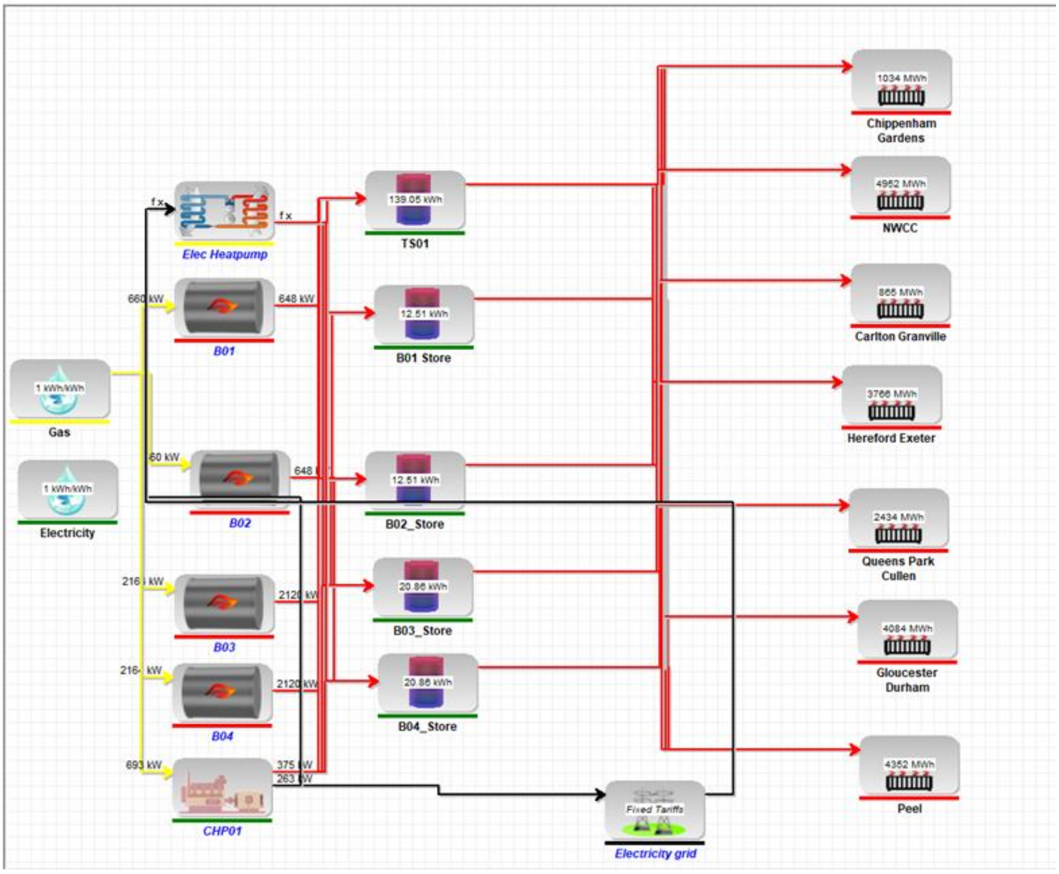
Figure 3. S3



Heat [kW]
9,000
8,500
8,000
7,500
7,000
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Wed 01/01/20
Sat 01/02/20
Sun 01/03/20
Wed 01/04/20
Fri 01/05/20
Mon 01/06/20
Wed 01/07/20
Sat 01/08/20
Tue 01/09/20
Thu 01/10/20
Sun 01/11/20
Tue 01/12/20
Fri 01/01/21
Wastewater HP01
GSHP with HS2
Wastewater HP02
Wastewater HP03
Wastewater HP04
Wastewater HP05
Wastewater HP06
CHP02
CHP01
B04
B03

Figure 5. S4

EnergyPro Plant Schematic



Partial Grid Import/ Export Capacity (600kWe import, 263kWe export)

Emissions

Emissions (tCO2e)			
Scenario	Gas	Electricity	Total
BAU – 6MW	5,021	0	5,021
S1	4,784	0	4,784
S2	4,565	0	4,565
BAU – 8MW	7,156	0	7,156
S3*	3,746	0	3,746
S4*	3,744	0	3,744

*Calculated at No Grid Import/Export.

Revenue and expenditure

Revenue and expenditure (£)				
Scenario	Revenue (£)	Operating Expenditure – Gas (£)	Operating Expenditure – Electricity (£)	Net Cash (£)
BAU – 6MW	2,229,557	986,008	0	1,243,549
S1	2,218,138	939,448	0	1,278,691
S2	2,207,606	896,490	0	1,311,116
BAU – 8MW	3,258,457	1,405,138	0	1,853,319
S3*	3,746	0	3,746	3,746
S4*	3,744	0	3,744	3,744

*Calculated at No Grid Import/Export

Heat and Electricity

Heat & Electricity						
Scenario	Heat Demands (MWh/Year)	Heat Productions (MWh/Year)	Peak Heat Demand (MW)	Peak Heat Production (MW)	Electricity Demands (MWh/Year)	Electricity Productions (MWh/Year)
BAU – 6MW	21,487	21,487	5.962	5.911	0	2,310
S1	21,487	21,487	5.962	6.041	326	2,310
S2	21,487	21,487	5.962	6.161	627	2,310
BAU – 8MW	31,776	31,757	8.597	8.679	0	2,310
S3*	31,776	31,723	8.597	9.196	6,185	6,185
S4*	31,776	31,759	8.597	9.446	6,207	6,207

*Calculated at No Grid Import/Export

EnergyPro Graphs

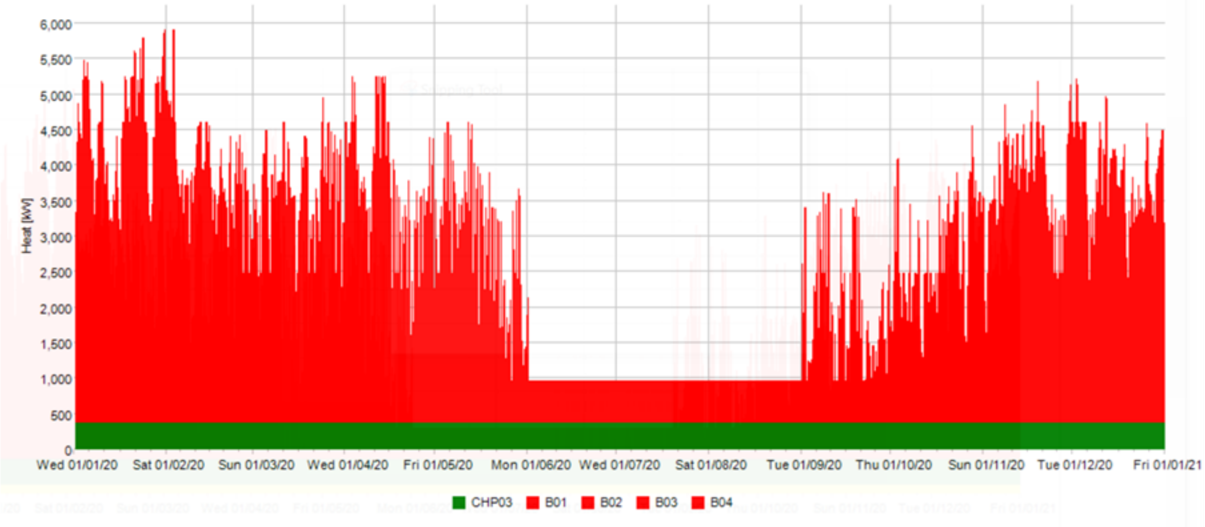


Figure 1. BAU 6MW

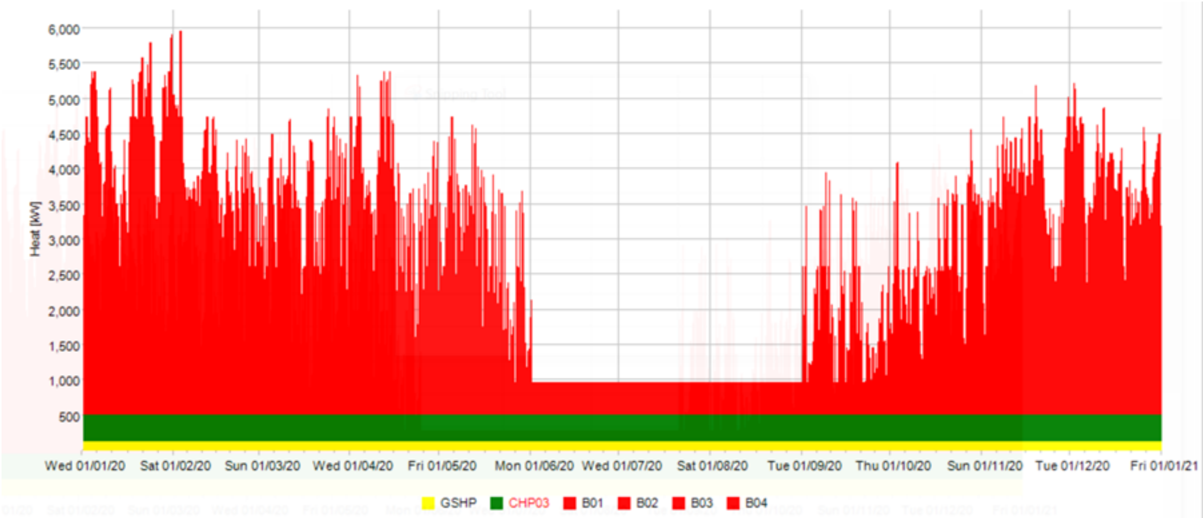


Figure 1. S1

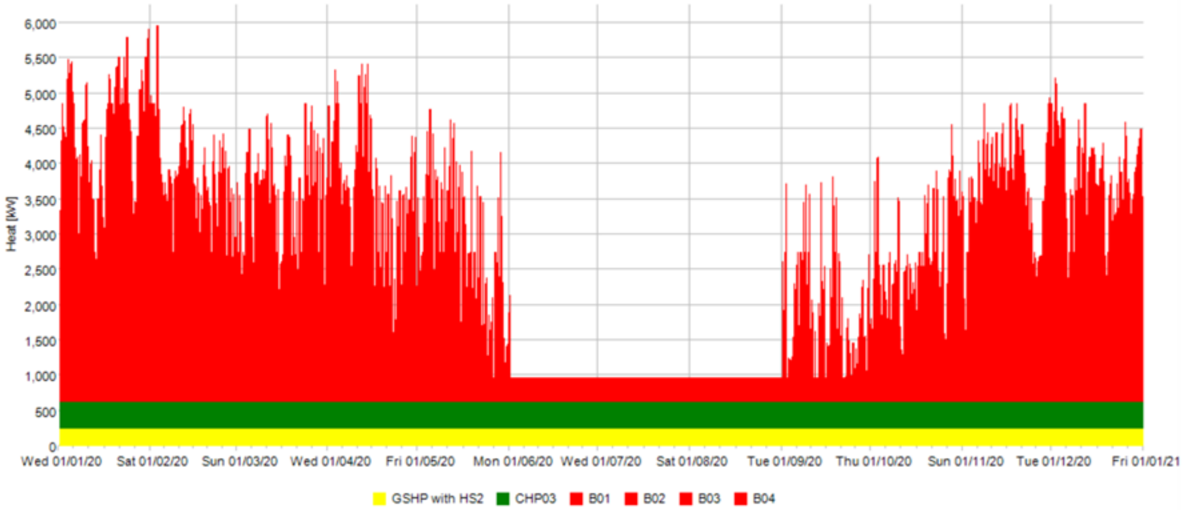


Figure 1. S2

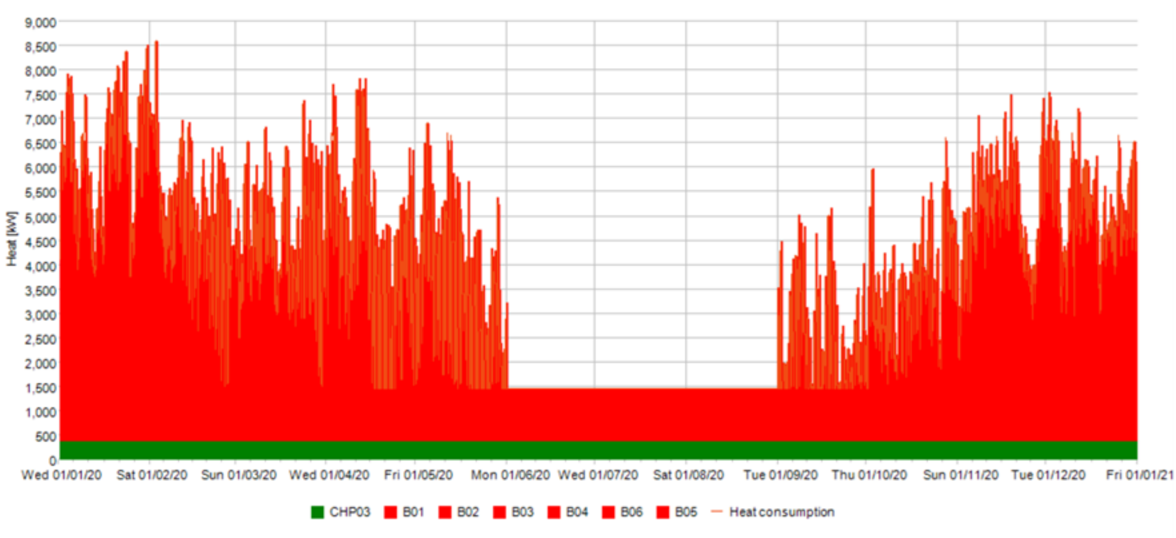


Figure 1. BAU 8MW

EnergyPro Plant Schematic

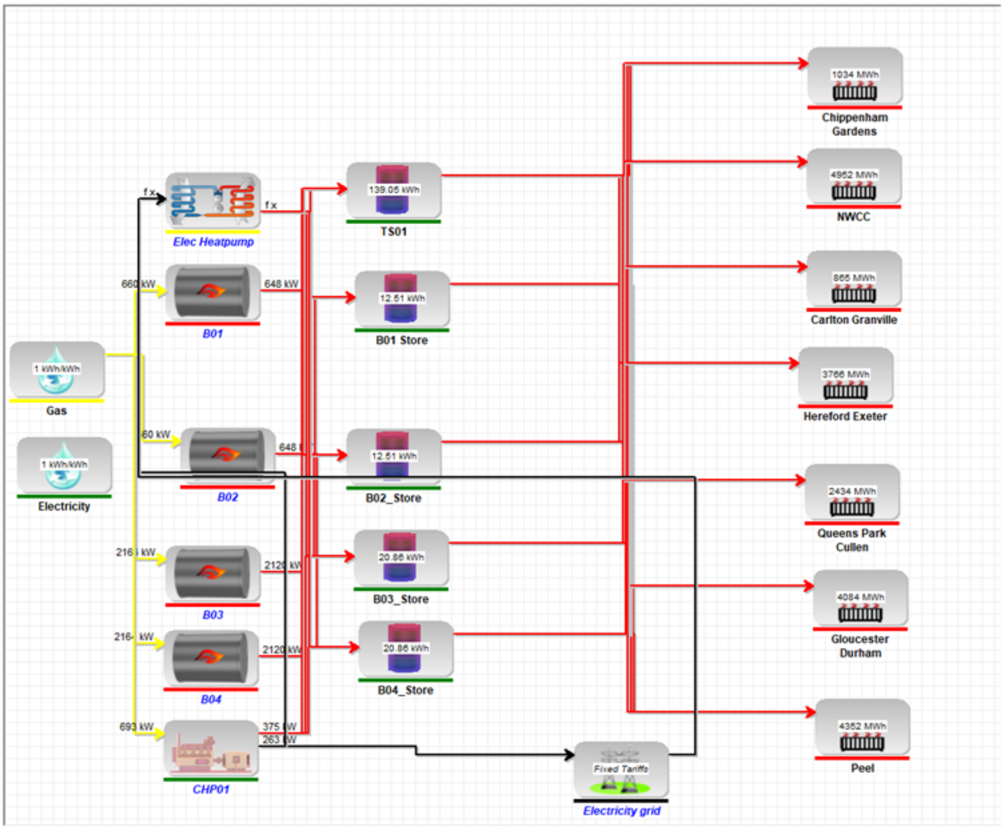
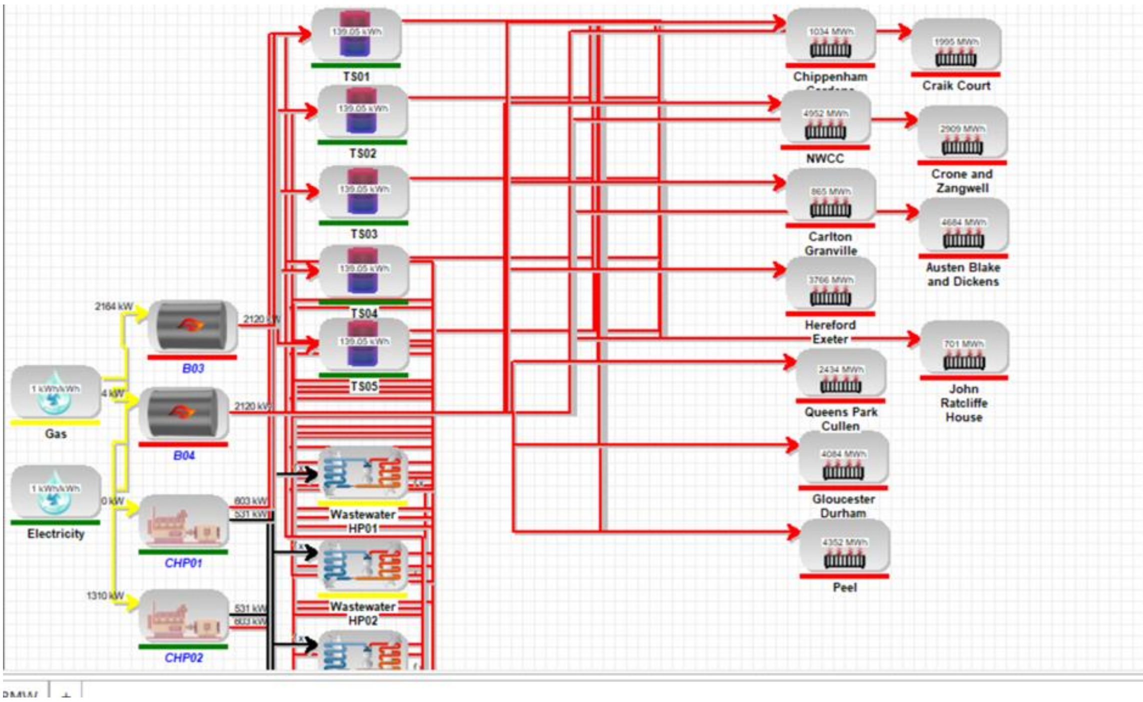


Figure 4. Schematic of energyPRO setup



No Grid Import/ Export

Emissions

Emissions (tCO2e)			
Scenario	Gas	Electricity	Total
BAU1	*	*	*
S1	*	*	*
S2	*	*	*
BAU2	*	*	*
S3	3,746	0	3,746
S4a	3,744	0	3,744

*Taken from full and partial grid capacity - These scenarios could not run under a strictly no grid capacity situation. The BAU cases require some way to export the electricity produced by the CHP, which could be fulfilled by plant loads. The minimum electricity load produced by the CHP is greater than the maximum load for the heat pumps in S1 and S2, however this may also be alleviated by plant loads. Both of these solutions will require further analysis.

Revenue and expenditure

Revenue and expenditure (£)				
Scenario	Revenue (£)	Operating Expenditure – Gas (£)	Operating Expenditure – Electricity (£)	Net Cash (£)
BAU1	*	*	*	*
S1	*	*	*	*
S2	*	*	*	*
BAU2	*	*	*	*
S3	3,177,600	735,646	0	2,441,954
S4	3,177,600	735,212	0	2,442,388

*Taken from full and partial grid capacity - These scenarios could not run under a strictly no grid capacity situation. The BAU cases require some way to export the electricity produced by the CHP, which could be fulfilled by plant loads. The minimum electricity load produced by the CHP is greater than the maximum load for the heat pumps in S1 and S2, however this may also be alleviated by plant loads. Both of these solutions will require further analysis.

Heat and Electricity

Heat & Electricity						
Scenario	Heat Demands (MWh/Year)	Heat Productions (MWh/Year)	Peak Heat Demand (MW)	Peak Heat Production (MW)	Electricity Demands (MWh/Year)	Electricity Productions (MWh/Year)
BAU1	*	*	*	*	*	*
S1	*	*	*	*	*	*
S2	*	*	*	*	*	*
BAU2	*	*	*	*	*	*
S3	31,776	31,723	8,597	9196	6,185	6,185
S4	31,776	31,759	8,597	9446	6,207	6,207

*Taken from full and partial grid capacity - These scenarios could not run under a strictly no grid capacity situation. The BAU cases require some way to export the electricity produced by the CHP, which could be fulfilled by plant loads. The minimum electricity load produced by the CHP is greater than the maximum load for the heat pumps in S1 and S2, however this may also be alleviated by plant loads. Both of these solutions will require further analysis.

EnergyPro Graphs

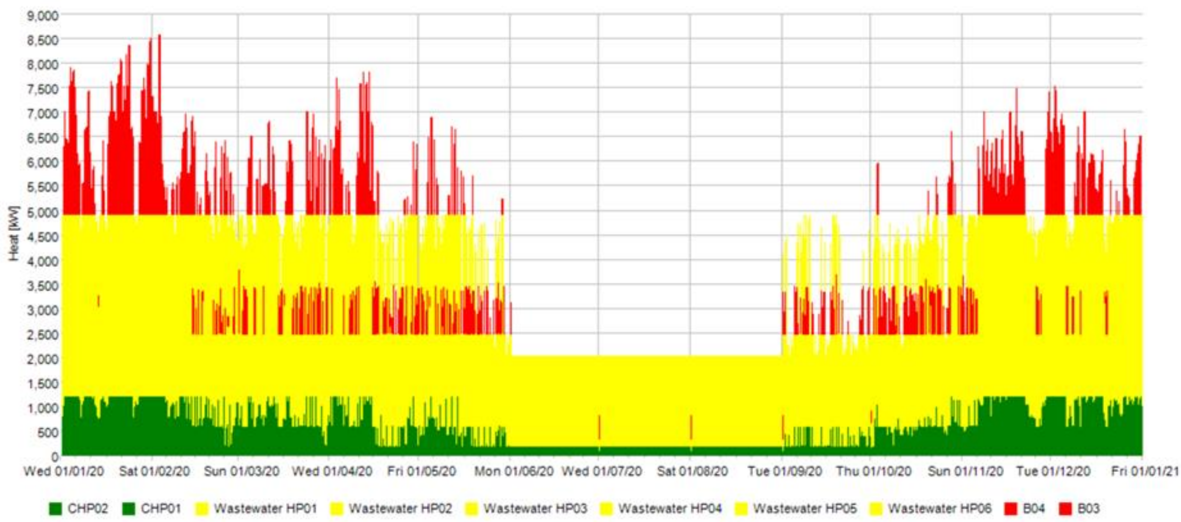


Figure 7. S3

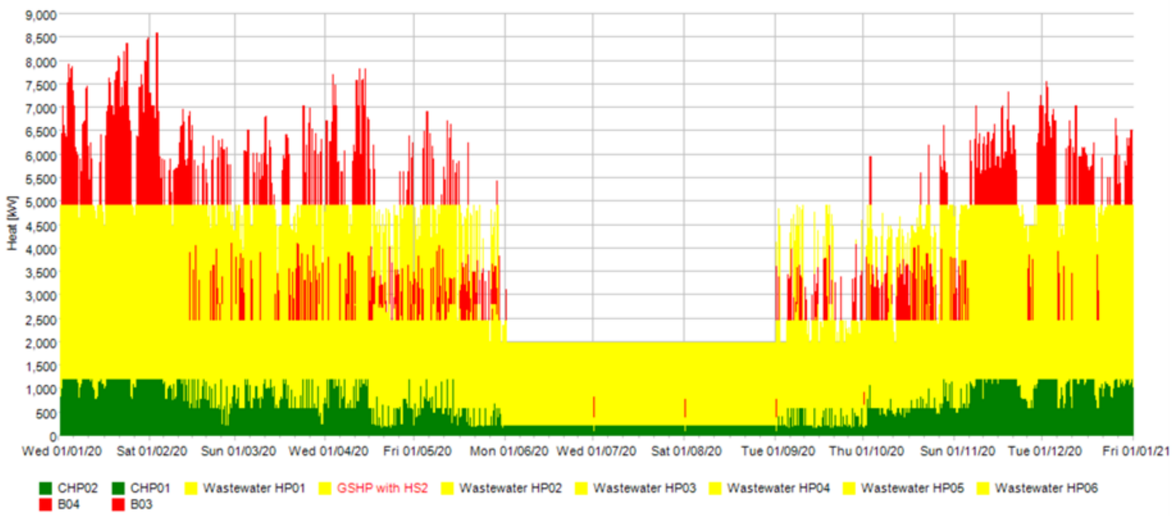


Figure 8. S4

EnergyPro Plant Schematic

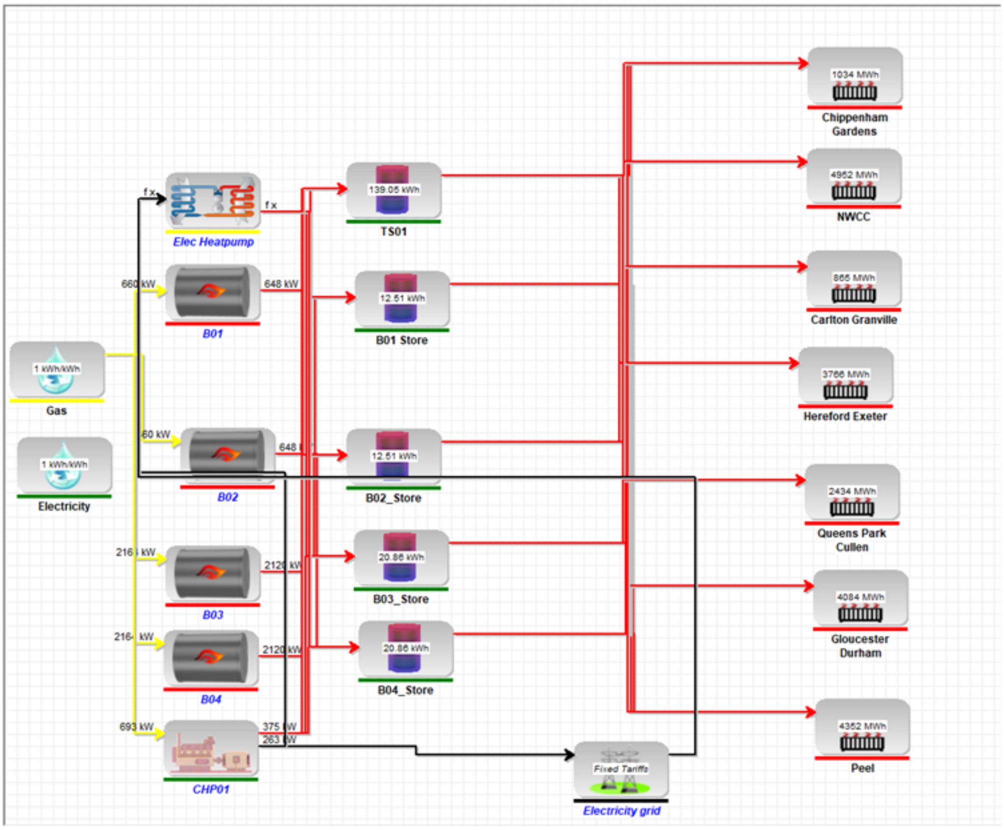
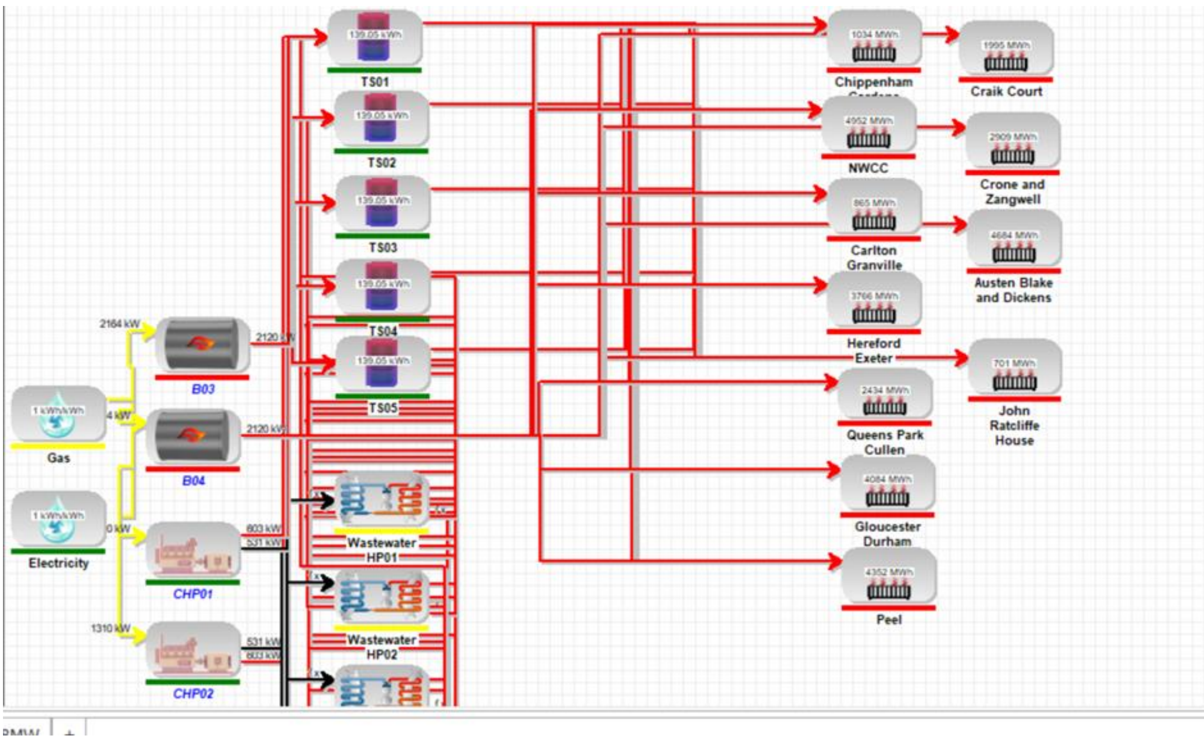


Figure 4. Schematic of energyPRO setup



5 Energy Layout Considerations – Scenario 3

The layout below aims to demonstrate that with reduced peak boiler capacity it may be feasible to incorporate options for larger CHPs and accommodate heat pumps into the energy centre scheme, thereby attempting to reduce the external footprint required and reduce cost.

This is relevant for Scenario 3 and the preferred option for further engineering and study in subsequent phases of project development, and assumes that any heat exchanger required for wastewater will be housed outside of the existing shell and core energy centre, local to the sewer in a location to be agreed with LBB and other relevant stakeholders.

This could be a dedicated building or containerised options with examples shown overleaf, based on technology currently available in the market, with exemplar projects case studies, thought to be in operation.

Alternative boiler arrangements providing peak could be proposed considering required operational redundancy during sewer maintenance, or as load increases prior to the heat pump coming online. The layout demonstrates one single 2.3MW and 2 no. 1.15MW (4.6MW installed).

The EnergyPro model refers to 2 no. 2.3MW as the equal capacity for demonstration purposes. The final layout will be dependent on footprint of installed heat pumps and requirement to accommodate the fire water tank in the most suitable configuration.

Any phasing of plant and equipment would need to consider the constraints of the existing shell and core energy centre.

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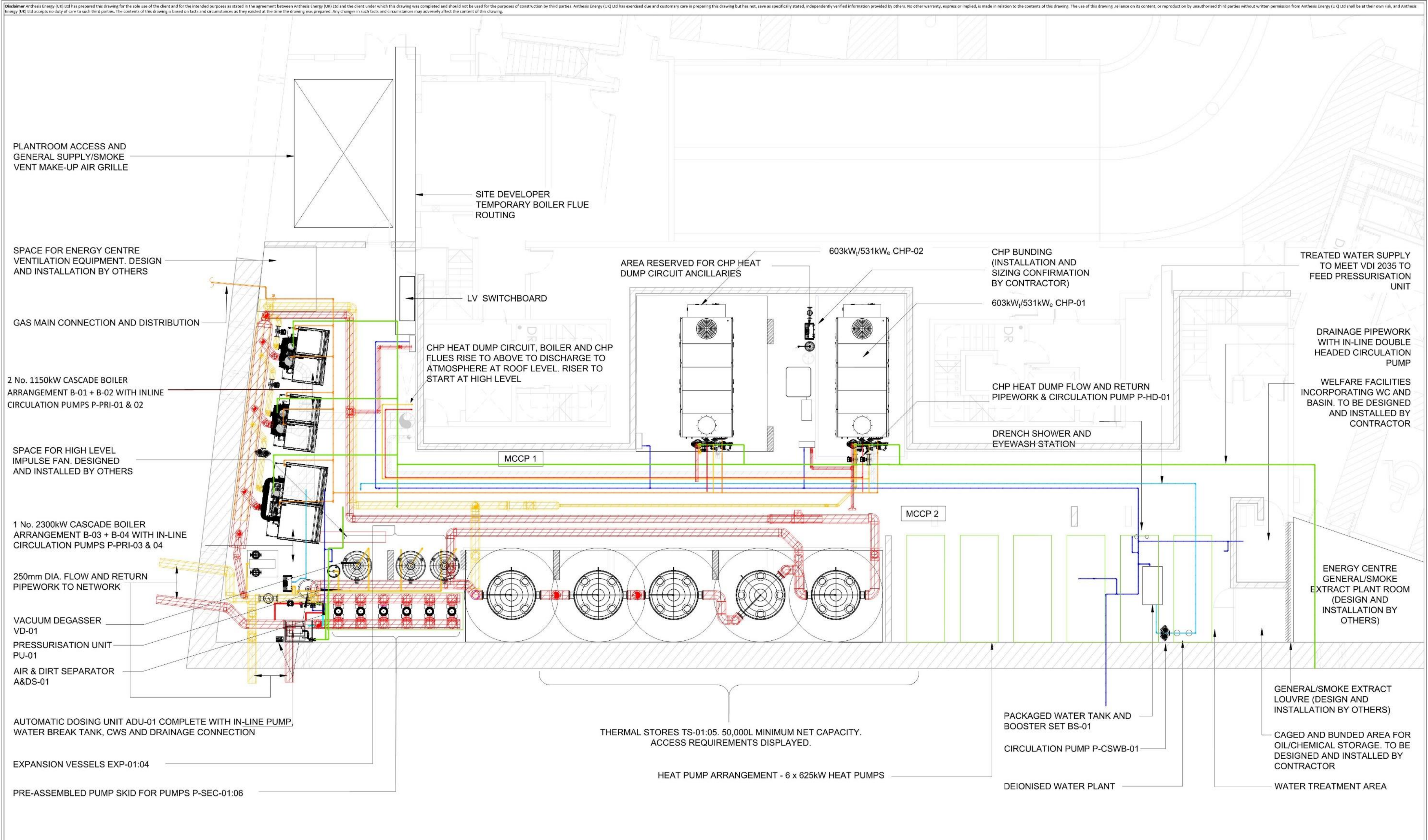

LEGEND

LTHW FLOW PIPEWORK	SINGLE-HEAD CIRCULATION PUMP
LTHW RETURN PIPEWORK	TWIN-HEAD CIRCULATION PUMP
GAS PIPEWORK	
DRAINAGE PIPEWORK	VERTICAL FULL-HEIGHT CONCRETE PILLAR
MAINS COLD WATER PIPEWORK	
TREATED COLD WATER PIPEWORK	GAS EXHAUST FLUE

NOTES:

1) Contractor to confirm flue routing in accordance with existing route
2) Contractor to confirm weight bearing limits for plant items and pipework suspension.
3) Contractor to coordinate water and drainage connections in accordance with nearest suitable locations
4) RIBA Stage 3 Design, not for construction.
5) For Stage 3 Design pipe & duct sizes, consult schematics.
6) Pumped drainage design to be finalised at detail design stage
7) Pipework insulation size and coordination to be designed at detail design stage
8) Gas Boosters to be accounted for as necessary by contractor

Ver.	Date	By	Chkd	Appd
P01	15/08/2020	AZ	MB	MH

Scale: 1:100 @A0 | Date: 08/2020 | Engineer: AZ | Checked: MB

Drawing Status: RIBA STAGE 3

CDM 2015

Drawing Title: ENERGY CENTRE LAYOUT - S4b
MECHANICAL & PUBLIC HEALTH SERVICES
PLAN VIEW

Drg No. 101947-BRENT-DEN-9001

Project: BRENT DISTRICT HEATING

Client: BRENT BOROUGH COUNCIL

Royal London Buildings
42-46 Baldwin Street
Bristol BS1 1PN
+44(0)117 403 2700
info@anthesisgroup.com

Typical Heat Pump Energy Centre

Containerised Energy Centre Option

6 Conclusions & Recommendations

- Scenario 3 offers the best opportunity for further analysis both in net revenue and carbon reduction whilst providing an opportunity to consider a wider peak load across the development; on the basis that the final heat demand is greater than the current 6MWth allowance constrained by the existing shell and core energy centre.
- Further stakeholder engagement including measurement of flows and temperature to confirm waste heat characteristics is essential in the next phase to provide accuracy in technical assumptions and costs.
- Involvement in local authority or other government incentives aimed at sharing knowledge and assisting project development.
- Enhanced supplier engagement to better understand the market costs and relevant aspects of any exemplar projects in operation.
- Further engineering is required to improve accuracies in costing and inputs to the TEM as well as to the phasing of capital spend and revenues in line with planned heat loads across the development.
- Techno-economic modelling based on gas boiler and CHP providing heat until the heat pump design is at a level (RIBA3) where costs accuracy is improved, and risks considered in design, delivery, operation, and maintenance.
- With option 3 the installed boiler capacity is 4.6MWth. The current South Kilburn Regeneration programme is schedule such that this demand may be reached by the last quarter of 2022. To benefit from the inclusion of low carbon technologies outlined in the report, the design development and commercialisation of the heat pump aspects could be completed; and this should be reflected in any phasing considerations.
- To complete the commercialisation phase in line with the current project development programme the Technical Solution will look to consider 4.6MWth primary gas boiler plant, 560MWe gas CHP, and 50 000 l Thermal storage; allowing for an additional 560MWe gas CHP, and 6 no. 625k Heat Pumps housed in the existing shell and core energy centre, with any additional heat pump elements to be housed externally.
- Initial capital spend could account for installed boiler capacity to meet peak demand up to the point where additional load over and above 4.6MWth would be increasingly provided by contributions from the future heat pump capacity.
- The opportunity to invest additional capital prior to this point could be measured against the future increased heat sales and whether projected revenues support the additional capital spend. The quantum of increased carbon reduction as the heat pump capacity is introduced would incentivise its introduction; if also aligned with the council's carbon reduction aims.
- For the purposes of the TEM, capital and operating costs for the heat pump elements will be taken from the ESBi desktop study, with risk and contingency to be considered; to account for the lack of engineering equivalent to the 4.6MWth gas boiler/ CHP plant.
- AUK current cost estimates for the gas/ CHP plant can be compared with ESBi costs for their equivalent gas boiler plant and any adjustments considered; to improve the contingencies applied to the cost provided for the heat pump solution. In working towards the end of the commercialisation phase and going to market, the deficiencies in design, costs estimates and operational certainty; for the heat pump solution will be highlighted. This could form part of the brief with the design element passing to the delivery partner.

Appendices

i. LSBU paper
ii. TW Flow Modelling Data
iii. Sewer Maps Data
iv. Heat Pump Specification
v. Huber Heat Exchanger Details

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2nd Global Conference on Energy and Sustainable Development, GCESD2018, 18-20 December 2018, John McIntyre Conference Centre, The University of Edinburgh, United Kingdom

Determining the UK's Potential for Heat Recovery from Wastewater using Steady State and Dynamic Modelling - Preliminary Results

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103 Borough Road, London SE1 0AA, United Kingdom
*Corresponding author's mail: alis133@lsbu.as.uk

Abstract

By 2050, UK plans to create 'low carbon society'. To meet this ambitious target, UK's heating sector must be completely decarbonized. The identification and deployment of low carbon heating sources is thus an urgent policy and research priority. Recovering heat from sewage wastewater is relatively new and attractive option as it can help UK move towards its climate change targets while decarbonising the heating sector & reducing the reliance on fossil fuels. In the domestic context, wastewater is normally discharged at higher temperature than ambient (a carrier of heat/ thermal energy) losses its energy to (ground) environment before it reaches to WWTP. Recovering this heat from wastewater could be a considerable source of energy, revenue and is environmental friendly as it results in the reduction of GHG emissions, resource conservation and in increase share of renewable energy. In last decade, many cities around the world have successfully implemented wastewater thermal energy recovery but UK is lagging behind. Pilot project such as in Scotland is leading the way, but further research is needed to build the evidence base and replicate the concept elsewhere in UK. The Home Energy 4 Tomorrow (HE4T) project at London South Bank University (LSBU) was created to address this evidence gap. The project objectives include sizing the heat potential recoverable from wastewater at designated sites. The current paper forms part of the HE4T project and the second in series of output on wastewater heat recovery in UK. In this paper we present some initially measured data, variations in wastewater temperature and flow, steady state and dynamic model results wastewater temperature and the potential heat recovery of the designated site. Early results, their limitations and possible routes to address these limitations are discussed along with policy implications for UK heat strategy.

Keywords: Energy recovery; Heat recovery; Urban wastewater; Sewer; Wastewater temperature, Wastewater flow; Combined sewer; Wastewater treatment plant; Heat pump; Heating of buildings; Modelling; Simulation; TEMPEST

Abbreviations

COD	Chemical Oxygen Demand
GHG	Greenhouse Gases
TWh	Tera Watt hour
WWTP	Wastewater Treatment Plant

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https://doi.org/10.32438/WPE.58181

1. Introduction

In order to meet the legally binding carbon reduction targets, the UK heating sector must be completely decarbonized by 2050. Utilising secondary heat sources like wastewater heat recovery can play an important role in meeting these targets [1]. Recovering waste heat from urban wastewater (often referred as sewer water or sewage) is an attractive option as thermal energy that can be recovered, offsetting fossil-fuel use and reducing GHG emissions. Wastewater or sewage when discharged from point of use is at higher temperature than ambient (roughly contains 80% thermal and 19.9% chemical and rest other form of energy embedded in it). It is possible to capture and reuse this thermal energy that would otherwise be lost to the environment before it reaches the Wastewater Treatment Plant (WWTP). The thermal energy available in waste water is described as 'low grade' heat and can be used for heating and cooling purposes. However, wastewater as an energy source has so far been under-utilised due to a range of technical barriers including: the uncertain impacts of lowering sewage temperatures on the sewer network; risks of increased blockages, reduced sewer capacity, risk of damage to sewer pipes, and impacts to WWTP efficiency. Waste water heat recovery also faces practical challenges such the need for heat pumps (currently also lagging in the UK), the comparatively low cost of natural gas, longer payback period of heat recovery systems, and in some cases finding a suitable application for the low grade heat.

In past the two decades, wastewater heat recovery technology deployment has grown. Many cities around the world have successfully implemented wastewater thermal energy recovery but the UK is lagging behind [2]. Projects such as Borders College, Galashiels, Scotland [3] are leading the way, but further experimental research is needed to build the evidence base and replicate and de-risk the concept elsewhere in the UK.

The Home Energy 4 Tomorrow (HE4T) project at London South Bank University (LSBU) was created to address this evidence gap along with a clean-tech firm (ICAX Ltd.), as well as two utility partners (Thames and Anglian Water).

In this paper we set the overall context for wastewater heat recovery systems in the UK, describe the HE4T project case study, then present some initially measured data, variations in wastewater temperature and flow, steady state and dynamic modelling to determine the energy potential of wastewater. Early results, their limitations and possible routes to address these limitations are discussed along with policy implications for UK heat strategy.

2. Overview

2.1 Wastewater Heat Recovery

A waste heat recovery system consists of a heat exchanger and a heat pump installed in and/or near the sewer (Fig. 1). The heat exchanger transfers heat from the sewer to the heat pump, which operates as a closed loop system, and absorbs heat from the heat exchanger. A heat pump then upgrades the low grade waste heat to a higher grade temperature that can be delivered to a heating system or a network [4]. The sewage (dirt) does not comes in contact with the working fluid (clean water or refrigerant) in the heat pump system and the recovered energy is reused for heating and cooling purposes. Thus the heat pump works more economically than fossil fuels and efficiently under low temperature conditions (of wastewater) and offers flexibility of integrating within existing or new systems. The recovered energy is ideal for use in district energy systems, serving range of domestic and non-domestic heating loads.

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Moreover, the recovered energy is environmentally friendly as it results in the reduction of greenhouse gas emissions, resource conservation and in increase share of renewable energy while protecting the environment from polluting and unsustainable practices.

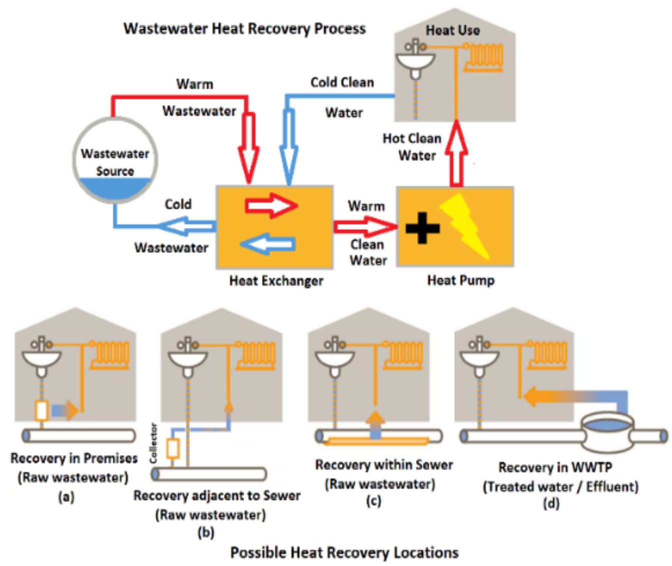

Fig. 1 Wastewater heat recovery process and possible locations of heat recovery [5, 6]

Wastewater or sewage normally when discharged from point of use is at higher temperature (~30°C) than ambient and could be reuse that would otherwise be lost to environment before it reaches to WWTP (normally between 12 to 10°C). However, the treatment processes done on wastewater within WWTP can again raise its temperature slightly from that of its entrance value. Therefore, heat recovery can be conducted from both; before WWTP from the influent or after WWTP from the effluent. Each of these options have their own advantages and disadvantages and the final choice depends on the local specific conditions.

Upstream of the WWTP, heat recovery can be done close to the heat source i.e. within the premises of the household / building referred as **in-house** (Fig 1a). **Close to the heat source** the sewage temperature is higher with no mixing with other drain water. Producers are also consumers of heat so more extraction is possible close to the home but flow is relatively low and varies in time. The wastewater flow from the nearby sewer can be diverted to a custom made collector or well containing screens to maintain clear intakes to specifically designed shell and tube heat exchanger **adjacent to the source (or side-stream)** (Fig 1b). In **Adjacent to heat source** while sewage temperature is high and wastewater is cleaner, its installation requires considerable space. Additionally, the system requires sieves to prevent particle accumulation in the well apart from periodic backwash of the sieve to prevent total or partial clogging. The system can be installed in existing and new developments. **In-sewer / trunk lines arrangements**, the heat exchanger itself is directly installed in the base of sewer pipe. These heat exchangers are in form of plates, panels or are pipes with built-in internal or external tube banks (Fig 1c). Because in this arrangement sufficient flow and pressure is available, they have the advantage of experiencing stable

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flowrates but are at low sewage temperatures (due to heat lost to the environment during its flow path in the sewer network). Further, installation of the heat exchanger may not be possible in all cases, for example due to the available length of straight runs or too great a slope [7, 8]. In many cases, these large sewers are combined sewers and weather and natural events like snow melt, rainfall, flood, ground water leakage could alter the sewage temperature significantly. Moreover, fouling and biofilm growth on heat exchanger surfaces of varying degree within sewer requires continuous monitoring, periodic maintenance and permissible oversizing. For all raw wastewater heat recovery arrangements, the common issues are; limited temperature drop due to impact on WWTP performance, fouling and biofilms growth of heat exchanger surfaces, solid handling, effects of seasonal diurnal variations and constant periodic maintenance [7].

Last possible option of heat recovery is either at pumping station wet wells or **after WWTP** from the discharge from treated water / effluent. For earlier case the wastewater is of similar characteristic as of in-sewer while for later a much cleaner and stable flow is encountered (Fig 1d). **Heat recovery from the WWTP effluent** has an advantage of being at slightly higher temperature than influent with a larger, steady and cleaner flow. Since recovery takes place downstream of WWTP no impact on its performance and effluent can be cooled down much more than upstream allowing higher energy potential. However, this option cannot be used in many locations as WWTPs are located remotely where no heat consumers are available and recovered energy can only be used by WWTP itself [7]. Some examples of wastewater heat recovery plants successfully operating around the world are given in appendix.

Some typical technical viability conditions for sewer heat recovery outlined by previous works are; the potential heat recovery site should be a densely populated area corresponding 15 to 30 l/s of wastewater to the minimum dry weather flow [7,8,9], minimum sewer pipe diameter for existing network should be 800 mm [7,9], potential heat reclamation site should be in the close proximity to heat consumers approx. 100 to 300 m (maximum 500 m) [7,8,9] and minimum heating load/ requirement should be ≥ 50 - 200 kW [7,8]. Lastly, the most important requirement is to ensure that that wastewater treatment activities at WWTP are not compromised by sewer heat recovery upstream, thus restricting the sewage temperature at WWTP inlet not to be less than 10°C. This limit is imposed to minimize any adverse effects on bio-chemical processes that can influence exiting effluent from the WWTP [7].

2.2 Modelling of sewer network

Most widely used techniques to model sewer temperature is linear method or mixture method [9]. The method assumes that the temperature of the mixed sewage downstream must lie somewhere between the temperatures of the main and lateral inflow. However, this method does not take into account the actual heat transfer processes occurring; within the sewer pipe, to/from soil surrounding the pipe or to/from the sewer air within the sewer pipe, thus can only be used as first approximation.

This work uses TEMPEST (<u>TEMP</u>erature <u>EST</u>imation) - a visually interactive simulation software for design and analysis of sewers. The software is based on pseudo two-dimensional mathematical model of a sewerline and is developed by Eawag - Swiss Federal Institute. TEMPEST determines the sewer response i.e. the axial and spatial distribution of the wastewater temperature in the sewer line - the most important parameter for determining heat recovery and its effects on WWTP. The software can be used for simple steady state calculations in a simple sewer line to full-scale dynamic sewer network with lateral inflows [10]. The numerical model in the software uses mass, heat and momentum balance equations for

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as well as consider heat transfer processes between wastewater, sewer air, pipe, soil and biochemical reactions within the nutrient rich wastewater in the sewer system. As with other simulation softwares, TEMPEST too require inputs; wastewater flow at upstream, wastewater temperature, ambient air pressure, ambient air temperature, ambient relative humidity, pipe material, nominal diameter, wall thickness, pipe slope, COD degradation rate, soil material, penetration depth and soil temperature. The main inputs; wastewater discharge and wastewater temperature can either be inserted as constant values in time or as a time series. TEMPEST also has a built-in library for pipe and soil properties that can be extended with user defined values [11]. A sewer line consists of two simple elements ‘node’ followed by ‘conduit’. A node represents discontinuity points at the start and end of conduits, e.g. headspace, inflow, lateral inflow, change in pipes diameter, change in pipe and soil properties etc. and is modelled by continuity conditions. Whereas the conduit is mass balance equations in which wastewater flow, air flow and wastewater/vapour temperature are continuous functions in time and space and is modelled by one-dimensional balance equations. A set of continuity conditions (nodes) are mathematically inserted into the mass balance equations (between conduits). Note that a simple model can be of single sewer line while large scale model can contain very large number of sewer lines. A complete mathematical review of the TEMPEST can be found in [10, 11].

3. Case study

3.1 Theoretical Potential

With daily discharge of 16 billion liters of sewage in more than 624,200 kilometers of sewer pipes to pass over to 9,000 WWTPs across UK - the potential of heat recovery is significant [12]. Typical, sewage temperature in UK sewers vary from 10 to 25 °C with a yearly average of 17.5 °C [13]. Theoretically, if above daily discharge is cooled by 3 degrees for heat recovery, it is possible to recover up to 20 TWh heat energy annually, enough to heat 1.6 million homes. Similarly, considering heat recovery from the effluent of the largest WWTP in UK, with daily average dry weather flow of 1207 million litres [14] and cooling it by 3 degrees, the recoverable heat potential is approximately 1.5 TWh heat energy annually, enough to heat more than 100,000 homes. In practice not all the heat can be recovered because the total amount of heat is a function of initial temperature of the raw wastewater/effluent, raw wastewater/effluent flow rates, minimum temperature requirements for the raw wastewater/effluent and the efficiencies of the heat exchanger and the heat pump. As shown, there is much theoretical potential along with significant opportunity for future energy reclamation and GHGs emission reduction in the longer term but the UK needs to overcome major practical constraints defined in introduction.

3.2 Experiments, Data and Model setup

The paper presents preliminary data collection and modelling carried out for the HE4T project. The major reason of using this preliminary data is that it not only contains the spatial and temporal details of wastewater flowrate and temperatures (normally not available) but it also provides a good opportunity to know the data requirements, quality and gaps. Moreover, this data can also be used in verify the existing modelling tools. Measured data includes raw sewage temperatures, discharge level and velocity. Where discharge cannot be directly measured, wastewater level and velocity can be used to calculate and calibrated against the reference values.

The data presented and analysed in the current paper belongs to a particular monitoring site in London and is for a week period between Monday, 19th March to Sunday, 25th March 2018. The weather during the stated period was dry and hence free of the influence of stromwater runoff on the flow and temperature measurements (dry weather flow). The site considered is combined sewer system (sewer collecting the

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domestic sewage, rainwater, surface water etc.), gravity driven lying around 3m beneath the ground. The incoming wastewater belongs to two large catchment areas upstream of A and B, which merge to a common main sewer collector before C, given in Fig 2. The points A and B are measuring data points and C is the point where heat recovery is expected. The weather related data is taken from closest weather centre from which rain and dry weather days are identified.

For TEMPEST modelling, in order to reduce the complexity of large sewer networks upstream, only last 500m length with nominal diameter of 1219mm and slope of 0.0091 is simulated for heat recovery potential where energy recovery centre is anticipated. The pipe is circular made of reinforced concrete while soil surrounding the buried pipe is taken as London clay with estimated temperature to be 8°C [15]. At approximately 220m after point A, there is a drain (A') which is assumed to be dry during this time period and can only allow little air exchange due to openings in the manhole cover. The outside average air relative humidity, air ambient pressure, air ambient temperature and exchange coefficient were 80%, 1015mbar, 7.7°C and 10% respectively. The measured daily discharge and temperature at point A is $0.122m^3/s$ and 7.8°C while at point B - a lateral inflow is $0.04m^3/s$ and 11.9°C. Downstream of the sewer under consideration there is vast sewer network (populated area) and heat recovery by the energy extracted can be reclaimed before entering to WWTP some 25km away.

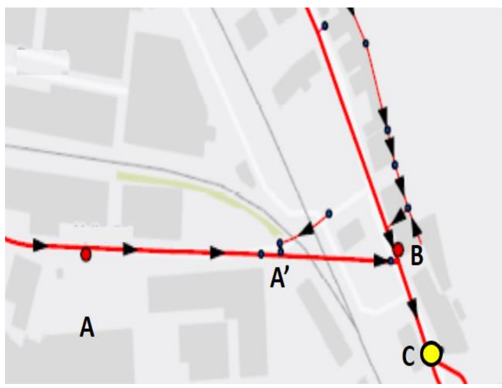

Fig. 2 Large sewer network with possible location of heat recovery at C

4. Results and Discussions

4.1 Data Analysis

A significant barrier in picking up this technology is lack of data and thus heat recovery modelling. Very few experimental works are accessible in public domain [9, 16, 17] and those available are confined to measurements of flowrates and temperatures of the single sewer upstream and downstream. Whereas the work presented here considers combined collection sewer with a lateral inflow in the sewer (point B), hence two flowrates and temperatures input profiles have to be considered, however where appropriate this work will compare results to previous works. The measured time series for a week of flowrates and temperatures at point A and B are given in Fig 3. Note that no smoothing has been performed on the data. The top schematic (a) shows the flowrates at the measuring points A and B with lower (b) representing the temperatures.

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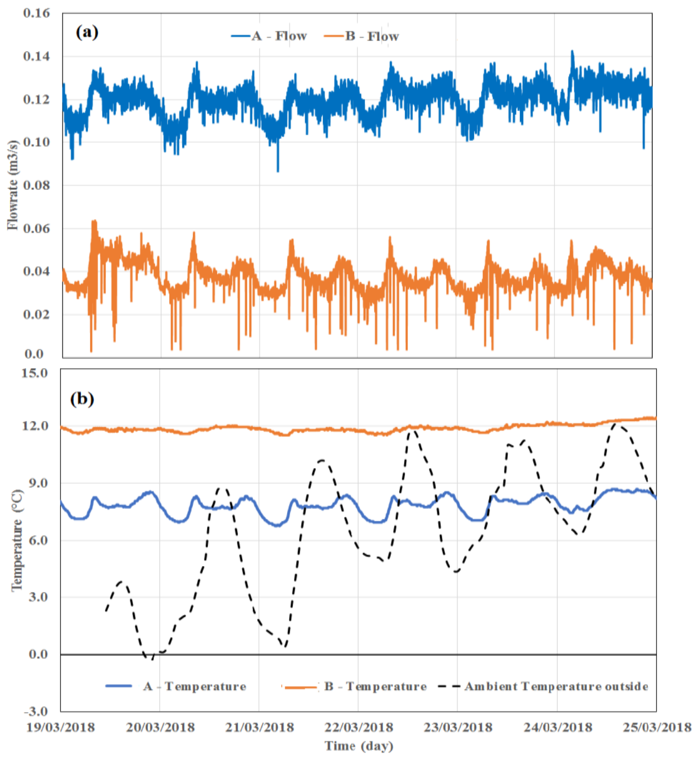

Fig. 3 Recorded Flows and Temperatures inside sewer at A & B along with trend of Ambient air temperature outside

The flowrates in Fig 3a clearly show constant daily diurnal or periodic fluctuations (maximum and minimum discharge measured during the day). The minimum discharge occurs during the night (precisely after midnight) as there is no warm discharges in the sewers. The warm discharges at point of measurements starts to increase little before 6:00am, reaching to maximum between 10:00am to noon. After midday, warm discharges at point of measurements drops and stabilizes, a second milder peak (than midday) of warm discharges occurs later in the evening at point of measurements signifying the consumer behavior. The covered period starts from Monday, and the same discharge is observed until Saturday becoming less evident peak on Sunday. It can be observed that both the flowrates changes (maximal and minimal) are more evident than the changes in their respective temperatures (Fig 3b), especially note that the temperature at point A, clearly exhibits two peaks (coinciding with early morning and late evening). The low temperature time series at A suggest that upstream to this point the sewer has sporadic lateral inflows hence the flow has reached steady state temperature. The map suggest this is the case as there are only two connections upstream quite far from point A; a combine sewer and surface-storm flow connection. Considering the lateral inflow at point B, temperature is consistently high and flat throughout with no visible diurnal. In Fig.2, it can be seen that there are close domestic points very near to the connection of major sewer line (point B), the residence time in this connection is relatively short thus the not allowing temperature to achieve steady state as that of in main sewer line (point A). This trend is also

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in line with previous work [9, 18] that wastewater temperature is highest at/ near the discharge point, hence the potential heat reclamation sites should be in close vicinity of such inflows confirming the technical viability condition also. Additionally, it can be observed in Fig 3b that in the monitored time frame, the sewer temperatures (average 7.8°C and 11.9°C) at points A and B are relatively stable, higher and less effective by average ambient air temperature outside (6.5°C). All the above measurement trends of flow and temperature; varying from day to day including working and nonworking days, more pronounced changes in flow than temperature and less responsive to ambient air temperature outside, all corroborates the finding of previous work [9, 16,17] performed between October and March.

4.2 Modelling Results

The distinctive features of this site are that it considers a lateral inflow (point B) while the previously conducted TEMPEST studies [10,11] only presents analysis for single sewer line with no lateral inflows. The site also satisfies the typical technical viability criteria (stated in section 2.10; flow requirements ($0.162m^3/s$), minimum pipe diameter (1219mm), not only closer to consumer proximity (500m) but also in close vicinity of major lateral inflow and anticipated heating load (300 to 500kW). The wastewater inflow temperature to WWTP (also called influent temperature) restriction is not an issue on this site as there is a concentrated urban area (presence of other lateral inflows) downstream of point C before the sewage reaches to the two pumping stations in south and north west after which it is pumped to the WWTP so there is no serious low temperature implication at the inlet to the pumping stations and WWTP.

The sewer network is modelled in TEMPEST software as a sewer line (Fig. 2) (extended from measuring point A (node) to point C (planned energy centre). Where the start node is A, A' is node with no wastewater inflow but allowing little air exchange, node at B is a lateral inflow and the end node is C, the point at which temperature is to be determined to calculate the amount of heat recovery potential. This point ‘C’ is the anticipated planned energy centre where wastewater recover heat system could be installed to recover heat. The whole length of sewer line is around 500m. The input data required for setting up the model in TEMPEST is already stated in section 3.2. Initially the steady state average values were used and later measured dynamic time series were inserted for dynamic calculations. For the daily average temperatures at point A and B of 7.8°C and 11.9° C, the steady state modelled temperature at point C by TEMPEST is 8.9°C. Note that for this particular campaign the downstream temperature at C was not measured.

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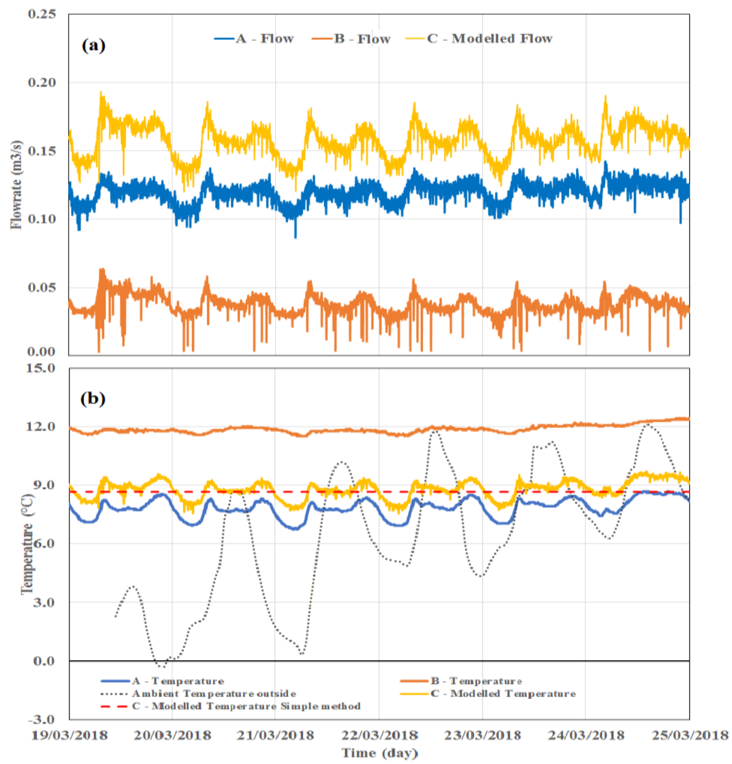

Fig. 4 Recorded and Modelled Flows and Temperatures inside sewers network at A & B

The dynamic modelling results are represented in Fig 4, it shows the measured flows and temperatures along with TEMPEST modelled flow and temperature at point C. As expected (in Fig 4a) TEMPEST predicted discharge at C is higher than A and B because of the mutual contribution of the two flows ($Q_C = Q_A + Q_B$) with the daily diurnal pattern clearly visible. Also in the Fig 4b the TEMPEST modelled temperature at C is shown. This is the TEMPEST predicted temperature at C when upstream temperatures are those measured at A and B. The temperature at A and of lateral inflow from B contribute in overall temperature adjustment in the sewer line at point C. Note that the wastewater temperature at downstream point C is approximately 1°C higher than upstream (at point A) due to the addition of higher temperature lateral inflow (from point B).

It is emphasised here that the TEMPEST predicted temperature trend corroborates the experimental observation of [19] that lateral inflows at higher temperature than the main sewer flow will positively influence the downstream temperature of the sewer. As no flow and temperature measurement were performed at point C during measurement period, the predicted temperature cannot be validated at this time. A satisfactory alternative to this limitation is to verify TEMPEST predicted temperature by comparing it with mixture estimation qualitatively. By using this alternate, the temperature is estimated to be 8.7°C, refer to Fig 4b (the constant red dotted line). In comparison to the constant temperature of the alternate, TEMPEST predicted temperature indicate true behaviour similar to that of upstream boundary (point A). Even daily diurnal temperature peaks are also reproduced well by TEMPEST.

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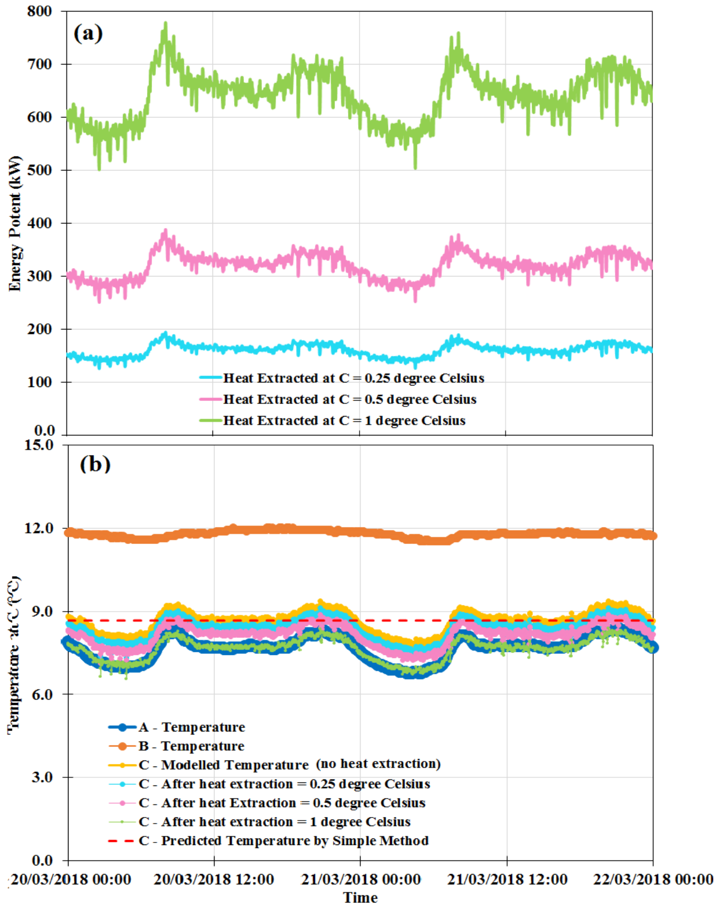

Fig. 5 Heat Recovery Potential from wastewater at the given site in north London

The Fig. 5 shows the heat recovery potentials along with the corresponding temperatures associated after heat recovery. To elucidate the heat recovery potential, above figure only shows the data for two days of March. The temperatures at measuring sites A, B and prediction site C are also plotted. If the wastewater heat recovery exchanger is placed at the site C and the drop in sewer wastewater is assume to be 0.25, 0.5 and 1°C than the amount of heat recovered in kW is depicted in Fig 5a obtained by heat balance. As can be seen, higher the wastewater temperature drop, more is the extracted heat averaging from 150 kW to 350 kW up till 650 kW. However, refer to Fig 5b that wastewater temperature drop of 1°C results in temperature as that of measured at A. Thus for this particular case, if heat extraction takes place at site C than because of the presence of a densely populated area downstream (addition of more lateral inflows to main sewer line) can counteract to keep temperature falling below the legal limit. So it can be concluded that the presence of higher temperature lateral inflows after heat recovery point and before WWTP could prove to be beneficial as they can counter the drop in wastewater temperature and damp out any impact of heat recovery on WWTP inflow.

Note in the figure that heat recovered exhibit diurnal pattern (similar to both flow and temperature maximal and minimal); when sewer inflow is minimum so is the temperature and hence heat recovered, while at peak flow, more is the temperature and heat recovered. This intermittent behavior of recovered heat suggests that in order to make this technology feasible, thermal energy storage should also be considered at design stage so that energy can be recovered when it is available and stored for later use.

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The Fig. 5 also shows that the alligation alternate fails to capture this diurnal heat recovered and overestimates energy content at C when sewer inflow is minimum (so is the temperature) and underestimates energy content at C when sewer inflow is maximum (so is the temperature).

The results from these preliminary measurements are promising. The next step is the detailed measurements for a year period to account for the seasonal variation in the flow and temperature to ensure an efficient heat recovery system design.

5. Policy implications for UK heat strategy

The UK heating strategy is fraught with uncertainty. Decarbonising the entire heating sector will require a combination of upgrades to existing electrical systems and the creation of new carbon-free gas (e.g. hydrogen and biogas). All such options carry costly implications for new infrastructure.

Past work has shown considerable potential for low-grade heat recovery (including from wastewater) to offset the need for new low-carbon heating infrastructure. Early results from the HE4T project support that this technical potential is likely to be considerable at the macro level, but subject to considerable spatial and temporal variation at the local level. Fig 3 shows a difference of over 3°C in flow temperatures from pipework that is separated by only a small distance (A & B), as well as very different responses to daily usage peaks, rain events, and external temperatures. This suggests that the static approach of much past research, which focused on engineering calculations and steady state models, will be insufficiently granular to determine the true potential for heat recovery from waste water in a given catchment. The gap between the theoretical potential and what is practically achievable will have costly knock on effects.

The UK will likely be making critical decisions about the future of the gas network in the late 2030s, as well as the nature, cost, and size of the gas network's inevitable replacement. There is therefore an urgent window for delivering waste water heat recovery demonstrations and pilot projects in order to better understand the practical constraints and the likely performance of such systems over time. These demonstrations will also create a vital evidence base upon which to validate more detailed models of wastewater heat recovery systems, particularly the potential to incorporate such models into integrated multi-vector energy systems as part of a cross-sectoral decarbonisation strategy.

6. Conclusions

Elsewhere across Europe, wastewater heat recovery is an established technology, however in England this is first pilot trial study. In this paper some preliminary measured data from a London site was analysed, its spatial and temporal distribution was discussed. It was found that for the given set of data, sewer wastewater was less responsive (more stable) to outdoor air temperature making it more suitable heat source for heat pumps than other low grade (air, water and ground) heat sources. In particular, the wastewater flowrate shows more pronounced changes than its temperature. It is observed that the flow and temperature of wastewater in the sewer system shows daily and seasonal variation with higher values in day time than at late night and early morning.

Two-dimensional TEMPEST computer program was used to set up a simple sewer network model consisting of main sewer with lateral inflow and wastewater temperature downstream to the sewer was determined. Different simulated temperature drops from above model indicates that the heat recovery will

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depend upon upstream flowrate, temperature, allowable temperature drop at the heat recovery site and the efficiency of the wastewater heat recovery system. These heat recovery potential results are encouraging, however further data is needed and therefore it is recommended; to measure the data across the year to capture seasonal effect to optimize the heat recovery, quantitatively verify the model and perform study on the influences of soil temperature, temperature of in-sewer air and the soil thermal conductivity. Further, the impact of surface water and rainfall in combined sewer systems on downstream wastewater temperature could also not be determined. These are very important and will be investigated in future when more data becomes available. In order to minimise the cost as well as the technical and policy risk, the HE4T project will be validating the modelling approach against measured data for a range of sewer networks over the coming year.

Acknowledgement

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References

[1] Department of Energy and Climate Change (2013) The future of heating: meeting the challenge.
[2] Ali, F. S. and Gillich, A. (2018) The theoretical versus practical potential of existing and emerging wastewater heat recovery technologies. Energy Systems Conference 2018, QEII Centre, London, UK: 19-20 June 2018.
[3] Dunsmore, I. (2016) Heat from wastewater. UK Water Projects.
[4] Fiore, S. and Genon, G. (2014) Heat recovery from municipal wastewater: evaluation and proposals. Environmental Engineering and Management Journal, 13(7) 1595 - 1604.
[5] Berliner, N. E. (2011) Gebäudebezogene Nutzung von Abwasserwärme.
[6] Drenten, S. (2016) Report Summary: wastewater heat recovery UK feasibility. The Cambridge Green Challenge, UK.
[7] Schmidt, F. (2008) Sewage water: interesting heat source for heat pumps and chillers. In proceedings of 9th IEA Heat Pump Conference, Zurich, Switzerland, 2nd May 2008.
[8] Culha, O. H., Gunerhan, E. B. and Hepbasli, A. E. (2015) Heat exchanger applications in wastewater source heat pumps for buildings: a key review. Energy Building, 104, 215 - 232.
[9] Kretschmer, F., Simperler, L. and Thomas, E. (2016) Analysing wastewater temperature development in a sewer system as a basis for the evaluation of wastewater heat recovery potentials. Energy and Buildings, 128, 639 - 648.
[10] Dürrenmatt, D.J and Wanner, O. (2012) User Manual ver. 1.02. Tempest: computer program for the simulation of the wastewater temperature in sewers. Eawag - Swiss Federal Institute of Aquatic Science and Technology.

https://doi.org/10.32438/WPE.58181

[11] Dürrenmatt, D. J. and Wanner, O. (2014) A mathematical model to predict the effect of heat recovery on the wastewater temperature in sewers. Water Research 48, 548 - 558.
[12] Recovering Heat from sewage. Edie.net, (2016) Online: http://wwtonline.co.uk/features/research-notes-recovering-heat-from-sewage#.WuxSHIgvzcs (accessed on 23-03-2018)
[13] Investment in waste and wastewater management. Water UK, 2018. Online: https://www.water.org.uk/policy/environment/waste-and-wastewater (accessed on 27-03-2018)
[14] Moran T. Email to author. 09 May 2018.
[15] MacKay, D (2008) Sustainable Energy - without the hot air, UIT Cambridge Ltd.
[16] Abdel-Aal, R., Mohamed, M., Smits, M., De Gussem, K., Tait, S. and Schellart, A. (2014) Modelling the viability of heat recovery from combined sewers. Water Science & Technology, 70 (2), 297 - 306.
[17] Cipolla, S. S. and Maglionico, M. (2014) Heat recovery from urban wastewater: analysis of the variability of flow rate and temperature. Energy and Buildings 69, 122 - 130.
[18] Wanner, O., Clavadetscher, P., Panagiotidis, V. and Siegrsit, H. (2005) Effect of heat recovery from raw wastewater on nitrification & nitrogen removal in activated sludge plants. Water Research, 39, 4725 - 4734.
[19] Schilperoort, R. P. S. and Clemens, F. H. L. R. (2009) Fibre optic distributed temperature sensing in combined sewer systems, Water Science and Technology, 60, 1127 - 1134.

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APPENDIX

Table 1. Wastewater heat recovery examples from around the world

City / Country	System mSupplier	Arrangement	HP capacity / COP	Purpose	Scale / year
Glarus, Switzerland [7]	Huber Technology RoWin	Collector, Screened Heat Exchanger	30 kW COP 3.8	Heating + Hot water	Pilot (2004)
Wintower, Winterthur, Switzerland [2]	Huber Technology RoWin	Collector, Screened Heat Exchanger	1.5 MW COP 5 - 6	Heating + Hot water + Cooling	Pilot (2011)
Mülheim, Cologne, Germany (CELSIUS project) [3]	Uhrig Kanaltechnik GmbH Therm-Liner	In-Sewer	150 kW	Heating	Pilot (2014)
Wahn, Cologne, Germany (CELSIUS project) [3]	Uhrig Kanaltechnik GmbH Therm-Liner	In-Sewer	200 kW	Heating	Pilot (2014)
SinTec Technology Park, Singen, Germany [4]	Uhrig Kanaltechnik GmbH Therm-Liner	In-Sewer	200 kW + 243 kW COP 3.5 - 3.9	Heating / Cooling	Large (2004)
Leverkusen, Germany [5]	Rabtherm AG Rabtherm - Liner	In-Sewer	170 kW	Heating + Cooling	Pilot (2003)
Ryaverket, Gothenburg, Sweden [6]	Göteborg Energi	Effluent at WWTP	2 × 50 MW + 2 × 30 MW, COP 3	Heating + Hot water	Large (2009)
Hammarbyverket in Stockholm, Sweden [7]	Fortum Energi	Effluent at WWTP	7 HP with 225 MW COP 3.5	Heating + Cooling + Electricity	Large (1986, 91 & 97)
Espoo, Finland [8]	Fortum Energi	Effluent at WWTP	2 × 20 MW + 2 × 7.5MW, COP 3.0	Heating + Hot water	Large (2014)
Katri Vala, Helsinki, Finland [8]	Friotherm AG	Effluent at WWTP	3 × 30 MW + 2 × 30 MW, COP 3.5	Heating + Cooling	Large (2006)
Sandvika, Oslo, Norway [1]	Friotherm AG	Screened, passed to Shell	2 × 6.5 MW + 2 × 4.5MW,	Heating / Cooling	Large (1998 & 08)

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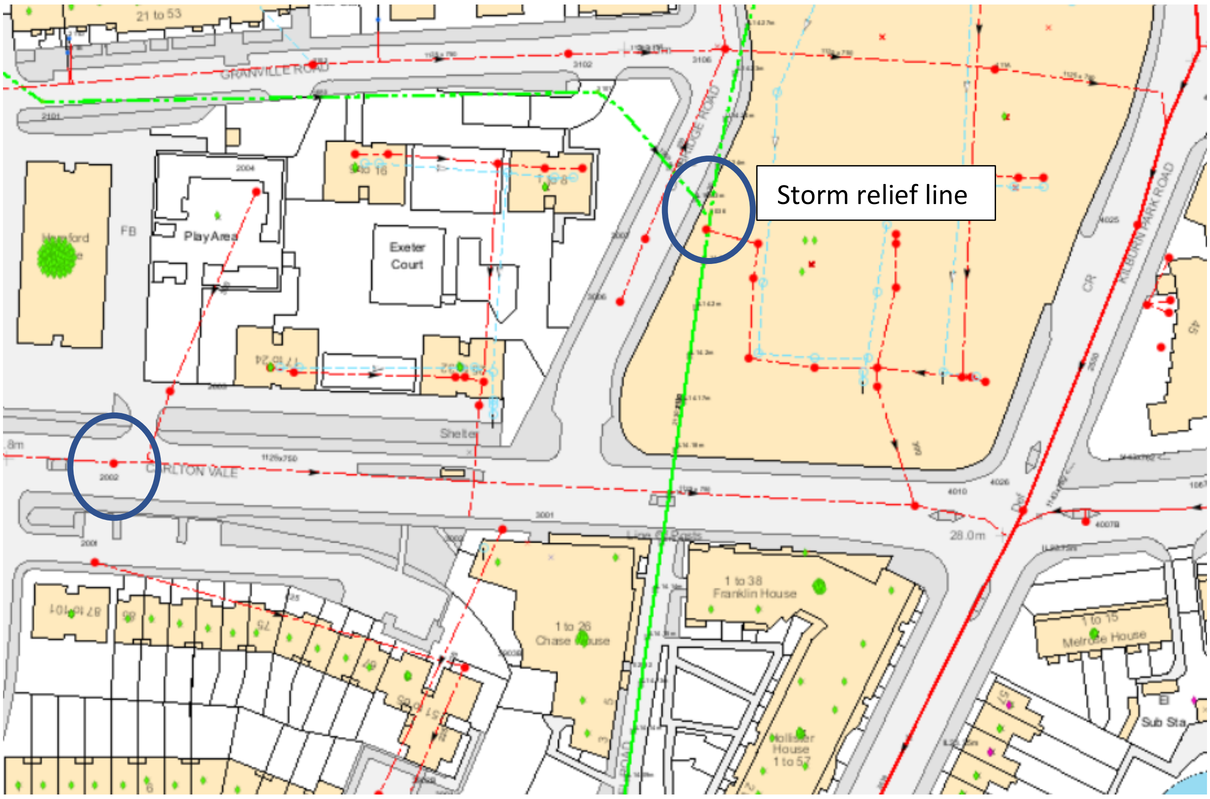
		& Tube Heat exchanger	COP 3.10		
Sköyen Vest, Oslo, Norway [6]	Hafslund Fjernvarme AS	Screened, Shell & Tube Exchanger	28 MW, COP 2.8	Heating	Large (2005)
Leuven, Belgium (INNERS project) [9]	Vlario	Collector Plate Heat Exchanger	250 kW COP 4.5	Heating + Hot water	Small (2014)
Budapest Military Hospital, Hungry [10]	Thermowatt Ltd.	Collector, Screened Heat Exchanger	3.8 MW + 3.4 MW, COP 6 - 7	Heating / Cooling	Large (2014)
Budapest Sewage Works, Hungry [10]	Thermowatt Ltd.	Collector, Screened Heat Exchanger	1.23 MW, COP 4.4	Heating / Cooling	Large (2012)
Eco-district Nanterre, Paris, France [11]	Suez Ltd. Degres Bleus	In-Sewer	2 × 400 kW, COP 2.7	Heating + Hot water	Medium (2015)
Beijing Olympic Village, China [12]	Skandinavisk Termoekonomi AB	Effluent with plate Heat Exchanger	4 × 5.4 MW + 4 × 5.25 MW, COP 3.85	Heating + Cooling	Large (2008)
Whistler Athlete's Village, BC, Canada [13]	IWS Sewage SHARC	Screened & Pumped into evaporator of HP	3.5 MW	Heating + Cooling	Large (2009)
Southeast False Creek, BC, Canada [13]	IWS Sewage SHARC	Shell and Tube Heat Exchanger	2.7 MW	Heating + Hot water	Large (2010)

https://doi.org/10.32438/WPE.58181

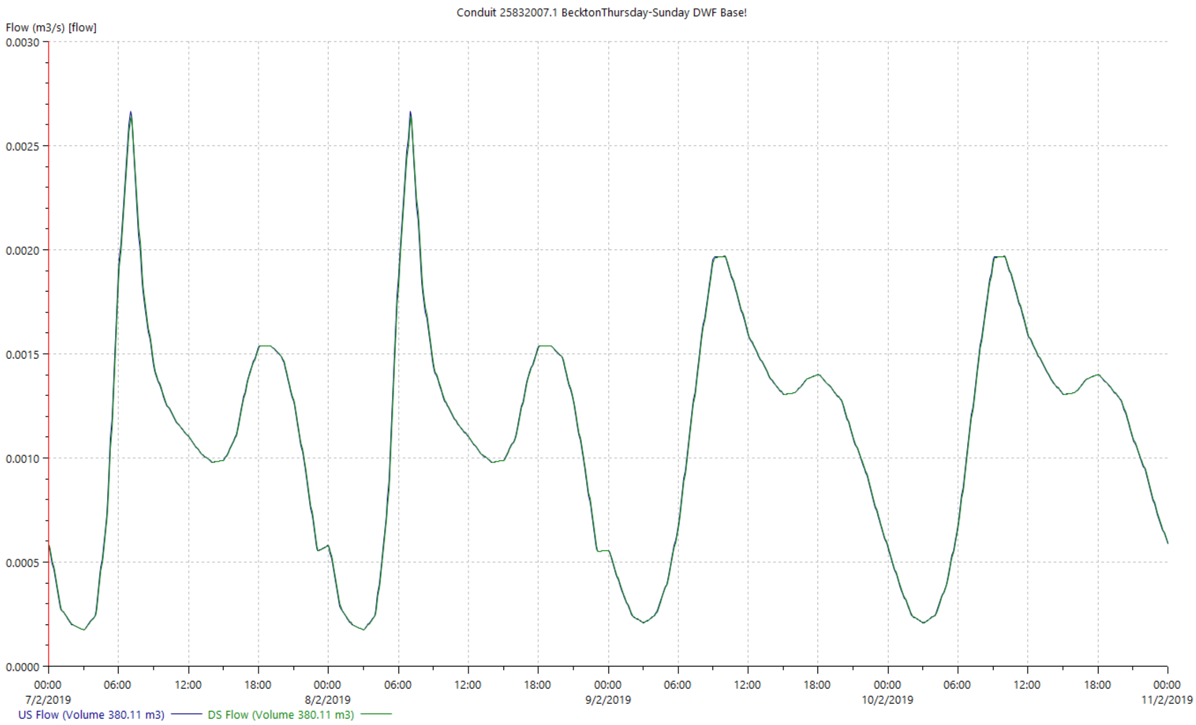
Heat Recovery flow information **16/09/2020**

Model database used - M:\sewerage modelling\- New Projects\Beckton\#Latest Beckton Model\Beckton25-02-2019.icmm

<u>Carlton Vale TQ25832002</u>

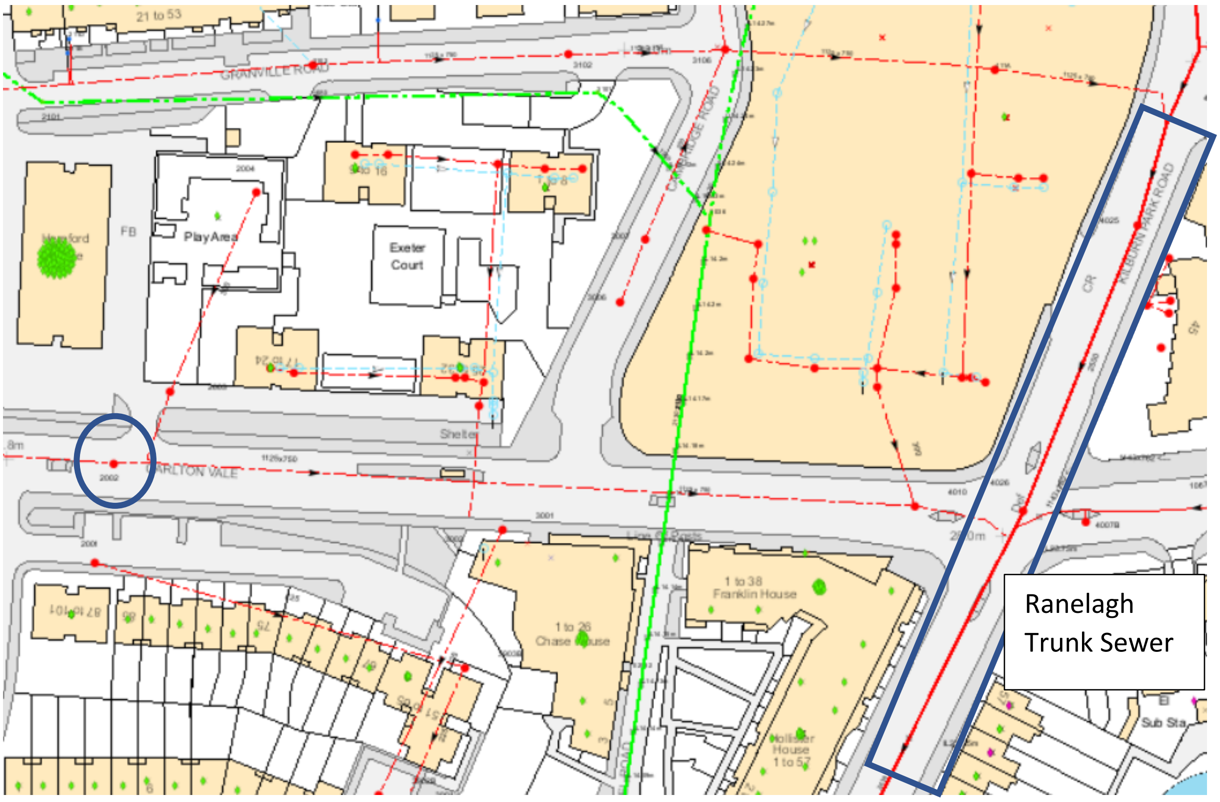


The sewer running along Carlton Vale is a foul/combined line and carries dry weather flow. However, the second manhole identified in this area TQ25833036 is part of the storm relief network and will only carry storm flow. This storm relief network is shown in the green lines above. Data for Carlton Vale is shown below.

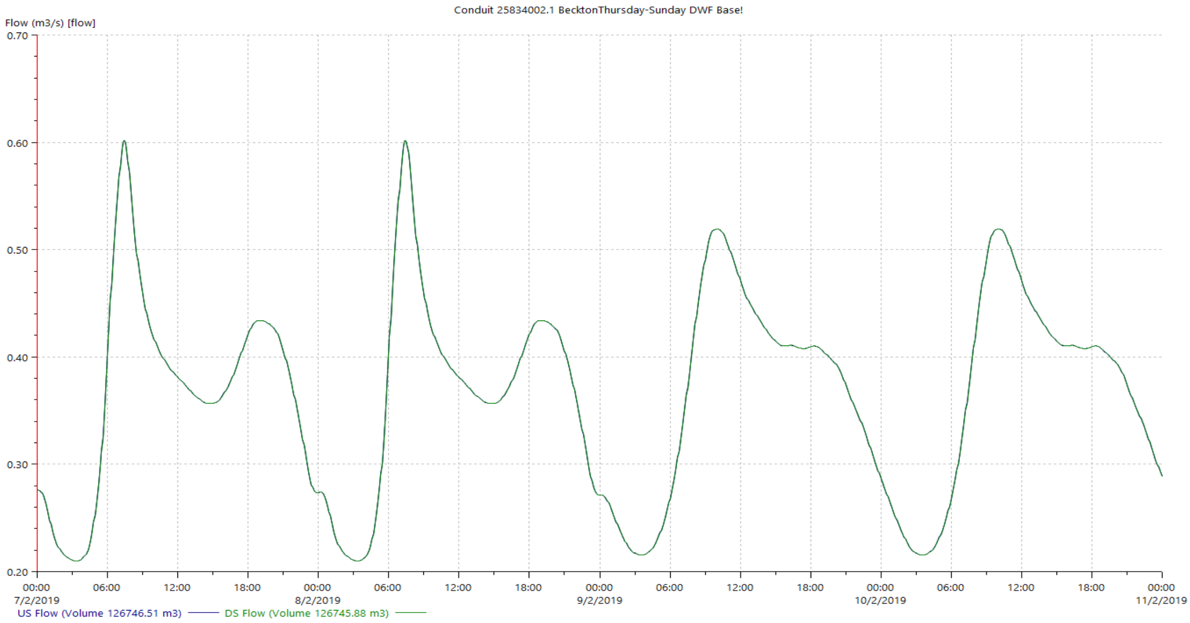


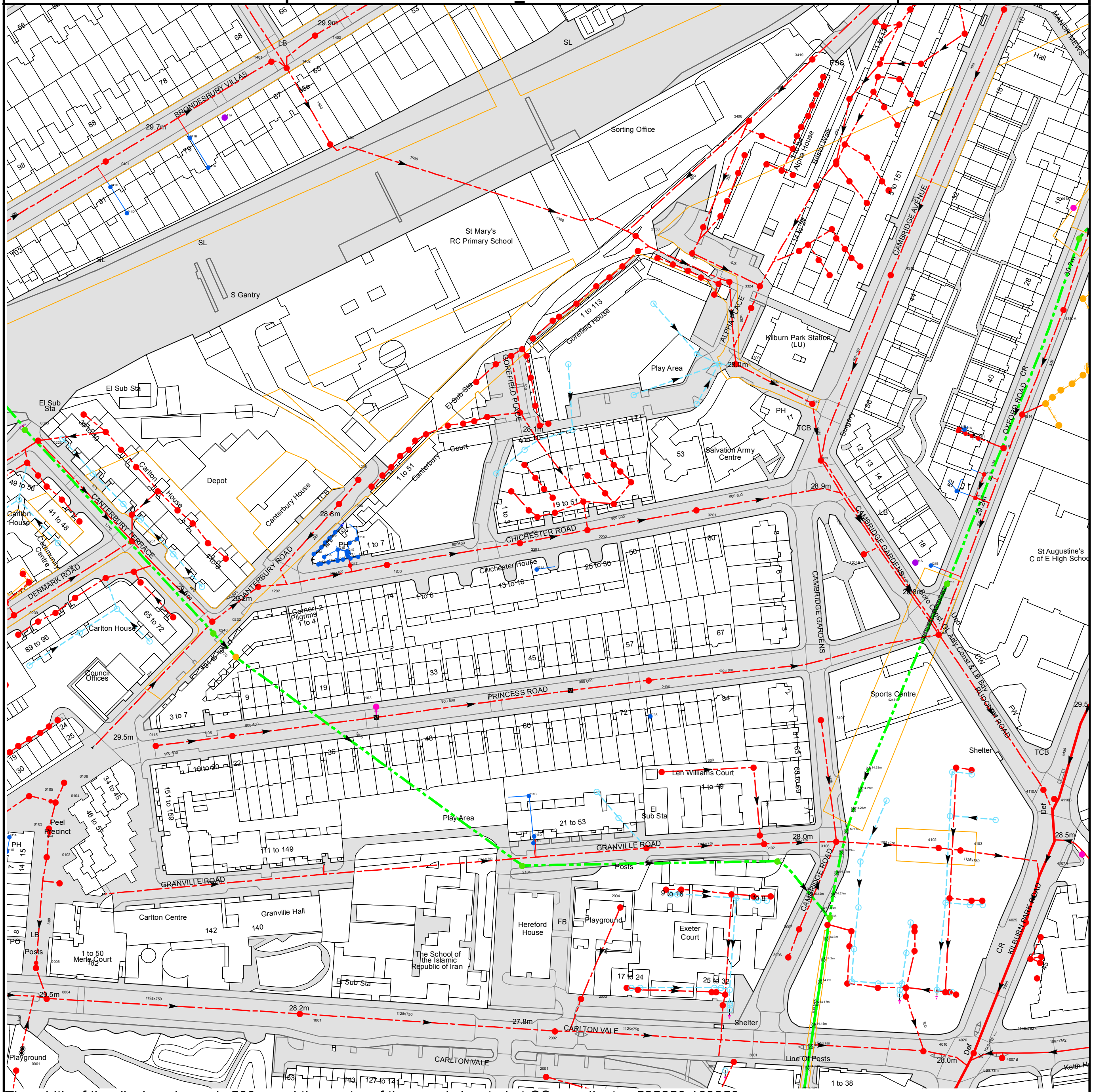
The difference in the diurnal pattern between weekday and weekend is clearer at this point in the model. However, the flows are very low as this line only serves a small upstream catchment. Night time flows are less than 0.5 l/s and the and the daytime peak is only around 2.5 l/s.

The Carlton Vale sewer connects to the top of the Ranelagh Trunk sewer just downstream of the selected location.



By contrast, the Ranelagh serves a much greater part of the upper catchment and the flows are significantly higher. Night time flows are around 210 l/s with peak weekday flows of 600 l/s and weekend peaks of 520 l/s.





The width of the displayed area is 500m and the centre of the map is located at OS coordinates 525250,183250

The position of the apparatus shown on this plan is given without obligation and warranty, and the accuracy cannot be guaranteed. Service pipes are not shown but their presence should be anticipated. No liability of any kind whatsoever is accepted by Thames Water for any error or omission. The actual position of mains and services must be verified and established on site before any works are undertaken.

Model: HWF3212°A°°°° + G0

Attention: please specify, during the order, the choice of the R513A (XP10) gas for proper unit configuration. Option G0.

Warning: please supply this document when ordering the unit to ensure correct expansion valve attribution and to check the operating field.

Code	HWF
Size	3212
Model	° - Heat pumps with reversible water side
Version	A - High efficiency
Set-up	° - Standard
Heat recovery	° - Without heat recovery
Evaporator	° - Standard and in compliance to PED directions
Power supply	° - 400V/3/50Hz with fuses

Certifications

CE EAC

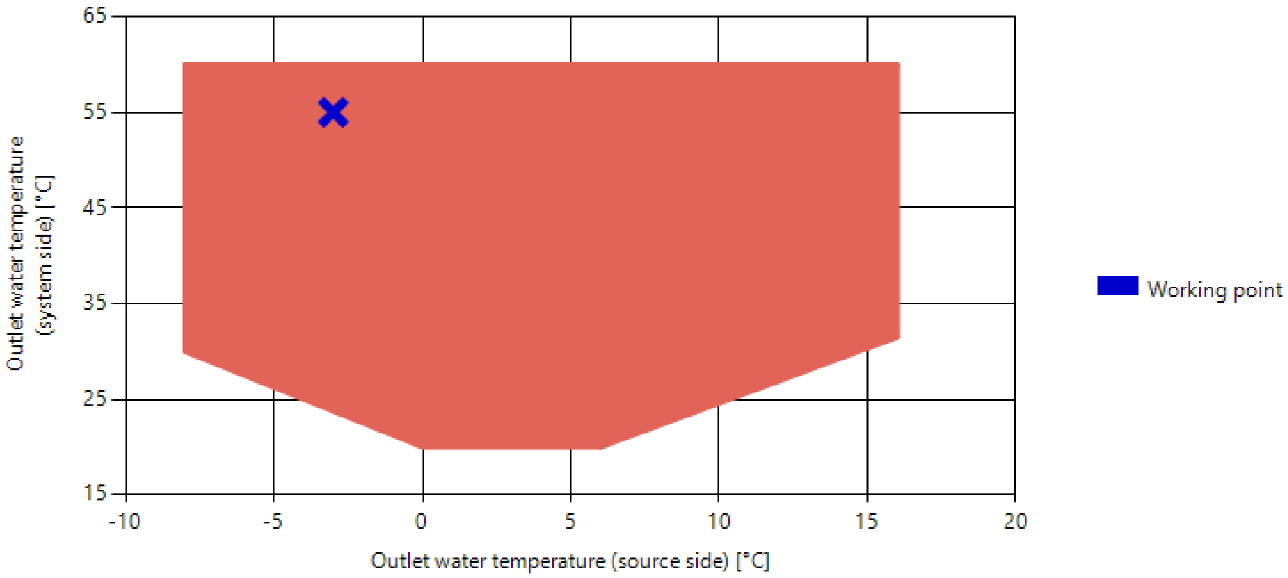
Notes

Data in accordance to EN 14511:2018

Data shown is calculated without soft-starter and/or power factor correction devices.

Heating

Capacity	kW	625.0
Input power	kW	242.2
Input current	A	400
COP	W/W	2.58
System side circuit		
Inlet water temperature	°C	50.0
Outlet water temperature	°C	55.0
Temperature difference	°C	5.0
Ethylene glycol	%	0
Water flow rate	l/s	29.9667
Pressure drops	kPa	26
Fouling factor	(m² K)/W	0
Source side circuit		
Inlet water temperature	°C	0.0
Outlet water temperature	°C	-3.0
Temperature difference	°C	3.0
Ethylene glycol	%	25
Water flow rate	l/s	34.2631
Pressure drops	kPa	46
Fouling factor	(m² K)/W	0



General data

Refrigerant circuit data

Refrigerant			R513A (XP10)
Compressor type			Screw
Number of compressors		n.	2
Number of cooling circuits		n.	2
Refrigerant gas charge	C1	kg	85
	C2	kg	85

Water circuit data (source side)*

Exchanger type		Shell and tube
Number of exchangers	n.	2
Water connections of exchanger	inlet	5"
	outlet	5"

** = referred to cooling mode*

Water circuit data (system side)*

Exchanger type		Shell and tube
Number of exchangers	n.	1
Water connections of exchanger	inlet	8"
	outlet	8"

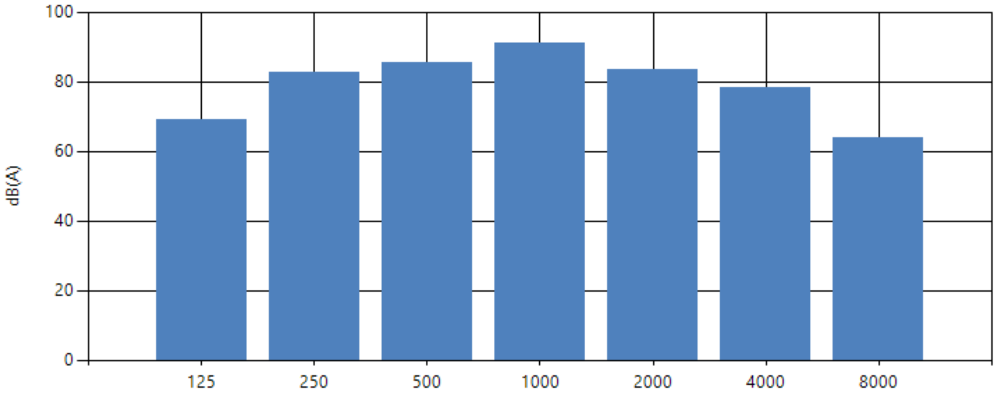
** = referred to cooling mode*

Sound data (Cooling)

Sound power - Lw	dB(A)	93.5
Sound pressure at 10 m	dB(A)	61.3

Sound spectrum for octave bands (center frequency)

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Lw - dB	85.2	91.3	89.0	91.3	82.6	77.3	65.2
Lw - dB(A)	69.1	82.7	85.8	91.3	83.8	78.3	64.1



The sound levels are given at full load, without pumps (if available) and at nominal conditions (external circuit water temperature (in/out): 30.0/35.0 °C, users circuit water temperature (in/out): 12.0/7.0 °C).

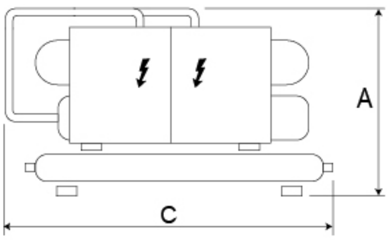
Electric data

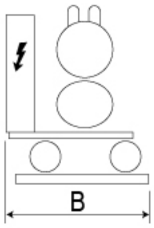
Full Load Amps (FLA)	A	468.00
Locked Rotor Amps (LRA)	A	670.00
Power supply		400V/3/50Hz with fuses

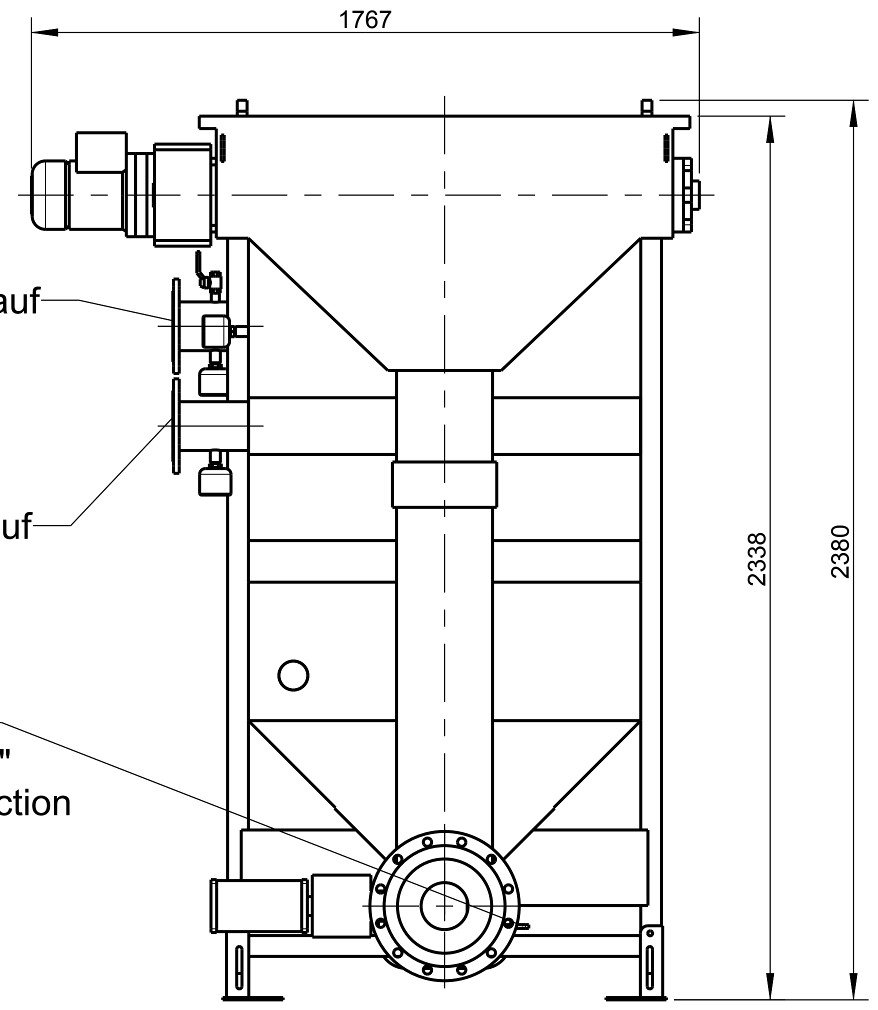
Dimensions and weights

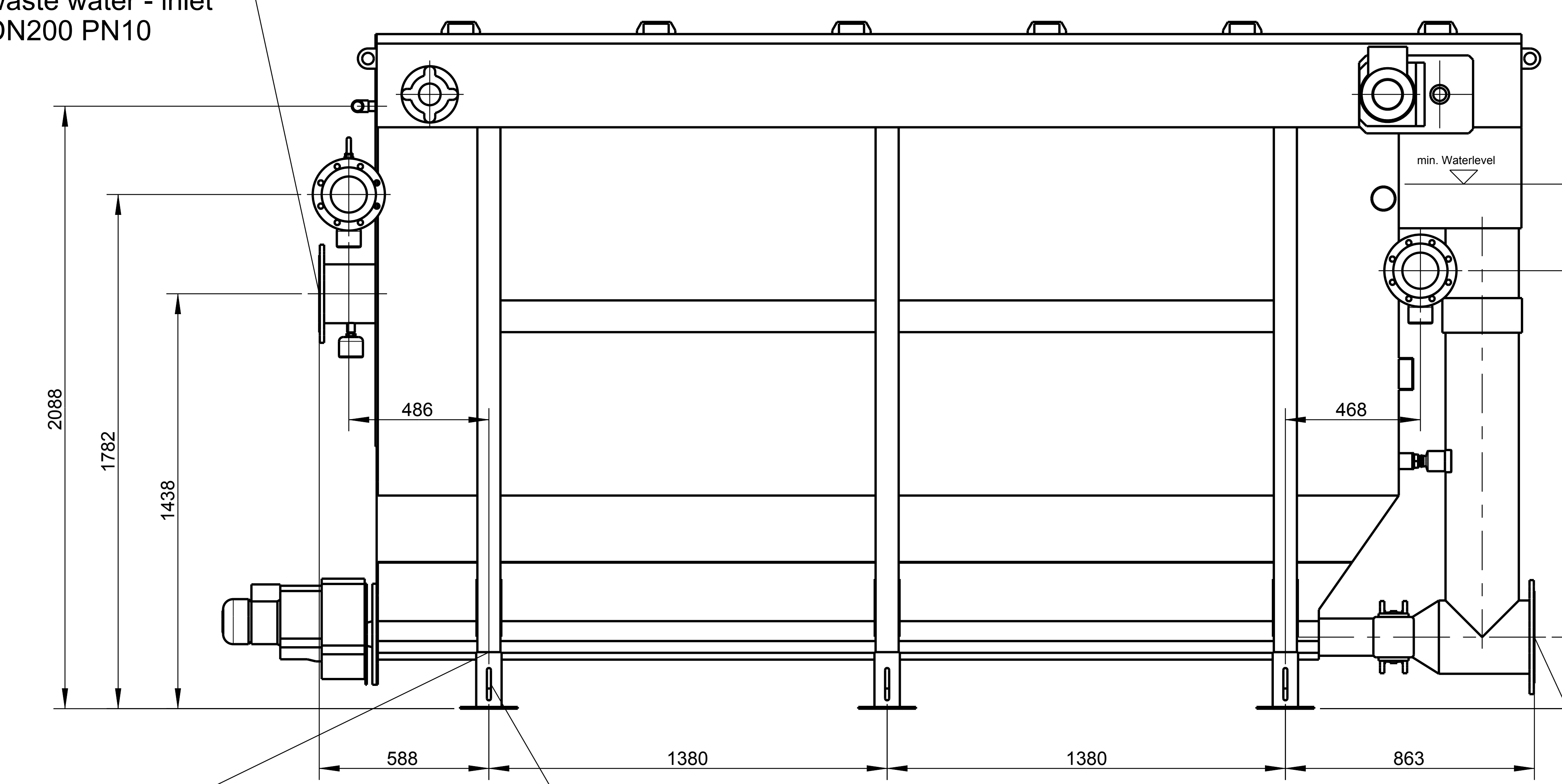
A[m]	B[m]	C[m]	Empty weight[kg]
2.19	1.54	4.33	5,470

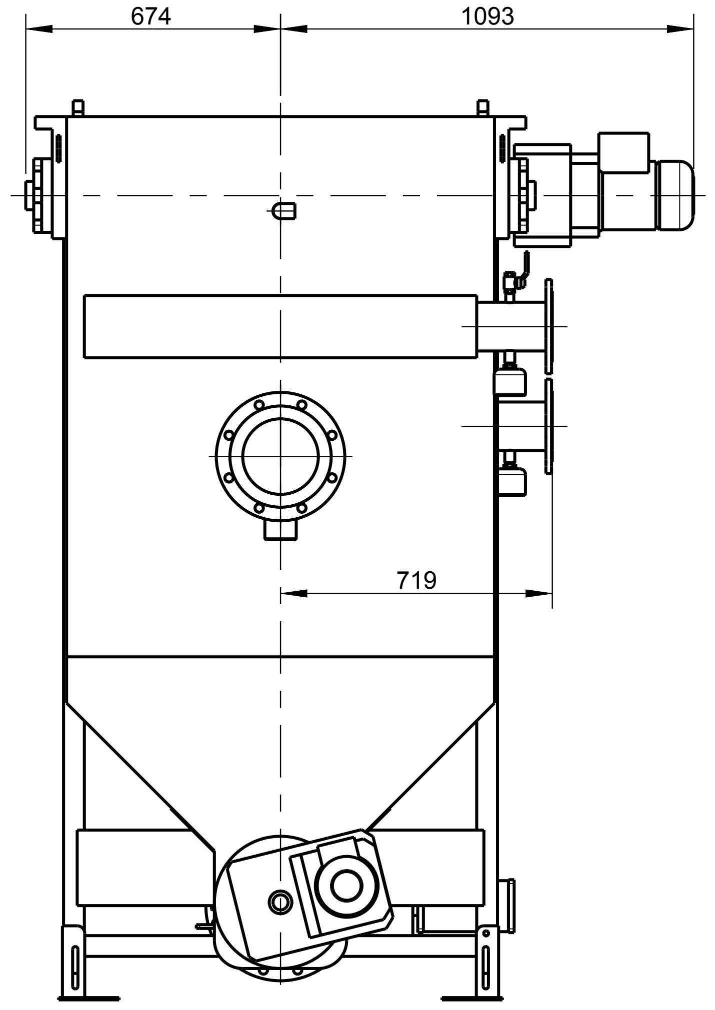
The dimensions and weight refer to the unit without packaging. For these data, consult the installation manual.

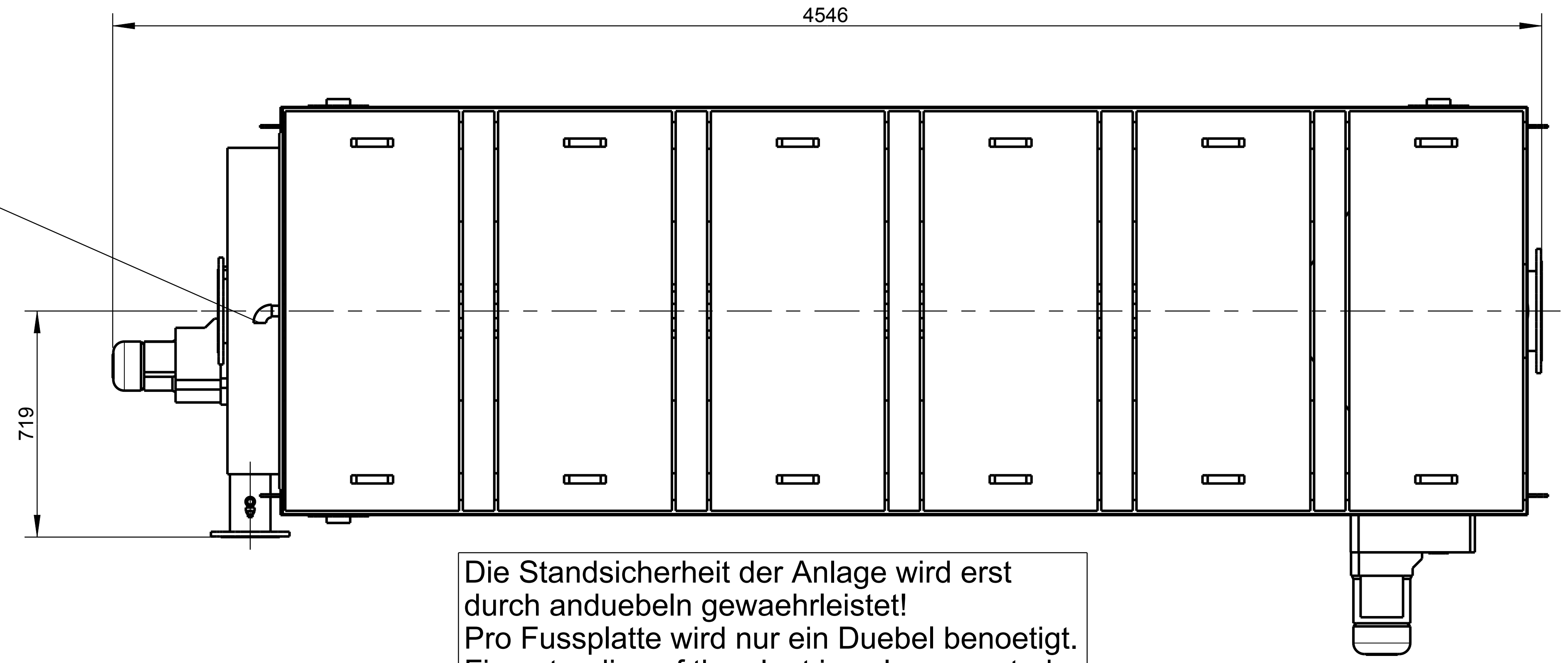

A
C


B

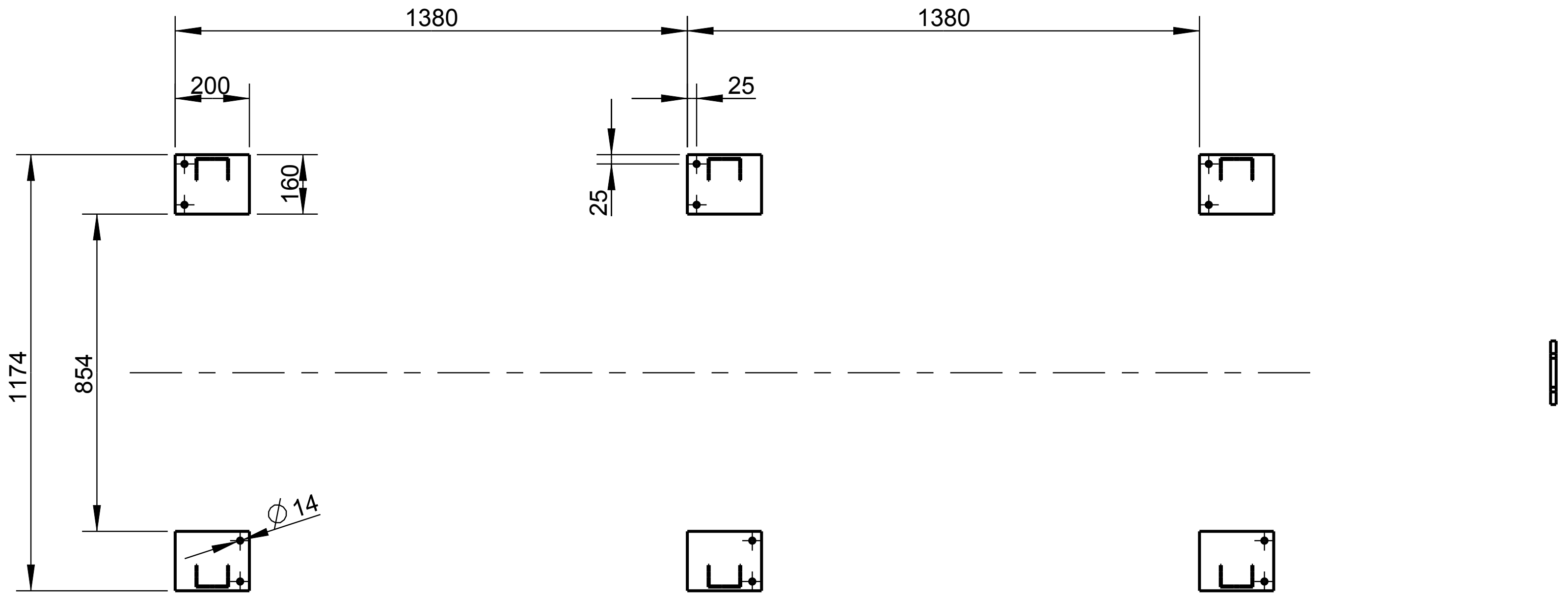








Detail: Fussplatten & Bohrbild
detail: base plates & drilling points



Flaechenbelastung betraegt 17kN pro Fussplatte
load per base plate is 17kN

Masse ohne Wasserfuellung / mass without water filling	: 2400 kg
Masse mit Wasserfuellung (ueberflutet) / mass with water filling (overflooded)	: 10000 kg

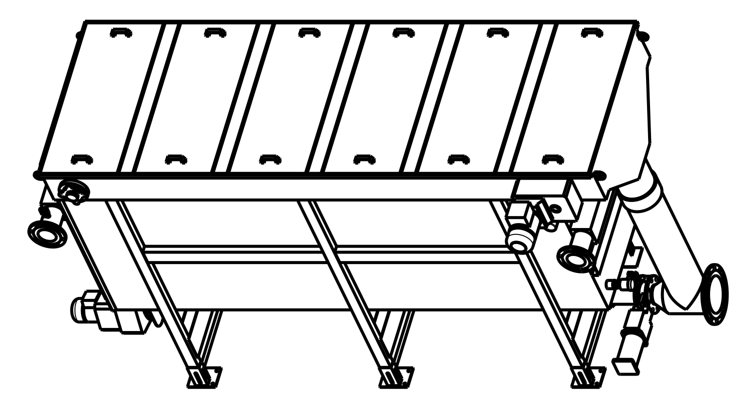
Die Standsicherheit der Anlage wird erst durch anduebeln gewaehrleistet!
Pro Fussplatte wird nur ein Duebel benoetigt.
Firm standing of the plant is only guaranted ofter dowelling!
You have to anchored only one drilling hole of the foot plate.

Platzbedarf zu Wartungszwecken:
4m vor der Maschine frei halten!
place requirement for reasons of maintenance:
4m in front of the machine to keep free!

freier Ablauf des Behaelters muss gewaehrleistet sein!
free drain of the tank must be guarantee!

zusaetzliche Lasten (z.B. durch Rohrleitungen, Bedienbuehnen , ...) auf der Anlage sind nicht zulaessig!
additional loads (e.g. through pipelines, service platforms, ...) on our plant are not allowed!

Unfallverhuetung gem. GUV und Maschinenrichtlinien (Gelaender, Wartungsbuehnen, Eingreifschutz usw...) bzw. laenderspezifischen Vorschriften bauseits beachten!
accident prevention acc. GUV and machine directives (railings, maintenance platforms, guards, etc...) or country specific regulations must be observed by others!



1:50

Technische Aenderungen vorbehalten / Subject to change — ISO 2768-mK

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Revi-sion	Aenderung Modification	Tag Date	Name		Datum/Date	Name
				Bear./Rev.	23.06.2010	grm
c	Aend. 2858	28.07.16	hfl	Gepr./Appr.	‖	‖
				Norm.		

HUBER Abwasserwärmetauscher
HUBER Heat Exchanger
RoWin 8

Projekt project	Dimension Sheet	Massstab scale	Nummer number	Blatt sheet
Massblatt - Sheet of dimensions		1:20	010_000751	1/1