GREATER**LONDON**AUTHORITY

London’s Zero Carbon Energy Resource: Secondary Heat

Report Phase 1

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Executive summary

The Greater London Authority (GLA) has commissioned a study into the capacity and utilisation of secondary heat sources in London where secondary heat is considered to be heat arising as a by product of industrial and commercial activities, from infrastructure operation, and from the environment (air, ground, water). This report is the first deliverable for the study and is accompanied by a number of analytical models and maps supplied separately.

The objectives of this first piece of analytical work are:

- To identify and analyse the origin, quantum, spatial distribution and thermodynamic and temporal (diurnal, seasonal) characteristics of sources of secondary heat in London
- To identify and analyse to what extent these heat sources may be utilised by matching to the heat demand profile of London
- To provide an understanding of how the utilisation of these sources of supply may evolve over the period to 2050 based on different and defined supply and demand scenarios.

Supply

To this end, secondary heat sources have been investigated in detail based on clearly defined methodologies that take into account the nature of the heat source and the availability of data in relation to its key characteristics and location.

This first step enabled the quantification of heat *available* from each source. The next step has been to determine the heat that could be *delivered* by each source. This distinction between available and delivered heat is necessary because for some heat sources use of heat pump technology is required to extract and utilise it. The heat available from these secondary sources is generally but not always of a low grade, that is, of a low temperature. To convert the lower grade heat into useful, higher grade heat, heat pumps are required. Heat pumps require electricity to operate which is also converted into useful heat. The efficiency with which heat pumps make this conversion is referred to as their Coefficient of Performance (COP).

In order to determine the quantum of *delivered* heat, an analysis of heat pump technologies has been undertaken as appropriate for each heat source. By applying the relevant seasonal COP to the available heat supply, the delivered heat supply has been calculated.

An initial review of how heat can be captured from each source has been undertaken, along with a review of how heat is used within buildings, and the impacts of changing heating system temperatures to operate at lower levels.

Precedent projects from Denmark and Canada suggest that sources such as waste water treatment plants, building heat rejection and refrigeration systems are all technically viable sources of heat. They also show that heat can be distributed using conventional district heating temperatures or systems which operate at ambient temperatures and use decentralised heat pumps within individual buildings to upgrade the heat.

The quantification and spatial distribution of delivered heat from each source has been assessed and presented geographically using geographic information systems (GIS) with the heat from each source aggregated at Middle Layer Super Output Area (MSOA)[1] level.

The analysis shows that the total amount of heat *available* in London from secondary sources is around 49,974 GWh/yr. This is equivalent to 76% of London's total heat demand in 2010. Total *delivered* heat is 71,330 GWh requiring an additional 21,356 GWh of electrical input from heat pumps.

The three highest sources of supply for delivered heat are air source (23%), water treatment works (20%) and ground source (19%). The environmental sources tend to dominate as they are effectively only constrained by demand, notwithstanding the high potential impact on electricity networks of large increases in demand. In practice the constraints applied to air source and ground source in particular are likely to significantly overestimate available supply.

Sources which appear to have limited potential (<0.1% of total heat demand) at a macro scale include London Underground ventilation (0.02%), small industrial processes (0.04%) and larger industrial sources (0.12%). Note this does not mean that these sources could not be used on a project specific basis. They are available in relatively concentrated quantities which makes them easier to recover than ground or air source recovered energy.

Utilisation

In order to explore potential utilisation, it has been necessary to analyse heat demand for London and the extent to which that heat demand could be met by secondary (low grade) sources. Heat demand for London, derived from natural gas consumption data, has been allocated to each MSOA and profiled using available data for the energy efficiency of London's building stock and for differing end uses (space heating, hot water, catering, process heat). It has then been converted into heat demand using assumed boiler efficiencies.

The approach attempts to take into account constraints related to the usability of low grade heat by different types of demand (such as space heating or domestic hot water) in buildings with different thermal efficiencies[2]. Modelling undertaken for buildings with differing efficiencies has been undertaken and suggests that more energy efficient domestic buildings can utilise as much as 82% of low grade heat, while less efficient ones can use significantly less[3]. The difference is more marked with the range of non-domestic buildings ranging from 99% for the most efficient down to 29% for the least.

Modelling associated with connection at lower temperatures and the impact of retrofit of buildings will be presented in the next stage of the project.

Assuming a market penetration for heat networks of 70% of heat consumption and applying the above constraints the study shows that 38% of London's heat demand in 2010 could be effectively met be low temperature heat sources.

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[1] A geographical area developed to ensure consistent boundaries are used for reporting statistics which vary by area. Typically a MSOA has a population of around 8,000 and an area of around 120Ha.
[2] Note that the impact on London's heat demand has been modelled with data available, but without more detailed information on the distribution of energy performance and heating system types within the building stock a comprehensive and robust analysis is difficult.
[3] Assuming the building heating system was designed to operate at 82/71°C

This constrained heat demand has then been matched against supply so as to ensure that where supply exceeds demand in a certain MSOA the excess supply is allocated to a neighbouring MSOA with unmet demand. This models the impacts of heat networks over wider areas, up to 5km from the heat sources in question.

The results of this exercise suggest that around 35% of London's total 2010 heat demand could be met by secondary sources of heat. This corresponds to meeting almost all of the heat demand considered to be suitable for utilising low grade heat.

Future potential

The above analysis provides an understanding of the potential contribution that secondary sources of heat could make to meeting London's heat demand based on existing heat demand. The final part of the analysis explores different heat supply and demand scenarios, quantifying changes out to 2050 based on a range of assumptions. Three scenarios were developed for demand with the key differentiating factors being heat network development rates and building retrofit rates. These are: a Business as Usual case representing a low penetration of heat networks and limited environmental progress; a Co-ordinated case representing medium progress on both fronts; and an Ambitious case representing significant progress. Under the Ambitious case it is assumed that penetration of heat networks increases from 70% to 80%.

Factors likely to affect supply are very varied with a major distinction being between environmental and process-related sources. In respect of the former, change is likely to be relatively limited in terms of available heat (although utilisation of that heat is largely driven by demand and may evolve over time depending on policy and technological factors); in respect of the latter, drivers for change are varied and depend on the specifics of the industry sector. A set of assumptions have been made in relation to heat supply and associated changes quantified for the periods 2030 and 2050.

The matching of heat supply and demand has been undertaken for the Ambitious scenario in 2050. This shows that around 38% of heat demand in 2050 could be met by secondary sources, contingent on significant improvements to the thermal efficiency of the building stock. Unlike in the 2010 case where utilisation is constrained by demand, in this case utilisation is more constrained by supply. It is assumed that due to building upgrades a far higher proportion of heat demand can be met by low grade heat sources thus demand is much less of a constraint.

It is likely that modelling the economic potential for heat networks would greatly reduce the proportion of heat able to be supplied by heat networks. The London Decentralised Energy Capacity Study suggested that only 22% of London's total energy demand (around 17% of heat demand) could be met by decentralised energy sources by 2031. This suggests that the potential of secondary sources is likely to be constrained by the deployment of heat networks.

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Abbreviations

ASHP	Air source heat pumps
CLG	Department for Communities and Local Government
CHP	Combined heat and power
CHPQA	Combined Heat and Power Quality Assurance
CO_2	Carbon dioxide
COP	Coefficient of Performance
DE	Decentralised energy
DEC	Display Energy Certificate
DECC	Department for Energy and Climate Change
Defra	Department for the Environment, Food and Rural Affairs
DESS	District Energy Sharing System
DHW	Domestic Hot Water
EA	Environment Agency
EfW	Energy from waste
EPC	Energy Performance Certificate
FIT	Feed-in tariff
GHG	Greenhouse Gas
GIS	Geographical Information System
GLA	Greater London Authority
GSHP	Ground source heat pump
GWh	Gigawatt hour
HDPE	High Density Polyethylene
HTHW	High Temperature Hot Water
LCBP	Low Carbon Buildings Programme
LUL	London Underground Ltd
LTHW	Low Temperature Hot Water
MTHW	Medium Temperature Hot Water
MW	Megawatt
MWe	Megawatt electric
MWth	Megawatt thermal
MWh	Megawatt hour
PV	Photovoltaic
RE	Renewable energy
RHI	Renewable Heat Incentive

SAP	Standard Assessment Procedure
SER	Seasonal Efficiency Rating
SWH	Solar water heating
TfL	Transport for London
UKPN	UK Power Networks
VLTHW	Very Low Temperature Hot Water
WWTP	Waste Water Treatment Plant

1 Introduction

1.1 Background

The Greater London Authority (GLA) has commissioned a study into the capacity and utilisation of secondary heat sources in London. For the purposes of this study, secondary heat is considered to be heat arising as a by product of industrial and commercial activities, from infrastructure operation, and from the environment (air, ground, water).

This study builds on the Mayor's *Decentralised Energy Capacity Study* (2011)[4] which suggests that 22% of London's heat and electrical energy could be distributed by district heating networks by 2031. Sources of this heat are forecast to be via combustion of primary fuel sources including gas, biomass and waste. With the likely reduction in availability and viability of gas and waste, there will be an increasing emphasis on alternative sources, of which secondary heat is one.

This study is being undertaken by Buro Happold in conjunction with specialist consultants DEC Engineering in Canada and COWI in Denmark. It is being overseen by a Steering Group from within the GLA with further input provided by an Advisory Panel, established to help steer the project, particularly in relation to data gathering and interpretation.

1.2 Study Objectives

This Phase 1 report addresses the following objectives:

- Objective 1: To identify and analyse the origin, quantum and spatial distribution of sources of secondary heat in London
- Objective 2: To identify and analyse the thermodynamic and temporal (diurnal, seasonal) characteristics of each heat source
- Objective 3: To identify and analyse to what extent these sources of supply may be utilised by matching to the heat demand profile of London
- Objective 4: To provide an understanding of how the utilisation of these sources of supply may evolve over the period to 2050 based on different and defined scenarios

The report is supported by a number of Excel models and GIS files which are supplied separately.

The outputs of this report will be built upon in the next phase of the study to address the remaining study objectives as follows:

- To provide an understanding of the impacts on network and energy systems of utilising these secondary sources of heat
- To provide an understanding of the viability and environmental benefits of each heat source in the context of meeting London's heat demand
- To understand the implications of development of low temperature heat networks for investment and employment
- To explore emerging spatial and project opportunities

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[4] GLA (2011) Decentralised Energy Capacity Study: http://www.london.gov.uk/priorities/environment/climate-change/decentralised-energy

- To explore policy, regulatory and project implications.

1.3 Report structure

The report is divided into the following sections:

- The first section reviews the sources of secondary heat in terms of quantum, location and characteristics (Objectives 1 and 2). This section is supported by detailed analysis and mapping included in Appendix A.
- The second section explores utilisation. In order to do this, heat demand across London has been matched spatially to the various sources of heat supply identified in the first section (Objective 3).
- The third section describes the ways in which demand and supply may change over the period to 2050 and how this might affect utilisation (Objective 4). This is based on three demand scenarios developed from the Decentralised Energy Capacity Study and explores ways in which supply may also change over this period.
- The final section outlines the next steps being undertaken in Phase 2 of the project to meet the remaining objectives of the study.

2 Secondary heat sources

2.1 Scope and origin

For the purposes of this study, secondary heat is considered to be heat arising as a by product of industrial and commercial activities, from infrastructure operation, and from the environment (air, ground, water). The list of sources covered by this study is provided in Table 2-1 below.

Table 2-1: secondary heat sources covered by the study

Category	Heat Source	Description / definition
Environmental sources	Ground source	• At depths below around 6m, ground temperatures are stable throughout the year. The ground can act as both a store and supply of heat. Heat can be extracted from open or closed loop systems, the former using aquifers, the latter boreholes. Both systems are included in this study.
	Air source	• Outside air, at any temperature above absolute zero, contains some heat, the quantity of which varies both seasonally and diurnally.
	Water and river source	• Water and river sources contain some heat. For rivers, the quantity of heat varies with both flow rates and temperature both of which can vary seasonally and diurnally.
Process sources	Power station rejection	• Power stations that burn fuel to generate electricity generally operate at electrical efficiencies of around 30-50% depending on fuel type and technology. Considerable energy is lost in the form of waste heat that is generally rejected to the atmosphere. Availability of this heat during the year will depend on the operating regime of the plant. • Gas fired open and combined cycle plant, energy from waste, landfill gas, biogas and sludge incineration are considered. • It is assumed that high grade heat from the CHP jacket cooler is utilised by the operator. Low grade 'waste' heat is recovered from the intercooler circuit and represents approximately 3% of the total input energy.
	Building cooling system heat rejection	• Buildings use a range of different cooling systems which mostly operate during summer months although many modern buildings with high cooling loads and efficient building fabric require cooling for significant periods of the year. Building cooling systems typically use air or water cooled chillers to reject heat at low temperatures.
	Industrial sources	• A number of industrial processes lead to the rejection of waste heat. Processes included in this study are crematoria, chemical industries, clinical waste incinerators and food producers.
	Commercial buildings non-HVAC	• Some buildings reject heat from equipment other than building cooling systems (e.g. from food refrigeration, IT equipment). Two key commercial operations analysed for the study are supermarkets and data centres.
	Water treatment works	• Low grade heat is released from water treatment works due to biological activity associated with sewage treatment.
Infrastructure sources	London Underground	• Heat generated underground through train braking, lighting and passengers is rejected through ventilated shafts at strategic positions along the network.
	UKPN / National Grid electrical infra-structure	• Electricity substations on both the transmission and distribution networks contain transformers to convert power from one voltage to another. Transformer coils are usually cooled and insulated by being immersed in insulating oil.
	Sewer heat mining	• Sewage in underground sewers contains heat which can be 'tapped' or 'mined' in a similar way to the extraction of heat from the ground or rivers.

2.2 Heat source analysis methodologies

Each source has different characteristics particularly in terms of how and at what temperature heat arises and where the source is located.

In order to assess the quantity and spatial distribution of heat potentially available individual methodologies were developed for each source. Table 2-2 summarises key elements of the methodologies with detail provided in Appendix A. The methodologies also indicate the thermodynamic and temporal characteristics of each source.

In each case, the first step was to calculate the total theoretical heat *available* based on key operating parameters and temperatures relevant to each source. Where constraints were obvious / known – such as potential limitations to the abstraction of river water for the extraction of heat – these have been applied.

In terms of allocating the heat available to a particular Middle layer Super Output Area[5] (MSOA) the approach differs depending on the nature of the source:

- For point sources such as power plants or buildings, this is relatively straightforward based on their location.
- For flow sources (primarily rivers and sewage systems) some estimates have had to be made based on physical features, such as length of river flow within a MSOA, and an assessment of potential spacing of water abstraction sites along rivers.
- For ground and air sources which are available throughout the city, the quantity available within each MSOA is dependent upon the amount of open space and the spare capacity within electrical infrastructure within that MSOA. For example, it is assumed that no ground source heat could be extracted from under buildings; and extraction of heat from the air using large scale heat pumps linked to heat networks is restricted by the availability of electricity supply within specific areas.

[5] A MSOA is a geographical area developed to ensure consistent boundaries are used for reporting statistics which vary by area. Typically a MSOA has a population of around 8,000 and an average area of around 120Ha.

Table 2-2: summary of methodologies used for each heat source (detail in Appendix A)

Category	Heat Source	Methodology
Environmental sources	Ground source	• The quantity of heat available from the ground is dependent upon geology, ground temperature and proposed end use (heating, cooling or a mixture of both). Once these are understood, constraints, mostly related to access, can be applied in relation to the potential location of ground source heat systems. • A geological map of London was overlaid with land use types (e.g. buildings, parks, vacant land, industrial land, recreation areas etc) and those types for which it was deemed unlikely / impossible to install ground energy systems were excluded. Excluded areas include English Heritage registered parks and gardens, although it is noted that there can be exceptions to this where circumstances allow. • Benchmarks of likely energy available by ground area for both closed and open loop systems were applied to eligible areas to give a figure of total heat available per MSOA. • Ground temperature is stable year round and so no consideration has been made of temporal variation.
	Air source	• The cost and carbon intensity of heat available from the air is technically dependent upon air temperatures and the efficiency of the heat pumps used. • Utilisation is mainly demand constrained providing building thermal efficiency can be upgraded. The methodology has applied a constraint related to spare electrical capacity at substations. This has then been converted to an available amount of heat using an assumed seasonal efficiency. Further work is required to confirm seasonal efficiencies for large scale heat pumps. • In terms of spatial allocation, useful air source heat has been allocated to those MSOAs in which there is a suitable primary (33/11kV or above) substation with spare capacity. In practice this supply could be carried many kilometres to meet demand. • Seasonal variations have been considered using weather data for average outdoor air temperature in London.
	Water and river source	• The availability of heat from rivers depends on the flow rate of the river and its temperature throughout the year. It is constrained by the rate at which the water is abstracted and the minimum temperature at which it can be returned. • Flow rates (m^3/s) and temperatures were provided by the EA from their monitoring sites and used to determine annual heat available. It was assumed that abstraction sites were located at the points at which tributaries enter the Thames. Information for underground rivers in Central London was not available. • An abstraction rate of 10% of average flow was assumed. Summer flows are lower but heat demand reduces at this period. It was also assumed that return temperatures would not fall below 2ºC and maximum increase in temperature or water abstracted would be 8ºC in line with EA regulations. • The heat was allocated to those MSOAs in which the proposed abstraction sites are located. • Temperature data from the Environment Agency (EA) has been used to determine seasonal variation.

Category	Heat Source	Methodology
Process sources	Power station rejection	• The availability of waste heat from power stations is dependent upon the thermal efficiency of the plant, its load factor and heat to power ratio. • Power stations in London were grouped into different technology 'classes': large scale (combined cycle gas turbine), peak load (open cycle gas turbine), energy from waste (steam cycle), sewage gas and land fill gas (gas engine), sludge incinerators (steam cycle) and combined heat and power (CHP) gas engines. For each class the technical heat available (MWh) was calculated from plant capacity (MW), load factor and power to heat ratio. • The available heat was then allocated to particular MSOAs based on plant location. • No seasonal variations have been considered based on constant output temperatures from each power station over the year.
	Building cooling system heat rejection	• Cooling systems in buildings reject heat while in operation. The quantity of the waste heat available is dependent upon the cooling load of the building and the seasonal efficiency rating (SER[6]) of the chiller system used. • Cooling loads have been estimated for offices, retail space and gyms using benchmarks (W/m^2) and taking into account seasonal variation. These benchmarks have then been applied to estimates of floor area by different space type (office, retail, gym) to give an estimate of cooling load. Heat rejected is then calculated by multiplying by a benchmark SER or COP for each system. • The maximum useful heat that could be available and has been mapped for London based on the quantity of air-conditioned floor space in each MSOA. • Whilst some building heat rejection systems vary the temperature at which heat is rejected according to the outdoor air temperature it has been assumed that heat rejection is at a constant temperature.
	Industrial sources	• A number of industrial processes lead to the rejection of heat. Those analysed for this study include crematoria, chemical industries, clinical waste incinerators and food producers. The sites have been divided into two primary typologies based on definitions in Environmental Permitting legislation. Part A are large installations regulated by the EA; Part B are smaller installations regulated by local authorities (in this case the boroughs). • For Part A installations in London, heat availability has been assessed based on flue gas velocity and temperature with several simplifying assumptions due to an incomplete dataset. For Part B installations waste heat has been assumed to be the same across all installations due to a lack of data. • No seasonal variation has been considered.
	Commercial buildings non-HVAC	• Some buildings reject heat from equipment other than building cooling systems (e.g. from food refrigeration, IT equipment). Two key commercial operations analysed for the study are supermarkets and data centres. • Methodologies have been developed for each type: – For refrigeration in supermarkets, total heat rejected is calculated from

[6] -The SER is the heat pump COP adjusted for seasonal variations in the temperature of the heat source (e.g. outside air) and the timing of when heating load occurs (more heating load tends to occur when outside air temperatures are lower, reducing SER compared to COP).

Category	Heat Source	Methodology
		benchmark cooling loads (W/m^2) for different refrigeration types (eg. freezers, cold food counters) as applied to estimated freezer / refrigerator size (m^2) per type per store (Waitrose, Tesco etc) and estimated utilisation. – For data centres, total heat rejected is calculated from benchmark cooling loads (W/m^2), utilisation and COP as applied to estimated floor areas. • Locational data has been obtained for supermarkets from open source 'SatNav' databases. Data centre locations have been obtained from aerial mapping. • Merchant data centres (e.g. capacity available for rent) are relatively easily identified. The location of enterprise data centres is kept secret due to security reasons. It is therefore likely that the estimated heat availability is significantly underreported. • Whilst some process heat rejection systems vary the temperature at which heat is rejected according to the outdoor air temperature it has been assumed that heat rejection is at a constant temperature.
	Water treatment works	• Low grade heat is released from water treatment works due to biological activity associated with sewage treatment. The quantity of heat available is dependent upon flow rate (m^3/day) and assumed heat extraction rate (delta T). • Flow rate data obtained from Thames Water has been used to determine the heat energy available at the plant outlets. A fixed delta T has been assumed. • Seasonal variation has been based on data from Thames Water.
Infrastructure sources	London Under-ground	• London Underground tunnel ventilation shafts reject heat throughout the year. The quantity of heat available is dependent upon the exhaust air temperature and flow rate. • Data from London Underground was used to estimate the total heat available from each shaft. Within each shaft heat recovery coils are assumed to be installed around the shaft circumference. Station shafts have been excluded on the basis that air inflow occurs as well out outflow. • The maximum useful heat that could be available and has been mapped for London based on approximate ventilation shaft locations in relation to each MSOA. • Further heat could be extracted from London Underground with the adoption of air handling units at platform levels or new thermally active tunnel liners. These have not been accounted for on the basis of very high capital costs in relation to the benefits obtained. • Retrofitting heat recovery coils along tunnel walls has been considered but has not been included in calculations on grounds of cost and available space. For a breaking distance of 50m approximately 100kW of heat could be recovered. • Seasonal variation has been assessed on the basis of data provided by TfL for tunnel temperatures.
	UKPN / National Grid electrical infra-structure	• Transformers in electrical substations reject waste heat. The quantity of heat available is dependent upon the peak load of the transformers in the substation, their load factor, efficiency and recoverability of heat. An estimate of efficiency and of the quantity of the heat that is recoverable has then been applied (assumed as 1% of peak load, with 40% load factor). • The maximum useful heat that could be available has been mapped for London based on

Category	Heat Source	Methodology
		approximate substation locations in relation to each MSOA. • A conservative approach to the temperature of the heat has been assumed along with no seasonal variation.
	Sewer heat mining	• The quantity of heat available from sewage systems depends on the volume of sewage and its temperature. It is constrained by the requirement for any heat extraction not to result in the temperature of the sewage falling below a minimum of 10ºC at the inflow to the wastewater treatment works to ensure biological activity is unaffected. • Volumes have been calculated by assuming sewage is generated from a percentage (90%) of potable water usage (both domestic and non-domestic). This has been converted into an average volume per person per day for London which can then be applied to the population of each MSOA to estimate a volume per MSOA. Each MSOA is assigned to a trunk sewer catchment, and the heat assumed to be available within MSOAs through which the trunk sewers pass. • A heat extraction rate has been assumed (delta T 5K). This has been applied to the flow volumes and converted to MWh to estimate heat available per MSOA. • Temperature data provided by Thames Water has been used to calculate seasonal variations in available heat.

The next step has been to determine the heat that could be *delivered* by each source. This distinction between available and delivered heat is necessary because the heat available from these secondary sources is generally but not always of a low grade, that is, of a low temperature. To convert the lower grade heat into useful, higher grade heat, heat pumps are therefore required. Heat pumps require electricity to operate, this electricity also being converted into useful heat. The efficiency with which a heat pump makes this conversion is referred to as its Coefficient of Performance (COP).

In order to determine the quantum of *delivered* heat therefore, an analysis of heat pump technologies has been undertaken as appropriate for each heat source. By applying the relevant seasonal efficiency rating (adjusted COP) to the available heat supply, the delivered heat supply has been calculated. See Section 2.2.1 for details.

The outputs of the calculations and spatial analysis have been mapped in GIS to provide heat maps for each heat source. These are included within the detailed methodologies in Appendix A.

There are a number of areas where assumptions have been made leading to varying levels of uncertainty in the outputs developed. The implications of this are discussed further in the results section (Section 2.4).

2.2.1 Heat pump performance

Data from a meta review of manufacturers' data and from a previously commissioned study has been used to determine the relationship between water source inlet temperature and heat pump COP. Performance varies by manufacturer due to the operating conditions and scale of the heat pumps. As such a central case has been assessed, for a 500-1,000 kW unit. Performance of this heat pump is similar to installations at new developments such as London Wandsworth Riverside Quarter development the new London RiverLight development.[6]

Performance of this heat pump range is highlighted in Figure 2-1 for different source (evaporator) temperatures for an output temperature of 70°C on the heat network (condenser) side.

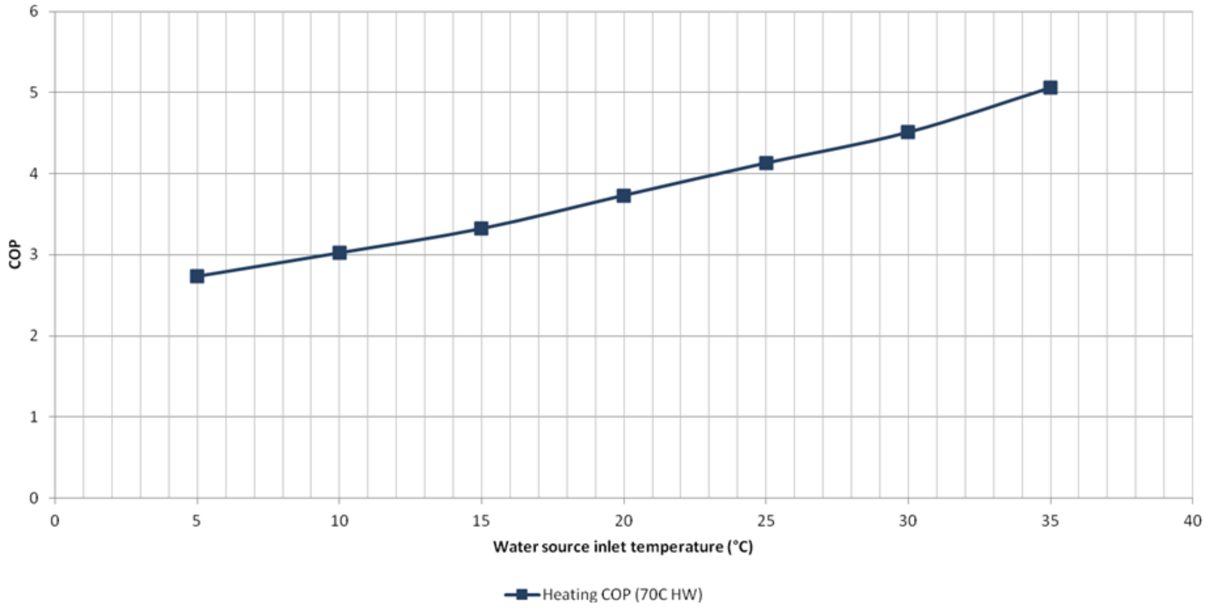

Figure 2-1: heat pump COPs by evaporator (source) temperature[7] (500-1000kW scale heat output)

The scale of heat pump will also influence COP. As such, general patterns in manufacturers' data have been used to develop the following scaling factor based on differences in performance at a 10°C water source inlet temperature. This scale factor is relative to the COP given in Figure 2-1 and can be applied to determine COP variation for higher and lower capacity units.

$$\text{COP change vs. base case} = 0.17 \ln (\text{heat pump capacity [in MW]})$$

This relationship is based on a sample of four different size heat pumps. In practice other factors such as refrigerant choice, input and output temperatures as well as scale will have an influence. A comprehensive study of heat pump efficiency variations by scale, manufacturer, refrigerant and temperatures could usefully be undertaken to inform feasibility studies into low grade heat systems.

[7] Heat Pump data is based on information provided J &E Hall International for high efficiency inverter drive water source heat pumps.

Table 2-3 shows the seasonal efficiency rating (weighted COP) applied by heat source. Where heat source temperatures vary over the year the data in Figure 2-1 along with the heat source seasonal temperature variation has been used to derive a seasonal efficiency.

Table 2-3: heat pump seasonal efficiencies and COPs applied by heat source

Heat source	Typical available heat supply temperature (°C)	Typical heat pump size (MW)	COP
Ground source - open loop	14	0.38	3.13
Ground source - closed loop	13	0.29	2.99
Air source	2-16	12.00	temperature dependant
River source	5-20	20.00	temperature dependant
Power station rejection	35	20.00	5.55
Building HVAC - Offices	28	0.50	4.37
Building HVAC - Retail	28	0.50	4.37
Building HVAC - Gyms	28	0.50	4.37
Industrial sources - Part A Processes	70	0.50	10.33
Industrial sources - Part B Processes	35	0.10	4.65
Commercial buildings non-HVAC - Supermarkets	32	0.50	4.74
Commercial buildings non-HVAC - Data Centres	40	3.00	5.77
Water treatment works	20	20.00	temperature dependant
London Underground	12-29	0.05	temperature dependant
National Grid electrical infrastructure	55	1.30	7.64
UKPN	55	0.15	7.27
Sewer heat mining	14-22	0.38	temperature dependant

2.3 Heat extraction and utilisation

2.3.1 Introduction

In order to utilise low grade heat from secondary sources, the heat needs to be captured, fed into a heating network and distributed within a building as illustrated in Figure 2-2. In this section some of the issues related to system design are considered through case studies of systems already in operation and a review of the impacts of different configurations of heat pumps across the system (centralised v decentralised). An initial overview of heat capture technologies and heat usage requirements within buildings is also provided. These issues are being explored in further detail in the next phase of the study.

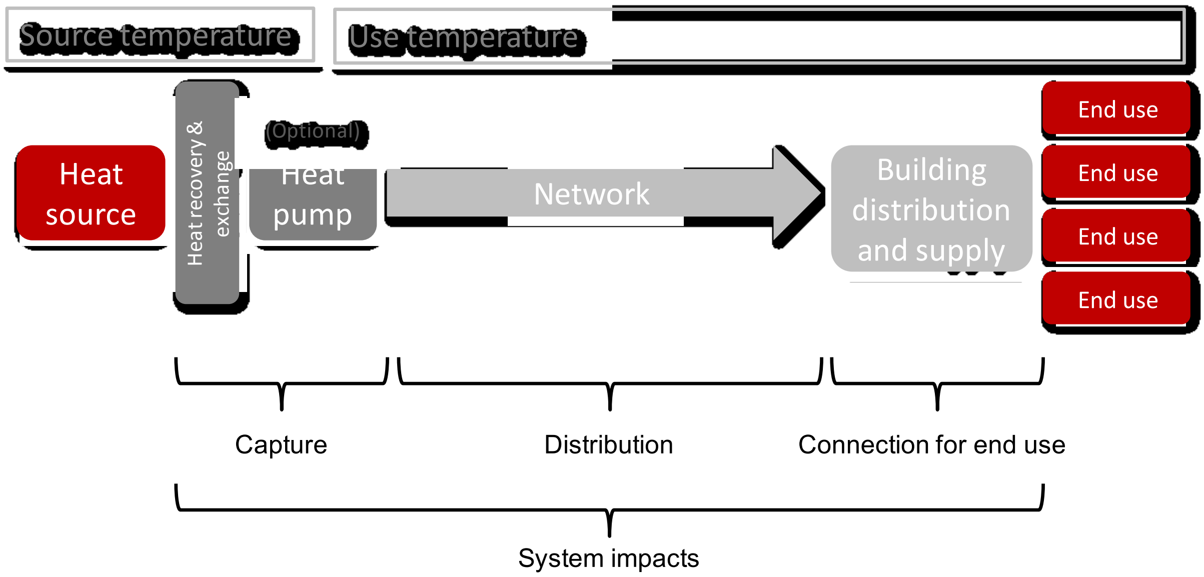

Figure 2-2: schematic indicating primary system elements to be reviewed in the study

2.3.2 Case studies

To explore options for heat extraction and utilisation from the different heat sources, case studies have been developed of existing schemes elsewhere[8]. These studies are summarised here and their implications for London are discussed. Full case study information is provided in Appendix B.

[8] These case studies have been prepared by DEC Engineering in Canada and COWI in Denmark specifically for this project.

Case Study 1: Bjerringbro Varmeværk/ Grundfos

Key features	
Heat source	Cooling from production plant, with ground borehole interseasonal storage
Temperature – district heating	68/38 ºC
Capacity	2MW
Heat pump type	Ammonia
COP	4.6 (manufacturer's data)

This is a 2MW system that captures excess low grade heat arising from the cooling of a Grundfos manufacturing plant and upgrades it for utilisation in the existing local district heating network in the town of Bjerringbro.

The upgrade is done by reciprocating compressors arranged in two groups. The first group of single step heat pumps upgrades the water from approximately 38ºC to approximately 46ºC while the second group of 2-step heat pumps upgrades it further to 68ºC.

The connection to the district heating network is designed to allow a flexible supply temperature to the network from the heat pumps. There is a CHP and boilers on the same connection, so the water from the heat pumps can be mixed up to the required flow temperature of the network.

The plant operates for 8 months of the year. During the 4 summer months when the heat is not required, it is stored by distribution via a network of underground pipes, this significantly improves the COP as heat can be recovered during summer months.

Implications for London

- To improve COP when capturing heat from sources with much lower temperatures than the supply temperature cascaded heat pumps (e.g. arranged in series) increase efficiency.
- Heat pumps need to be configured with specific refrigerants to match the required evaporator (input) and condenser (output) temperatures.
- Building heat rejection systems are useful sources of heat, from which it is feasible to upgrade heat to higher temperatures.

Case Study 2: Frederikshavn, Denmark

Key features	
Heat source	Sewage water
Temperature – district heating	80°C flow; 40°C return
Capacity	1MW heat pump capacity
Heat pump type	CO_2
COP	2.8 (manufacturer's data)

This system utilises low grade heat from the waste water of a sewage treatment plant and feeds it into the existing local district heating network.

The sewage has an average temperature of 12.8°C over the year, with a minimum of 7.6°C and a maximum of 18.1°C. The heat pump produces 1MW of heat with a COP of 2.75 (when sewage flow is 12.8°C).

The overall district heating network is supplied by a waste to energy plant to provide the base load and is topped up by gas fired CHPs and boilers as necessary. The 1MW heat pump is run to replace heat which would otherwise be produced by natural gas.

As the overall capacity of the system is 65MW and uses a number of different heat sources, it is relatively easy to manage in terms of security of supply since the entire network does not rely on the effective operation of the heat pump.

Implications for London

- Good example of utilising and integrating different sources of supply to fully utilise the energy available from each sources at a different time. Appropriate base load and peak load plant are used as required.
- Larger, interconnected schemes allow alternative heat sources to operate for long periods of time (as base load plant), helping to recover their relatively high investment cost.
- Low return temperatures on heat networks allow heat pumps to operate at relatively high efficiencies.

Case Study 3: North Saanich Waste Water Treatment Plant heat recovery

Key features	
Heat source	Treated effluent heat exchange
Temperature – district heating	10/15 °C supply (winter / summer) 8/13°C return (winter / summer)
Capacity	2.35MW
Heat pump type	Commercial water to water; R410a
COP	5.7 (in use); 3.4 (manufacturer's data)

This is a 2.35MW district heating system that utilises very low grade heat from the effluent system at the Saanich Peninsula Waste Water Treatment Plant (WWTP) in British Columbia, Canada to buildings which upgrade this heat to usable temperatures using heat pumps. It is also designed to recover waste heat from a nearby ice rink refrigeration system to augment the heat available from the WWTP and provide greater reliability and efficiency.

Heat is circulated using 'ambient' warm supply and return pipes, which operate at very low temperatures and also provide thermal storage. The heat is used to supply surrounding facilities including an existing pool, school, residential neighbourhood, greenhouses and the WWTP building.

The heat pumps for the ice rink refrigeration heat recovery have been placed in a pre-packaged container as a 'mini-plant' due to space constraints.

Flow and return temperatures are 10/15°C and 8/13°C respectively for winter/summer. Note, in the local climate these temperatures represent a significant increase versus average outdoor air temperature over the heating season, and therefore improve the efficiency of heat pumps. Individual R410a refrigerant heat pumps in each building deliver heat at 50°C. The heat pumps have been designed to run autonomously based on a call for heating or cooling from the building control system and drive the circulating pumps and control valves that are connected to the energy source. The heat pumps achieve an annual average COP of 5.7.

The first phase involves heating only, however the system can be configured as a two pipe district energy sharing system with a warm and cool pipe.

Implications for London

- Using low temperature networks with distributed heat pumps is an effective way of spreading capital investment over time, reducing initial costs.
- A better understanding of the relative benefits of using ambient networks and decentralised heat pumps, versus traditional district heating networks and centralised heat pumps is required from the next stage of this study.

Case Study 4: Westhills District Energy Sharing System

Key features	
Heat source	Geoexchange vertical borefield and heat pump; ice rink heat recovery; natural gas boilers
Temperature – district heating	13-18ºC warm pipe 8-15ºC cool pipe
Capacity	1.9MW
Heat pump type	Residential: commercial, water to air reversible with water to water for DHW; commercial, water to water for heating only. Refrigerant: R410a DESS: custom water to water. Refrigerant: ammonia
COP	Residential: space heating 4.2; DHW 3.8 (manufacturer's data) DESS: 8.3

The system is an integrated district heating, cooling and water recovery system, referred to as a district energy sharing system (DESS). This is a two-pipe ambient temperature system that allows the use of either extracted or contributed energy. Residential buildings requiring heating during winter days can be supplied by office buildings that require cooling during occupancy. Meters within the buildings track whether the client is contributing or using energy from the DESS.

The system serves a 210 hectare new community development in a suburb of Victoria, British Columbia, Canada. On completion the development will comprise approximately 6,000 residential units and 0.46 million m^2 of commercial, retail and educational and cultural buildings.

The system uses ground energy extracted from a closed loop vertical borefield located under an association football pitch, comprising 212 boreholes that are 125m deep. It also uses waste heat recovered from an ice rink refrigeration system and natural gas boilers for peak load.

The network operation temperatures are 13-18ºC for the warm pipe and 8-15ºC for the cool pipe.

The system comprises a number of energy centres across the site serving local areas. Energy can be shared between these depending on demand within the site. Energy transfer stations deliver energy to specific buildings at temperatures that best match the buildings' needs.

Implications for London

- Energy can be shared between buildings and recovered from very low temperature sources. Using ambient networks mean lower cost pipework can be used (e.g not steel pre-insulated pipe).
- Reversible heat pumps can be used to provide heating or cooling from an ambient network.
- Decentralised heat pumps allows for decentralised control, though some additional pumping energy is required to ensure good circulation in the warm and cool pipes, ensuring even distributions of temperature around the systems.

2.3.3 Heat pump configuration

The issue of whether ASHP are best utilised centrally, linked to large scale substations and supplying heat into heat networks, or located within buildings supplying energy directly is a complex one, dependent on a number of factors.

A centralised approach to using ASHP (as detailed in Appendix A) entails ASHP supplying heat to a heat network, and onwards to consumers. The ASHP would be of the large multi-megawatt scale and connected to the medium voltage (11kV) distribution network. Heat pump motors would be low or medium voltage (400V or 6.6kV).

A decentralised approach entails installing ASHP within buildings with the energy supplied via building electrical connections and the electricity distribution network. This connects to the buildings via low voltage feeders (400V) and subsequently back to the grid supply point via medium voltage (typically 400V/11kV) transformers and feeders, and primary substations (typically 11/33kV or 132kV) and their feeders. Often installing a heat pump requires reinforcing electrical connections to cope with the additional demand. For a residential property this might entail an upgrade from a 100A consumer unit to a 150A consumer unit. The cost of this is relatively small. More significantly the low voltage distribution network must be capable of supplying the required coincidental heat demand.

The factors affecting whether centralised or decentralised heat pumps are the most economically viable include the following:

- Presence of an existing heat network and its ability to operate at low temperatures (e.g. less than 85⁰C)
- Capacity of the electricity distribution network to deal with additional loads
- Where neither heat network nor electrical network capacity exist the relative capital cost difference between building a new network of each type
- The operating cost difference between a heat network and electrical network capable of providing the heat demand
- Capital cost difference between large and small scale heat pumps, and the impact of diversity
- Efficiency difference between large scale heat pumps together with heat network losses, and building scale heat pumps together with electrical network losses (I2R losses)
- The extent to which storage can be incorporated into either approach
- The extent to which limiting peak load on the electrical transmission and generation system is considered important.

Further discussion of this issue is provided in Appendix D.

2.3.4 Heat capture

Table 2-4 describes the approach taken to heat capture for each of the heat sources under consideration. The type of heat exchanger is described, along with typical temperatures. The table should be read in conjunction with Appendix A which shows schematics of each system and, where seasonal variation is expected, how this occurs.

Table 2-4: summary of approach for capturing heat for each secondary heat source

Heat Source	Heat capture approach	Heat source	Typical temps (°C)
Environmental sources			
Ground source	Ground source heat systems are divided in two main categories, open system (using aquifers) and closed loop (using boreholes). In the former case water is extracted from the ground, passed through a heat exchanger and returned to a separate borehole. The heat extracted is available through a water to water heat exchanger. Boreholes are typically arranged on 100m centres. In the latter case a glycol mix is circulated around the borehole array, and this is connected to the evaporator side of the heat pump. In both cases the available heat is easy to access, but available over a large area, in relatively diffuse amounts. Open loop systems provide better point sources of heat suitable for distribution, and so are better suited to heat networks. A typical open loop borehole pairing can provide around 378kW of heat energy. The amount of energy available from open loop schemes is subject to regulatory constraints by the Environment Agency (EA). The EA prefer balanced schemes which both extract and reject heat to aquifers on an annual cycle. Relaxation of their requirements for borehole separation could increase the amount of heat available. It has been assumed the borehole ground energy systems are best suited to individual building systems, rather than wide area heat networks, but their potential has been included as there are precedents for connection into heat networks. It is likely that the vast majority of ground source potential is in standalone building applications. Each borehole provides around 5-8kW of heat output (3.7-6.4MWh/yr). There are no heating applications where this source can be used directly without heat pumps.	Water to water OR Glycol to water	13-14°C

Heat Source	Heat capture approach	Heat source	Typical temps (°C)
Air source	Air source heat pumps serving district networks are assumed to follow two approaches. The first is to be sized based on a proportion of the available spare capacity at any substation of voltage level 33kV or above. This means that the existing electrical system can in principle, without undertaking network impact studies, cope with this additional demand. It is assumed that heat pumps are located in a central plant, connected to a heat network and with an electrical supply at 11kV. These heat pumps are able to operate continuously on the basis of this electrical capacity. This is a simplification of the available network capacity, but does put an upper bound on the amount of heat pump capacity which can be accommodated using the existing electrical infrastructure. A second approach uses air source heat pumps to charge large thermal stores during off-peak periods, where electrical usage is lower and capacity may be available at substations. Off-peak periods of around 8hrs per day are available overnight, though air temperatures are lower at such times and therefore efficiency will be reduced. In both cases the heat must be captured using air to water heat exchangers, before being upgraded to usable temperatures. Average air temperatures show heat available at very low levels during winter months, and in practice peak heating demand periods coincide with much lower outside air temperatures. In London around 3% of hours below 15°C are less than 2°C, and around 31% of hours below 15°C are less than 7°C. This means that for a significant proportion of the heating season air source heat pumps perform at higher efficiency, but should be complemented by sources such as natural gas boilers when external air temperatures drop below a certain level. For example, for a domestic heat pump designed to provide heat at 50°C, the manufacturers' COP data varies from around 2.2 at an outside air temperature of 10°C, dropping to 1.6 at an outdoor air temperature of around 0°C[9]. Similar impacts are expected for larger scale heat pumps. There are no heating applications where this source can be used directly without heat pumps.	Air to water	2-16°C (can be much lower)
Water and river source	Heat is extracted by passing a proportion of the river flow through a plate heat exchanger system. Water is then returned to the river, with no net abstraction and no changes in chemical composition but at a lower temperature. Robust screening and water intake arrangements are required, along with measures to deal with biological fouling and to protect fish from being entrained within the intake pump suction. Redundancy in heat exchangers is often allowed. Heat output is restricted to the allowable temperature difference and the	Water to water	5-20°C

[9] Stafell, I. (2009) A Review of Domestic Heat Pump Coefficient of Performance: http://wogone.com/science/review_of_domestic_heat_pump_cop.pdf

Heat Source	Heat capture approach	Heat source	Typical temps (°C)
	minimum water return temperature, both regulated by the EA. Heat available is directly proportional to the volume of water abstracted. There is a significant degree of temperature variation, roughly corresponding to variations in average monthly air temperature. There are no heating applications where this source can be used directly without heat pumps.		
Process sources			
Power station rejection	Various different types of power station reject heat, at temperatures often considered to be unusable in conventional heating systems or industry. For simplicity a fixed temperature for all power stations has been chosen. Steam cycle plants, such as energy from waste, combined cycle gas turbine and sludge incinerators reject heat at their condensers. Assuming such plants operate on a year round basis this heat source is not affected seasonally. Heat is extracted from the working fluid after the condenser but prior to the flow to the cooling tower or dry air cooler. These represent the vast majority of available heat and so a typical condenser temperature has been selected. Sewage and landfill gas are both generated using gas engines, which typically reject heat at relatively high temperatures through their cooling systems. Heat from flue gas is also available but this would require retrofit of a heat recovery boiler. Open cycle gas turbines reject heat at very high temperatures in their exhaust gas stream. Typically they are either used in CHP plants or as peak load plant, and hence only run for a small proportion of the year. On the basis that peak loads often coincide with periods of high heat demand this heat has been included. Retrofit of a heat recovery boiler would be required. There are some heating applications where this source can be used directly without heat pumps e.g. air-preheating in an air handling unit frost coil, and underfloor heating. Where gas engines or open cycle gas turbines are used this heat can be used directly in conventional systems.	Water to water	35°C In some cases much higher
Building cooling system heat rejection	Building cooling systems typically use air or water cooled chillers to reject heat at low temperatures. Many modern buildings with high cooling loads and efficient building fabric require cooling for significant periods of the year. Some buildings are equipped with free cooling systems which can bypass the chiller when external temperatures are low enough to generate chilled water directly. Alternatively an additional amount of fresh air over that required for ventilation can be used to cool directly. Both of these limit the amount of heat which is available at low outdoor air temperatures, when heat demand is highest. For water cooled chillers it is assumed that heat can be captured using a heat exchanger fitted into the condenser water circuit after the chiller condenser but before the cooling tower intake. This could be relatively easily retrofitted without major changes (e.g. retaining existing chillers). Typically this water is circulated at temperatures up to around 28°C (may be greater during hot weather), but may	Water to water OR Refrigerant to water	28°C

Heat Source	Heat capture approach	Heat source	Typical temps (°C)
	vary depending on the outdoor temperature to maximise chiller efficiency. Further work is required to confirm variation of condenser input temperatures. For air cooled chillers a heat recovery heat exchanger is required within the refrigerant circuit. If this is not present at the initial installation it may be difficult to retrofit. The heat would be extracted after the compressor and prior to the fluid flowing to the air cooled condenser. Typically this refrigerant is circulated at temperatures up to 28°C, but may vary depending by outdoor temperature. Further work is required to confirm variation of condenser input temperatures. There are some heating applications where this source can be used directly without heat pumps e.g. air-preheating in an air handling unit frost coil, and underfloor heating.		
Industrial sources	Industrial sources are highly variable and the data available is not of good quality. Part A processes have some limited data on flue emissions. It has been assumed that they extract heat from the flue, using a gas to water heat exchanger. This would require retrofitting of the flue gas ductwork. The water could be used directly, assuming it is available at 70°C. A similar approach has been taken for Part B processes. Heat is assumed to be available at 35°C. In both cases no seasonal variation is expected. Some industrial heat sources could be used directly in conventional heat networks, whilst others are at lower temperatures so could be used in such things as air-handling constant temperature circuits or underfloor heating.	Flue gas to water	Highly variable 35-70°C
Commercial buildings non-HVAC	Both data centres and supermarkets reject large amounts of heat through cooling servers and refrigeration respectively. Data centres reject heat through large chiller plant, either air or water cooled. Air-cooled systems are often preferred where large water storage tanks are not available or able to be accommodated, as this avoids reliance on water availability. Heat recovery is the same as for air cooled chillers in building cooling system heat rejection applications. Heat is available at temperatures up to around 28°C, though this will vary with outdoor temperatures and be much less in winter. Free cooling is likely to be used during conditions where outdoor air temperatures and humidity levels mean chillers can be bypassed (below around 5°C) or fresh air can be used directly (below around 14°C). Supermarkets reject heat from the refrigeration systems required to maintain chilled and frozen food cabinets and storerooms at required temperatures. Some supermarkets already use heat recovery heat pumps from their refrigeration packs for heating domestic hot water, ventilation air and air at around 15°C to maintain comfort temperatures in chilled food aisles. It has been assumed that most stores do not at present do this. In addition the ratio of electricity use to heating fuel use is 4 to 1 in a typical supermarket[10]. As a large proportion of	Refrigerant to water	28°C

[10] CIBSE (2004) Guide F: Energy efficiency in buildings, 2nd Edition, Table 20.5

Heat Source	Heat capture approach	Heat source	Typical temps (ºC)
	electricity use is for refrigeration a surplus of heat is likely. Heat recovery is the same as for air cooled chillers in building cooling system heat rejection applications. Heat is available all year round from each source, but during colder weather the condenser temperatures may be reduced, reducing the temperature of available heat. Further work is required to better understand how widespread this is. There are some heating applications where this source can be used directly without heat pumps e.g. air-preheating in an air handling unit frost coil, and underfloor heating.		

Heat Source	Heat capture approach	Heat source	Typical temps (°C)
Water treatment works	Heat is extracted by passing the treated clean effluent through a heat exchanger prior to discharging it into either a cooling pond or water course. A heat exchanger, or series of heat exchangers, would have to be inserted into the rising main from the final stage of treatment to the discharge point. Water exiting water treatment works is at a relatively constant temperature year round compared to outdoor air temperatures. There is some seasonal variation based on sewer temperatures and external air temperatures, with lowest temperatures in the winter. There are no heating applications where this source can be used directly without heat pumps.	Water to water	14-22°C
Infrastructure sources			
London Under-ground	Heat recovery from mid-tunnel ventilation shafts has been assumed. A spiral heat exchanger lining the internal circumference of the shaft is used to transfer heat from warm air to water flowing through finned pipework. Temperature data from TfL shows significant seasonal variation, though in all cases temperatures are significantly higher than external air temperatures. There are some heating applications where this source can be used directly without heat pumps e.g. air-preheating in an air handling unit frost coil or pre-heating domestic hot water but these are very limited. Very well insulated buildings would be required to utilise this heat in underfloor heating systems.	Air to water	12-29°C
UKPN / National Grid electrical infra-structure	Transformer coils are usually cooled and insulated by being immersed in insulating oil. The natural convention driven circulation of this oil moves heat away from the coils, and towards the top of the transformer, where it is then cooled by a series of cooling fins. Forced convection cooled transformers are also available. By extracting the cooling oil at the top of a transformer and circulating it through an oil to water heat exchanger some of this heat can be recovered. Only transformers with voltages of at least 33/11kV have been considered, as they could be expected to yield around 300kW of heat for a typical 30MVA capacity. 11kV/400v transformers are much smaller (typically 800kVA) and the available heat is therefore only around 8kW[11]. A temperature of 50°C has been assumed on the basis that maximum temperatures are likely to be around 70°C at the top of casings, with a temperature of around 40°C at the bottom of casings. The assumed temperature allows for most of the available heat to be captured. Surface temperatures of transformer winding coils are expected to be up to 85°C.[12] Where transformers are enclosed in a ventilated building a heat recovery coil could be used to capture more energy from the exhaust air. This has not been modelled on the basis that the majority of transformers are installed outdoors.	Oil to water	50°C

[11] 1% recoverable heat assumed

[12] ABB (2007) Average oil temperature rise in distribution transformers, presentation by Nordman, H., IEEE Standards meeting Minneapolis MN 10 07

Heat Source	Heat capture approach	Heat source	Typical temps (°C)
	This heat will vary seasonally, as coil heating is associated with higher loadings (through there is some element of constant loss due to the energy required to maintain the electromagnetic field) and higher loadings tend to occur during the winter. Leakage in the oil to water heat exchanger could lead to water ingress into the insulation oil which may compromise its insulation properties, comprising a safety risk. Some industrial heat sources could be used directly in conventional heat networks, whilst others are at lower temperatures so could be used in such things as air-handling constant temperature circuits or underfloor heating.		
Sewer heat mining	Heat is abstracted by diverting the sewer flow into a chamber or series of chambers which form a sump or sumps. Screening is used to maintain clear pump intakes. Sewage is then pumped to a specially designed large diameter shell and tube heat exchanger which is less prone to blocking. Cooled sewage is returned to the sewer downstream of the abstraction point. A maximum temperature change of around 5°C is assumed. Overflows are built into the chambers along with a flap valve in the sewer which allows sewage to continue to flow in the event of any blockages in the chambers. Sewer temperatures remain relatively stable throughout the year, though tend to drop significantly after rain and drop very low after snow. There are no heating applications where this source can be used directly without heat pumps.	Water to water	14-22°C

2.3.5 Heat utilisation

The following section provides a brief overview of heating systems within buildings, setting out how heat is typically delivered. For full descriptions refer to CIBSE Guide B1[13].

Heating systems in buildings are composed of three elements:

- Heat sources
- Distribution networks
- Heat emitters

This section reviews the types of distribution networks and heat emitters currently in use in buildings in London. Understanding these systems, and the flow temperatures that may be applied in each case, is important in understanding how low temperature heat can be used within buildings.

Heat distribution

The following media can be used to distribute heat within buildings:

- Hydronic systems[14]

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[13] Chartered Institute of Building Services Engineers (2002): CIBSE Guide B1, Heating

- Low temperature hot water (40-85^{0}C, low pressure)(LTHW[15])
- Medium temperature hot water (~ 100 - 120^{0}C, < 5bar pressure)(MTHW)
- High temperature hot water (>120^{0}C, < 10bar pressure)(HTHW)

- Steam (usually used in hospitals and in often in older buildings e.g. Palace of Westminster)
- Electricity
- Air

By far the most common heat distribution media are thought to be low temperature and medium temperature hot water. LTHW systems are sometimes further subdivided into very low temperature hot water (~50^{0}C, low pressure) (VLTHW).

LTHW systems have historically been designed to operate at 82-71^{0}C flow and return temperatures as this keeps return temperatures above the level where condensing of combustion water vapour occurs (~66^{0}C), which has traditionally been avoided. This has the added advantage of maintaining high mean radiator temperatures, reducing required heat emitter areas. The advent of condensing boilers means it is now common to design heating systems on a 70-50^{0}C flow and return system, lowering the mean radiator temperature to 60^{0}C and enabling improved efficiency of condensing boilers. The relative split of building heating system distribution media in London is not known and further research is required to determine this, outside the scope of the study.

Previous guidance for district heating schemes suggested modifying temperatures to operate at 80-50^{0}C flow and return (mean radiator temperature of 65^{0}C), providing a reduction of 25% in peak heat loss could be made. Requirements to maintain Legionella disinfection suggest a minimum network temperature of 70^{0}C[16].

Heat emitters

The following heat emitters may be used to deliver heat directly to spaces:

- Radiators: Normally found on LTHW circuits. Convective component 50 – 70%. Manufacturer's quoted output usually assumes a 50 ˚C difference between water and air. Reductions in temperature are permissible if the unit size is increased to compensate, assuming correct sizing initially. Temperature change across the radiator should be a minimum of 12 ˚C in a correctly commissioned system.
- Fan convectors: Often fed with low temperature hot water but can be electric (up to 5kW in capacity). The additional convection provided by the fan can allow lower temperatures than radiators to be used; a 40 ˚C can be reached.
- Unit heaters: May be electric or served by low temperature hot water. In the hot water case entering and leaving temperatures are typically ~ 95 to 75 ˚C, respectively.
- Ceiling panels: Typically operated at 79 to 85 ˚C. May be electric or low temperature hot water driven. Radiant component ~ 65%.

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[14] Chartered Institute of Building Services Engineers (2002): CIBSE Guide B1, Heating, Table 4.3
[15] LTHW and MTHW are also often described as low/medium pressure hot water (LPHW or MPHW)
[16] DETR (1998) Good Practice Guide 234: Guide to community heating and CHP Commercial, public and domestic applications http://www.chpa.co.uk/medialibrary/2011/04/07/81f83acc/CHPA0003%20Good%20practice%20guide%20to%20community%20heating%20and%20CHP.pdf

- Underfloor heating: Operating temperatures are typically around 35 – 45˚C and so are commonly used in conjunction with air or ground source heat pumps. Maximum allowable surface temperature is 29⁰C to avoid discomfort. Circuit temperature and heat load determine required spacing of pipework within the floor screed. Lower temperature systems require closer spacing. Output is limited to around 100W/m^2.[13]
- Wall heating: Similar to underfloor heating but with reduced output due to the lower mean temperature difference between the air and wall surface (warmer air higher up). This is not a common type of system.

During the next stage of the study modelling will be undertaken to determine the impact of reducing distribution temperatures on heating system emitters and on the ability to maintain internal design temperatures during peak heating conditions.

The extent to which heating systems can be oversized is not clear, but anecdotally we are aware of suggestions of oversizing by up to 50%. Further research is required to understand the spread and extent of oversizing of heat emitters in the London building stock. Oversizing may have the unexpected benefit of making reductions in flow temperatures acceptable in many buildings.

Domestic hot water

Legionella regulations require any domestic hot water storage to be disinfected on a daily basis by raising temperatures to a minimum of 65⁰C. This can limit the practical district heating network temperature to around 70⁰C for indirectly connected systems. Domestic hot water is required to reach 50⁰C after 1 minute of operating a tap. In practice temperatures higher than this can cause scalding and are rarely required in domestic and most non-domestic buildings.

Neglecting the storage disinfection requirements it is possible to operate an indirectly connected heat network at 55⁰C and maintain a 50⁰C outlet temperature. In new flats in Denmark they operate their systems at 50⁰C and deliver hot water at 45⁰C, minimising health risk by having negligible storage of hot water in their systems. Storage is limited to 0.5l in the plate heat exchanger and 3l in the domestic hot water pipework to the outlet. Achieving the latter requires careful location of outlets relative to heat exchangers. The Danish approach is illustrated in Figure 2-3.

Further analysis of the acceptability of lower network temperatures from a public health perspective is being undertaken in the next phase of the study.

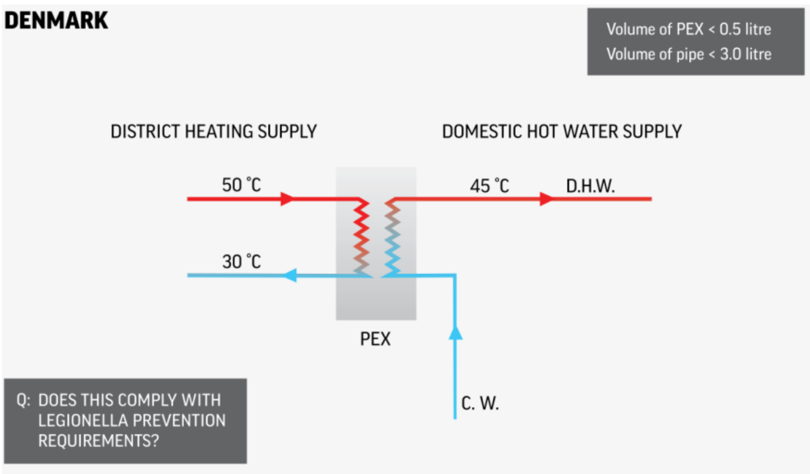


Figure 2-3: Danish heat network temperatures in new buildings for domestic hot water supply

2.4 Results and discussion

2.4.1 Available and delivered heat

Figure 2-4 shows the distribution of *available* secondary heat sources within London. The colours indicate heat density in kWh/m², that is the annual available heat from all supply sources in each MSOA, divided by the area of the MSOA. The figure shows some concentration of available supplies in the centre primarily related to building heat rejection, along with several very high point concentrations related to power station condensers and river water abstraction sources[17].

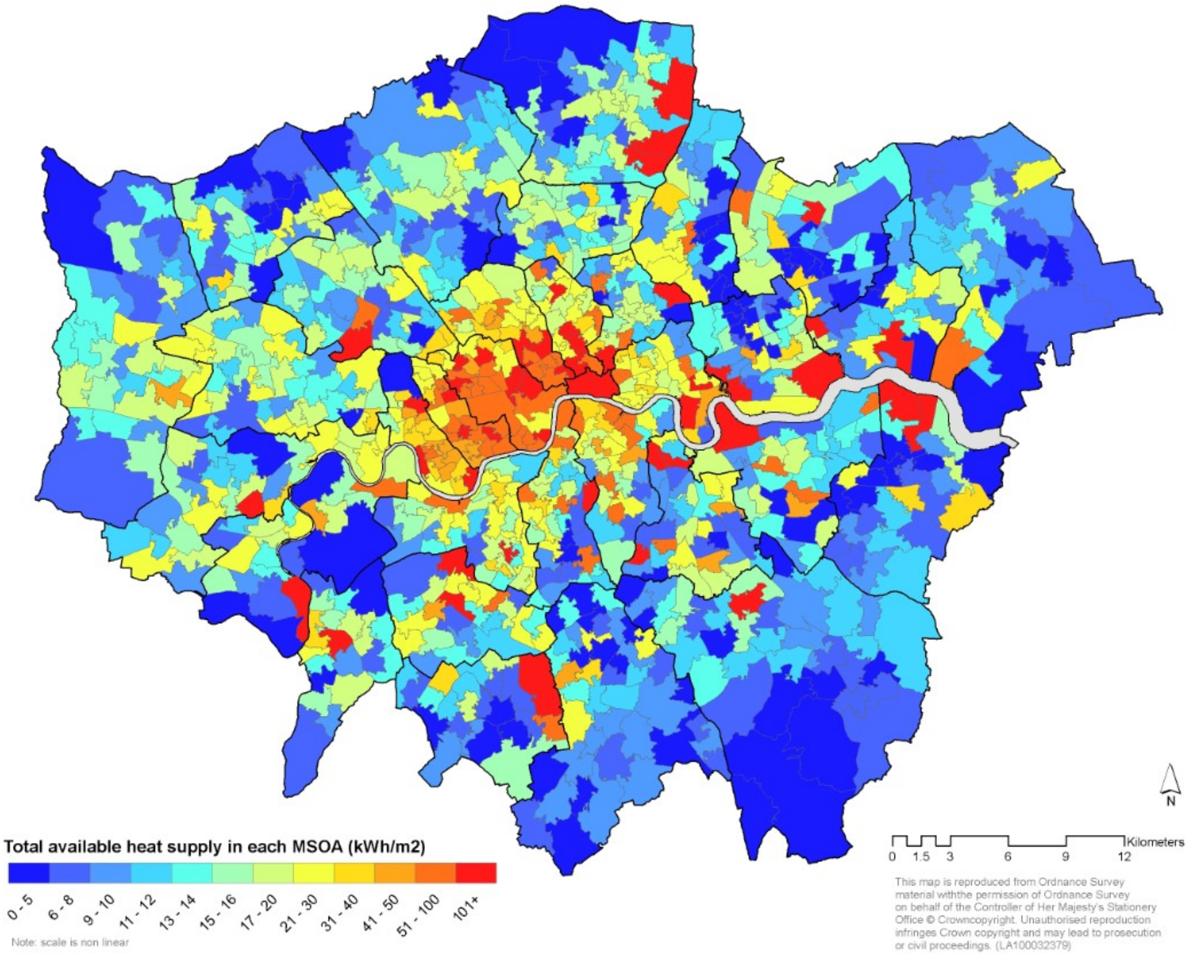


Figure 2-4: total secondary available heat density, all sources – 2010

Table 2-5 summarises both the quantity of heat *available* and the quantity of heat that could be *delivered* at 70°C from each source and the percentage of London's total heat demand that this represents. This data is shown graphically in Figure 2-5.

[17] Note that the scale is non linear to highlight differences in the lower range of heat densities. The distribution by type of heat source shown in Appendix A gives a clearer idea of where particular sources are available.

Table 2-5: summary of heat availability by source and the percentage of London's heat demand this represents

Source	Specific type	Total secondary heat available (GWh)	Total heat delivered[18] at 70°C (GWh)	Electricity input required (GWh)	Secondary *delivered* heat as % of total heat demand	Dataset completeness and quality (red/amber/ green)
		A	B	C = B – A	D=B/66,006 GWh	
Ground source	Open loop	296	435	139	0.7%	
	Closed loop	8,048	12,102	4,054	18.3%	
	Total ground source	8,344	12,537	4,193	19.0%	
Air source		8,435	15,159	6,724	23.0%	
River source		2,251	3,165	914	4.8%	
Power station rejection		8,283	10,104	1,821	15.3%	
Building cooling system heat rejection	Offices	2,700	3,503	802	5.3%	
	Retail	5,400	7,005	1,605	10.6%	
	Gyms	79	102	23	0.2%	
	Total building cooling	8,179	10,610	2,430	16.1%	
Industrial sources	Part A processes	77	77	-	0.1%	
	Part B processes	22	29	6	0.04%	
	Total industrial sources	100	106	6	0.2%	
Commercial buildings non-HVAC	Supermarkets	278	352	74	0.5%	
	Data centres	755	914	158	1.4%	
	Total commercial	1,033	1,266	233	1.9%	

[18] In order to utilise the secondary heat, heat pumps are required to raise it to a suitable temperature. These heat pumps operate at a particular Coefficient of Performance (COP). This indicates how much usable heat is generated per unit of electrical energy input. Thus a COP of 3 indicates that 3 units of heat can be generated from 1 unit of electricity. The total heat supplied is therefore the waste heat plus the additional heat generated by the heat pumps.

Source	Specific type	Total secondary heat available (GWh)	Total heat delivered[18] at 70°C (GWh)	Electricity input required (GWh)	Secondary *delivered* heat as % of total heat demand	Dataset completeness and quality (red/amber/ green)
Water treatment works		9,723	13,308	3,585	20.2%	
London Underground		9	13	4	0.02%	
UKPN / National Grid electrical infrastructure		350	403	53	1.0%	
Sewer heat mining		232	267	35	6.7%	
TOTAL		49,974	71,330	21,356	108%	

(Note – figures are quoted to 2 decimal places due to the range in results; this should not be mistaken for the level of accuracy)

The data has been categorised using a RAG rating explanation, as follows:

Red – data unavailable or data used considered to be potentially misleading

Amber – some uncertainty over data source or scope for improvement of data available OR review of methodology required by Steering Group

Green – reasonable confidence of data and results, within necessary limitations of a high level study.

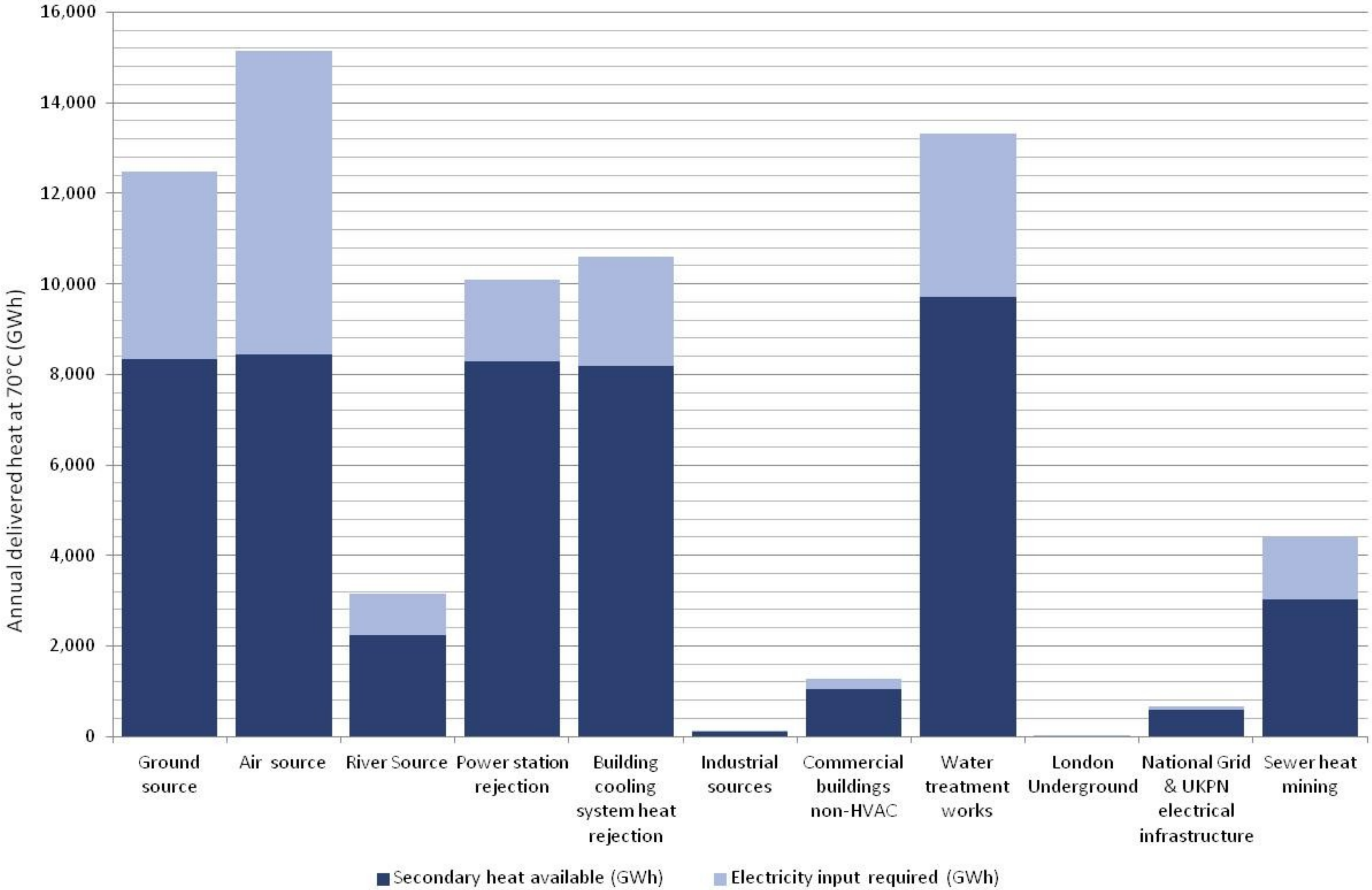


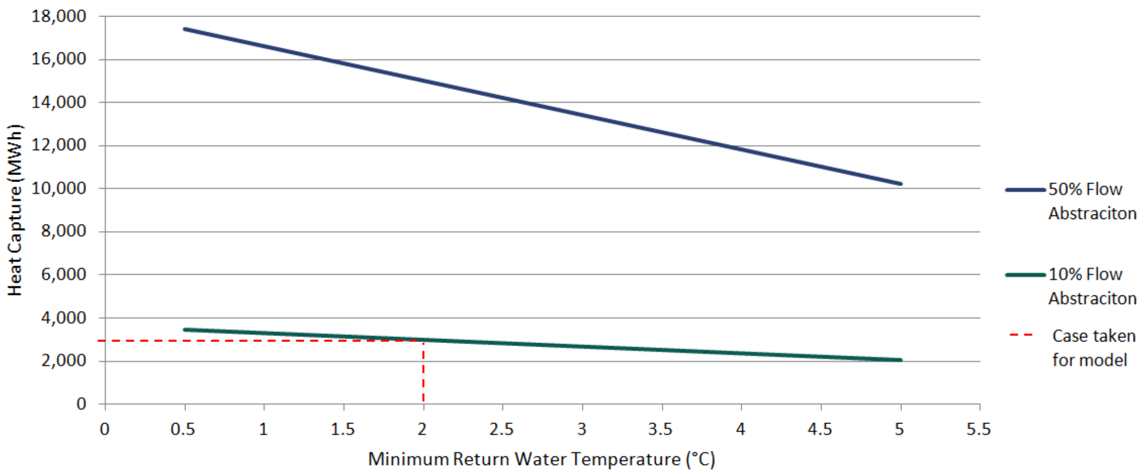
Figure 2-5: delivered heat by source showing split of that supplied from secondary heat source and that supplied via the heat pump

2.4.2 Assumptions and uncertainties

For each source, assumptions have been made regarding the extent to which the heat can be recovered. In some cases, changes to these assumptions would result in a significant difference in the assessment of the quantity of heat available.

For example, in the case of river source heat rejection, key assumptions are the abstraction rate and return temperature. For the purposes of this study, a 10% flow abstraction has been modelled, with a minimum return water temperature of 2°C. As indicated by the red line on Figure 2-6 below this results in an annual heat capture of just under 3,000 MWh, however if a higher return temperature and abstraction rate were used, quantified heat output would be significantly higher.

Figure 2-6: example of impact of assumptions on quantification of heat availability from rivers



In particular, there are a number of assumptions and uncertainties associated with the analysis of the capacity for ASHP. The study assumes two main energy sources:

- Using 'spare' electrical capacity at primary (33/11kV and above) substations. This is actually the difference between firm capacity and peak winter load
- Using 'trough' electrical capacity during off-peak (e.g. overnight) hours coupled to large thermal storage tanks.

There are a number of practical issues which are likely to significantly limit the capacity for ASHP identified in the analysis. These are explored below.

- **Impact on the ASHP capacity of spare electricity network capacity**

  In practice the majority of firm capacity in excess of peak winter load is not coincident with the central areas of London where heat demand is greatest and the viability of heat networks likely to be highest. Information from UKPN suggests that much of the central area of London from Hyde Park in the West to Canary Wharf in the East, and from the Thames in the South to parts of Camden and Islington in the North, suffers from constrained supplies. This is confirmed by anecdotal evidence from developers in the central activity zone areas where long delays for electricity connections are common, due to the significant off-site network reinforcement required. Demand growth is predicted, particularly in central activity zone areas, including due to new development. A significant investment programme is underway by UKPN which seeks to alleviate capacity constraints, as well as seeking load reduction from customers. However, the majority of spare firm capacity is located in and around the fringes of the central activity zone, rather than in the most dense areas. This is likely to curtail the available capacity for use with heat pumps significantly unless heat networks are also built in the outer areas of the central activity zone.

More accurate estimations of the electrical capacity available for heat pumps in practice should take into account the impact on the electrical network of connecting large motor loads which can cause high fault currents due to their impedance. This requires detailed knowledge of properties and operation of the electrical network in question and the motor equipment (e.g. driving the compressor of the heat pump) which are beyond the scope of this study. In practice the limitations of existing electrical networks are likely to curtail capacity available for heat pumps.

The significant heat pump capacity estimated (around 2,000MW) is distributed around the UKPN London network (which covers only part of the GLA area). This is likely to significantly over estimate the potential for the two main reasons discussed above.

- **Impact on the ASHP capacity through using off-peak trough in capacity**

  The use of electricity is significantly curtailed during off-peak hours (typically around midnight to 7am) particularly as homes and workplaces are generally not 24 hour operations. Typically the difference between peak and base load is around 60%, but a lower factor has been applied in the study. This capacity is underused in the network and provided the impact of the large compressor motors in heat pumps do not cause problems to the operation of the electrical network this approach is more likely to be able to make use of the stated capacity. A firm agreement for load curtailment of the heat pumps would be required out of the agreed off-peak hours. Another approach would be to use instantaneous electrode boilers within thermal stores which responded to troughs in electricity price due to excess production from intermittent sources like wind. This is an approach being used in Denmark in conjunction with district heating networks.

  Electric vehicles are likely to use the trough periods for charging and so detailed study of the compatibility of such approaches with electric vehicle charging is required. However, in the short to medium term penetration of electrical vehicles would not impact the proposed approach.

Care has been taken to document all assumptions made. Key assumptions are given in Appendix A and detailed further in the models associated with this report. A review of uncertainties by source is given in Table 2-6 below.

Table 2-6: key uncertainties and potential impact on results

	Heat Source	Uncertainties and potential impact
Environmental sources	Ground source	• The main uncertainty over the quantity of heat that could be utilised in practice is related to land availability and access. For open loop systems the extent to which wells are separated is subject to regulation and influences available heat by a factor of 2-4.
	Air source	• In addition to the discussion above, the main uncertainty over the quantity of heat that could be utilised in practice is demand growth on the electrical network, and the cost of reinforcement works. No consideration of network design issues has been included (e.g. increased fault currents).
	Water and river source	• There are a number of uncertainties over the quantity of heat that could be utilised in practice. Assumptions regarding abstraction rates and return temperatures are important as are assumptions over the re-warming of water from the environment, and hence the permissible distance between abstraction sites. The approach taken is considered to be conservative.
Process sources	Power station rejection	• The main uncertainty over the quantity of heat that could be utilised is variation in load factor of large scale plants (e.g. Barking Power Station) and variation in condenser temperatures of steam cycle plants.
	Building cooling system heat rejection	• The main uncertainty over the quantity of heat that could be utilised is understanding the proportion of the retail and office stock which is air-conditioned. A further consideration is the practicality of accessing heat rejected from roof mounted plant, particularly air-cooled chillers which do not have heat recovery coils.
	Industrial sources	• There is significant uncertainty over both the quantum and practical availability of heat available. Only Part A processes record data about flue outputs. No meaningful data is available for Part B processes.
	Commercial buildings non-HVAC	• There is significant uncertainty over the energy use in supermarket refrigeration systems, as in some stores this heat is used for space heating. The secure nature of data centres restricts the information available for modelling. The results acknowledge that this is not an extensive list of data centres and that free cooling during winter months may be utilised at some sites reducing heat output and increasing uncertainty.
	Water treatment works	• The main uncertainty is the quantity of heat that can utilised. This must not double count heat abstracted in rivers or sewer heat mining. Upstream mixing at the WWTP outfall is unknown and so a conservative estimate has been taken on the minimum return water to rivers.
Infrastructure sources	London Under-ground	• The main uncertainty over the quantity of heat that could be utilised is the heat transfer co-efficient of the heat recovery coils within the ventilation shafts.
	UKPN / National Grid	• The main uncertainty over the quantity of heat that could be utilised is the extent of transformer losses (on-load and off-load) and the proportion of this heat that could be recovered in practice (e.g. from oil cooling). Mapped transformers are also limited to those operated by National Grid /UKPN. Data for substations operated by SSE has not been included.
	Sewer heat mining	• The main uncertainty is over the quantity of heat that could be utilised in practice as WWTPs are sensitive to inflow temperatures. Combined sewer temperatures are also affected by precipitation, particularly during winter when heat demand is greater and rainfall higher.

3 Utilisation

In order to explore the potential utilisation of secondary heat it was necessary to first understand the nature and spatial distribution of heat demand across the city and to what extent this demand could be met by heat supplied at lower temperatures. Following this, the next step was to explore the extent to which this could be met by the various different sources of secondary heat identified taking into account where they are in relation to demand and the quantity of heat they could supply. This chapter outlines the steps taken and results observed.

3.1 Heat demand analysis

In relation to the utilisation of secondary heat based on existing (2010) heat demand data, key issues to consider are:

- The location and nature of heat demand (e.g. in terms of temperatures required)
- The location of each heat source in relation to the location of demand
- The nature of the end use and end use temperature
- The energy efficiency of the building

To these ends London's heat demand was broken down by the following hierarchy to establish the quantity and spatial distribution of heat demand that could effectively utilise low grade sources of heat:

- Total heat demand for London
- Heat demand per MSOA
- Heat demand for domestic and non-domestic uses
- Heat demand per usage type (space, hot water, catering and process)
- Heat demand by building energy efficiency rating

The method for this analysis is described below. Forecasts for 2030 and 2050 are discussed in Chapter 4.

3.1.1 Quantification and spatial distribution of total heat demand

Values for total London heat demand, heat demand per MSOA and the demand from domestic and non-domestic buildings within a given MSOA have been sourced from the *London Decentralised Energy Capacity Study*[19]. This data provides the total heat required for each MSOA and is used to estimate its heat density. It accounts for the different composition of MSOAs, for instance an MSOA in Westminster has a larger non-domestic heat demand than domestic with the converse being more likely for a MSOA in Bromley. The Westminster MSOA also has a higher heat density.

Each borough has a different mix of non-domestic buildings[19] which is important in understanding how heat is used. Data for non-domestic heat usage[20] was combined with a variety of UK

[19] GLA (2011) Decentralised energy capacity study Phase 2: Deployment potential: http://data.london.gov.uk/datastore/package/decentralised-energy-capacity-study
[20] Choudhary (2012) Energy analysis of the non-domestic building stock of Greater London. Building and Environment, 51, 243-254

benchmarks[21,22,23] to build up a picture of heat end usage for each MSOA. This reflects the different usage needs of, for example, a hotel compared with an office or home. Generally hotels use more hot water than homes which use more hot water than offices; factories may require very hot water for industrial processes. This method gives each MSOA a unique demand for space heating, hot water, catering and processing heat.

3.1.2 Analysis of heat demand suitable for supply by low temperature sources

Not all heat demand can be met by low temperature sources. For example, it is not possible to meet cooking demand with any temperature that can be supplied through a heat network. The same is true for process heat required at temperatures above 100°C. In addition, buildings with different thermal efficiencies and different within building heating systems (radiators, underfloor heating etc) will be able to utilise low grade heat to differing degrees. With this in mind, it was necessary to 'filter' total demand to remove certain types of demand that would be unsuitable for use of low grade heat, leaving a more realistic demand figure that could then be matched against supply.

The 'filters' used were the type of heat end use (space heating, hot water, cooking, process) and the building energy efficiency rating, as illustrated in Figure 3-1. Particular attention has been paid to understanding the implications of buildings with different efficiency ratings and their potential to use low grade heat. This is described in Section 3.1.4.

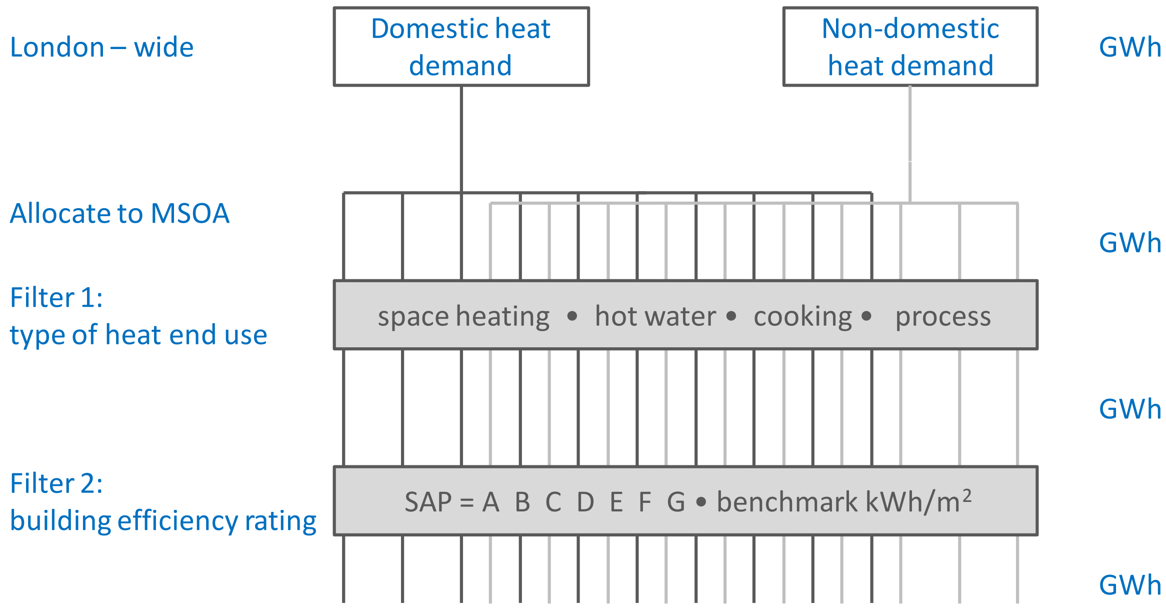


Figure 3-1: illustration of derivation of heat demand suitable for utilisation of secondary (low grade) heat showing application of filters

[21] Pegg (2007). Assessing the role of post occupancy evaluation in the design environment - A case study approach. Brunel and Surrey Universities
[22] CIBSE (2004) CIBSE Guide F: Energy efficiency in buildings. London
[23] BRE (2008) Domestic energy factfile: http://www.bre.co.uk/page.jsp?id=879

3.1.3 Filter 1: heat demand type

For the purposes of this exercise, only heat demand associated with space heating has been included in the analysis as shown in Table 3-1.

Table 3-1: inclusion of heat end use type in demand analysis for domestic and non-domestic buildings

	Heat end use	Space	DHW	Cooking	Process
Filter 1	Domestic	1	-	-	-
	Non-domestic	1	-	-	-

3.1.4 Filter 2: building use efficiency

In order to understand to what extent buildings of different efficiency could utilise low grade heat, thermal models of residential and non-residential buildings were developed[24]. This allows the investigation of scenarios where, for instance, heat networks supply all heat required for energy efficient buildings but only a proportion of heat to energy inefficient buildings. A proportion of energy demand to be assigned to each energy performance category within an MSOA can then be determined.

Typical occupancy, lighting and internal equipment profiles were added in each case. The non-residential case considered typical office profiles to be representative of non-domestic buildings. Fabric and infiltration values were then added to two model variants to determine the limiting cases in terms of fabric quality. The best case used passive house standard U-values and low infiltration. The worst case used typical U-values from buildings with uninsulated solid brickwork and single glazing, along with high infiltration.

In the residential case the best and worst case models were run to establish a Standard Assessment Procedure (SAP) rating. The models were then run again to obtain annual heating loads. It was assumed that all residential buildings are heated with gas-fired central heating running on flow and return temperatures of 82 and 71 ˚C, respectively, and that all systems are sized to the peak heating load. Then by applying standard manufacturer's radiator temperature and output relationships, the reduced maximum output of the 'existing' central heating systems was calculated for lower flow temperatures from future low temperature district heating schemes.

The proportion of the total heat load that may be covered by a lower temperature source was then found by selecting all loads from the heating load profile that are below the calculated reduced maximum output and dividing by the total load. This procedure was applied for the best and worst case models. This allowed values to be entered for SAP ratings of C and E[25]. The corresponding values for the remaining ratings were calculated by interpolating or extrapolating between the obtained values. Values above a SAP rating of C were assumed to be the same as C since this corresponded to a Passive House standard case.

The non-residential cases were treated in a similar way but rather than obtaining an Energy Performance Certificate (EPC) rating, the obtained heat loads were used in conjunction with figures

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[24] Modelling software used was IES VE 2012

[25] SAP ratings range from A to G with A being the best performing and G the worst. SAP ratings can be obtained from Energy Performance Certificates (EPCs).

for typical end-use energy and small power to calculate a likely total energy per unit floor area for both fabric quality cases. Reduced heating system outputs were calculated in the same way as in the residential cases and provided proportional heating load figures for cases of buildings with up to 100 kWh/m2 and 400 – 500 kWh/m2 total energy use. The remaining energy use categories were then filled in through interpolation and extrapolation.

The outcome of this analysis is provided in Table 3-2 below. This shows that more energy efficient buildings (with an EPC rating of C or above) can utilise as much as 82% of low grade heat, while less efficient ones can use significantly less. The difference is more marked with the range of non-domestic buildings ranging from 99% for the most efficiency buildings down to 29% for the least.

Table 3-2: percentage of heat demand suitable for utilisation of secondary (low grade) heat for buildings with differing energy efficiencies

Filter 2	Building efficiency rating	A	B	C	D	E	F	G				
	Domestic	82%	82%	82%	79%	76%	73%	69%				
	Building efficiency rating - EUI (kWh/m2)	**0 to 100**	**100 to 200**	**200 to 300**	**300 to 400**	**400 to 500**	**500 to 600**	**600 to 700**	**700 to 800**	**800 to 900**	**900 to 1000**	**1000 +**
	Non-domestic	99%	92%	85%	78%	71%	64%	57%	50%	43%	36%	29%

3.1.5 Heat demand suitable for utilisation by secondary heat

Following the above methodology, the amount of demand across London that could make use of secondary (low grade) heat could be of the order of 38% as detailed in Table 3-3 below.

A more ambitious application of these filters is explored in Chapter 4 that deals with future supply scenarios in 2030 and 2050. It is noted that these results exclude constraints from supply and demand matching, as discussed in section 3.3.

Table 3-3: heat demand suitable for utilisation of secondary (low grade) heat after application of filters

User type	Total (MWh)	Demand which is suitable for utilisation low grade heat (MWh)	Suitable for use (%)
Domestic	42,695	15,471	36%
Non-domestic	23,311	9,419	40%
Total	66,006	24,891	37.7%

3.2 Methodology for matching secondary heat supply to demand

The total delivered heat from secondary sources in each MSOA has been subtracted from the total heat demand for low temperature heat to determine the amount of heat which could be used locally. However, this approach does not account for the potential spatial distribution of supply and the benefits of heat networks (e.g. moving supply over considerable distances to match demand). As such, any excess supply in a particular MSOA would be lost by simply comparing each supply to its corresponding demand.

A way of representing the function of heat networks is therefore required. A spatial redistribution tool has been developed to address this problem and allows redistribution of supply to a given number of surrounding MSOAs within a constraint radius. Key aspects of the tool are highlighted below:

1. MSOA spatial distribution	MSOA centre points generated in GIS and the distances between each point in the map is exported as a numerical matrix
2. Initial supply/demand match	Comparing supply and gross restricted demand[26] suitable for district heating per MSOA, noting excess supply and demand remaining. For MSOAs where only a proportion of demand can be met it is assumed that an equal proportion of user heat demand and network losses are met.
3. Distribution	Lookup function finds MSOAs with excess supply and matches them to the closest MSOA with excess demand. The demand is then met where possible and the excess supply reduced
4. Constraint	A maximum radius of 5,000m is applied to restrict the feasible spatial redistribution mimicking a heat network27
5. Iteration	Further iterations copy the distribution stage 10 times - a compromise between adequate redistribution and model size.

3.3 Results and discussion

Table 3-4 below shows the percentage of net heat demand[28] in each of the London boroughs that could be met using secondary sources of low grade heat (net restricted heat demand[29]). The percentage ranges from 48% in City of London down to 21% in Harrow with an overall figure of 35%. The total corresponds to meeting almost all of the heat demand considered to be suitable for utilising low grade heat.

The boroughs with the highest potential generally correspond to inner London boroughs. This is driven by the fact that these areas contain many new buildings which have high energy efficiency ratings and may therefore be better suited for supply with low grade heat. The City of London and Westminster also both have high concentrations of air-conditioned buildings which can supply significant amounts of heat.

[26] Total heating demand including network losses
[27] The distance constraint has been applied as 5,000m based on project team experience as there are few heat networks which move heat over greater distances. Where heat is moved over greater distances in continental Europe it has tended to be at relatively high temperatures. This constraint can be varied for future scenarios where more extensive heat networks could be expected.
[28] Heat demand excluding network losses
[29] Heat demand excluding network losses and limited to demand suited to low temperature heat supply

Table 3-4: amount (MWh) and percentage of heat demand met by secondary (low grade) sources of heat for each London borough sorted in order of percentage, 2010

Borough	Heat demand (MWh)	Heat demand met by secondary sources of heat	
		MWh	%
City of London	908,452	440,129	48%
Westminster	4,020,043	1,752,874	44%
Hammersmith and Fulham	1,583,773	637,832	40%
Southwark	2,113,395	839,062	40%
Camden	2,551,638	1,011,459	40%
Islington	1,637,987	648,197	40%
Tower Hamlets	1,483,087	577,429	39%
Lambeth	2,254,913	861,502	38%
Richmond upon Thames	1,655,550	626,847	38%
Hackney	1,336,101	504,006	38%
Kensington and Chelsea	1,857,202	699,645	38%
Greenwich	2,230,227	834,795	37%
Hounslow	1,889,454	706,517	37%
Lewisham	1,719,025	635,786	37%
Kingston upon Thames	1,209,782	447,031	37%
Wandsworth	2,290,293	842,975	37%
Merton	1,488,201	544,236	37%
Redbridge	1,794,376	642,660	36%
Newham	2,372,041	848,463	36%
Waltham Forest	1,569,003	550,136	35%
Bexley	2,071,290	722,066	35%
Barking and Dagenham	1,002,801	347,486	35%
Havering	1,656,443	570,772	34%
Brent	2,146,138	725,043	34%
Hillingdon	3,049,524	995,816	33%
Ealing	2,501,867	814,894	33%

Borough	Heat demand (MWh)	Heat demand met by secondary sources of heat	
		MWh	%
Bromley	2,585,053	797,816	31%
Sutton	1,385,263	416,512	30%
Enfield	2,278,009	674,894	30%
Haringey	1,724,681	496,994	29%
Croydon	2,631,755	728,535	28%
Barnet	2,888,476	782,770	27%
Harrow	2,120,156	435,399	21%
Total	66,006,000	23,160,580	35%

4 Forecast utilisation

4.1 Introduction

The previous section sought to provide an understanding of the potential contribution that secondary sources of heat could make to meeting London's heat demand based on heat demand data from 2010. In order to explore how the heat may be utilised in future as heat networks are built out across the city requires an analysis both of the evolution of heat demand, and in particular low grade heat demand, and of changes that may occur in relation to the quantum and location of the various different sources of supply.

This section outlines the different heat demand scenarios, quantifying changes in demand out to 2050 based on a range of assumptions. It also assesses possible changes that could occur to supply under each of these scenarios. A revised view of matched demand and supply is then provided in 2050 under the most ambitious of these scenarios to illustrate how and to what extent changes to the potential utilisation of low grade heat may occur.

4.2 Demand scenarios

Total demand for heat was analysed out to 2030 as part of the *Decentralised Energy Capacity Study* (2011) [30] based on a number of different scenarios. These scenarios have been adapted for this study by extending out to 2050.

Future heat demand of London was extrapolated from current heat demand with differing assumptions being made in relation to anticipated levels of new construction[31], and expected retrofitting of energy reduction measures[32]. The resultant heat demand forecasts are given in Table 4-1.

Table 4-1: summary of total heat demand for London out to 2050 for the three different scenarios at different supply temperatures

	2010	2030			2050		
Scenario	BaU	BaU	Co-ordinated	Ambitious	BaU	Co-ordinated	Ambitious
Heat supplied	Space heating	Space heating	DHW and space		Space heating	DHW and space	
Total heat demand	66,006	90,472	69,364	69,364	108,770	80,825	80,825

An outline of the three scenarios is given below:

[30] GLA (2011) Decentralised Energy Capacity Study: http://www.london.gov.uk/priorities/environment/climate-change/decentralised-energy
[31] GLA (2011) The London Plan: http://www.london.gov.uk/priorities/planning/londonplan
[32] GLA (2011) Climate Change Mitigation and Energy Strategy: http://www.london.gov.uk/priorities/environment/climate-change/climate-change-mitigation-strategy

Scenario 1 - Business as Usual (BaU)

Table 4-2: Business as Usual key assumptions

Factor	Scenario
Energy prices	DECC Low projections[33]
Heat demand	Growth with no efficiency measures
Network take up	70%

This scenario reflects a market driven investment model leading to limited investment in long term infrastructure. The development of extensive heat networks is assumed to be relatively limited. Energy demand in the BaU scenario is higher than the other scenarios because little improvement in energy efficiency has occurred, whilst population, total non-domestic building floor area and the housing stock continue to grow. It is assumed that hot water demand cannot be supplied from low temperature networks.

Scenario 2 – Co-ordinated Action

Table 4-3: Co-ordinated action key assumptions

Factor	Scenario
Energy prices	DECC Central projections[33]
Heat demand	Growth with some efficiency measures
Network take up	70%

Under Scenario 2, a combination of national and regional action encourage infrastructure investment and development. Good levels of retrofit reduce the overall heat demand of the London building stock. The potential for decentralised energy is also supported by medium energy prices following the DECC 'central' forecast. Changes to regulations regarding Legionella disinfection mean that hot water demand can be provided from lower temperature heat sources.

This scenario assumes heat pumps are located centrally rather than being decentralised within individual buildings. A discussion of the issues surrounding this assumption is given in Section 2.3.3 and in Appendix D.

[33] Source: DECC Updated Energy & Emissions Projections - October 2011

Scenario 3 – Ambitious Action

Table 4-4: Ambitious action key assumptions

Factor	Scenario
Energy prices	DECC High projections[33]
Heat demand	Growth with ambitious efficiency measures
Network take up	80%

Scenario 3 assumes that ambitious policy is in place across all levels of government to improve energy efficiency and reduce carbon emissions. It also assumes that energy prices are high. Most buildings in London have had some level of retrofit and therefore heat demand is reduced. Heat networks and sources are well developed with the penetration of heat networks reaching 80%. Only the most inefficient buildings have to obtain a proportion of heat from alternative methods such as electric panel heaters, electric heat pumps or peak load plant capable of boosting heat network temperatures (e.g. natural gas fired boilers, electrode boilers).

4.3 Supply scenarios

Factors likely to affect supply are very varied with a major distinction being between environmental and process-related sources. In respect of the former, change is likely to be relatively limited in terms of available heat (although utilisation of that heat is largely driven by demand and may evolve over time depending on policy and technological factors); in respect of the latter, drivers for change are varied and depend on the specifics of the industry sector.

Change could impact on the amount of heat available per unit, the numbers of units and the spatial location of units. Key drivers for each heat source are outlined in Table 4-5 below.

Table 4-5: outline potential drivers of change in quantum and location of secondary heat supply

Category	Heat Source	Potential drivers for change
Environmental sources	Ground source	• Climate change could impact on ambient temperatures although impact likely to be insignificant in period to 2050. • Change in respect of location is not relevant as ground energy is available everywhere and geology is fixed. • The ability to access ground energy could be impacted by building development, planning policy and technological innovation.
	Air source	• Climate change could impact on ambient temperatures although impact likely to be insignificant in period to 2050. • Change in respect of location is not relevant as air is available everywhere. • The ability to use low grade heat from the air could be impacted by building regulations and energy policy for example, fiscal support through the Renewable Heat Incentive (RHI).
	Water and river source	• Climate change could impact on ambient temperatures and flow rates although impact likely to be insignificant in period to 2050 • Theoretically location could change (eg. new canal construction) but it is highly unlikely that this will occur in the period to 2050.
Process sources	Power station rejection	• Energy and emissions policy will be the main driver for change in relation to the nature and distribution of power stations within the city. Policies could impact on the utilisation of spare capacity within existing gas fired plants; new smaller plants could be constructed using different technologies and fuels.
	Building cooling system heat rejection	• Cooling demand could increase due to both increased summer temperatures resulting from climate change and changes in building practices driven by building user expectations. • Waste heat arising from cooling could reduce due to technological innovation driven by the need for greater energy efficiency and reduced operating cost.
	Industrial sources	• A range of different industrial sources are explored each with different sector specific drivers. • Improved energy efficiency within processes is likely to be common to all, linked to improved environmental performance.
	Commercial buildings non-HVAC	• The two commercial operations considered here are data centres and refrigeration in supermarkets. • The number and spatial distribution of data centres will be driven by demand for IT services and is likely to increase. There are however constraints on location related to security issues and availability of land suggesting data centres could move outside the city. • Similar drivers apply to supermarket refrigeration in relation to demand as constrained by land availability. • Environmental regulation and rising energy costs are likely to impact on both sectors to improve process energy efficiency thereby reducing heat available.

Category	Heat Source	Potential drivers for change
	Water treatment works	• Volumes and flow rates could be affected by population growth. • Location could be affected by infrastructure projects to improve capacity.
Infrastructure sources	London Underground	• The most significant development in terms of extending the number of sources of secondary heat from LUL is the completion of Crossrail. • Other drivers for change are likely to be linked to technology such as future cooling initiatives such as LUL's 'Cooling the Tube' programme.
	UKPN / National Grid electrical infra-structure	• Policies in respect of electrification of heating and transport could have a major impact on the quantity of electrical infrastructure that could be required in future. • Technological innovation could impact transformer efficiency and cooling mechanisms.
	Sewer heat mining	• Volumes and flow rates could be affected by population growth. • Location could be affected by infrastructure projects to improve the capacity of London's sewers. • The Thames Tideway Tunnel has been excluded as a driver as this is designed for storm water flows. Such effluent will only be available periodically and at a low temperature due to the high rainwater content.

For the purposes of this study, assumptions have been made for each secondary heat source in relation to whether and to what degree available heat from that source will change under each of the three scenarios discussed in Section 4.2. The output of that analysis is provided in Table 4-6 below.

In practice the uncertainty around any prediction of availability of heat supply sources in 2030 and 2050 is considerable but the approach outlined provides a clear and transparent way of developing appropriate supply side responses to the three scenarios. These scenarios are therefore highly subjective.

Table 4-6: assumptions regarding changes in available secondary heat from different sources of supply out to 2050 under each of the different demand scenarios

Category	Heat Source	Secondary heat source availability by scenario					
		2030			2050		
		BaU	Co-ordinated	Ambitious	BaU	Co-ordinated	Ambitious
Environmental sources	Ground source	No change	No change	No change	No change	No change	No change
	Air source	Capacity reduced as new development uses spare electrical network capacity	Medium reduction in capacity as electrical demand increases due to electrification of heat and transport	High reduction in capacity as electrical demand increases due to electrification of heat and transport	Capacity reduced as new development uses spare electrical network capacity	Medium reduction in capacity as electrical demand increases due to electrification of heat and transport	High reduction in capacity as electrical demand increases due to electrification of heat and transport
	Water and river source	No change	Regulation permits increase	Regulation permits increase	No change	Regulation permits increase	Regulation permits increase
Process sources	Power station rejection	No change	Medium reduction as gas power stations phased out	Medium reduction as gas power stations phased out	No change	Medium reduction as gas power stations phased out	Medium reduction as gas power stations phased out
	Building cooling system heat rejection	Medium increase as cooling usage increases	Small increase as cooling usage increases	Cooling use reduced by new technology	Medium increase as cooling usage increases	Small increase as cooling usage increases	Cooling use reduced by new technology
	Industrial sources	No change	No change	No change	No change	No change	No change
	Commercial buildings non-HVAC	No change	Small decrease due to new technology	Medium decrease due to new technology	No change	Small decrease due to new technology	Medium decrease due to new technology
	Water treatment works	No change	No change	No change	No change	No change	No change
Infrastructure sources	London Under-ground	No change	No change	No change	No change	No change	No change
	UKPN / National Grid electrical infra-structure	Small increase due to demand growth	Medium increase due to demand growth and electrification	Large increase due to demand growth and electrification of heating and	Small increase due to demand growth	Medium increase due to demand growth and electrification	Large increase due to demand growth and electrification of heating and

Category	Heat Source	Secondary heat source availability by scenario					
		2030			2050		
		BaU	Co-ordinated	Ambitious	BaU	Co-ordinated	Ambitious
			of heating and transport	transport		of heating and transport	transport
	Sewer heat mining	No change	No change	No change	No change	No change	No change

The changes described above have been quantified at a high level as a percentage on baseline. The results of this exercise are illustrated in Figure 4-1 below with detailed analysis tables provided in Appendix C. As indicated by Figure 4-1, scenarios as currently developed differ between them regarding the availability of heat between now and 2030 but limited change forecast between 2030 and 2050. In both the Co-ordinated and Ambitious scenarios significant reductions in air source heat pump capacity are assumed as spare capacity on the electrical network is used up by new development and for individual building heat pumps. Reductions in the output of low grade heat from power stations is also notable, as gas fired plant is assumed to be retired due to its relatively high emissions.

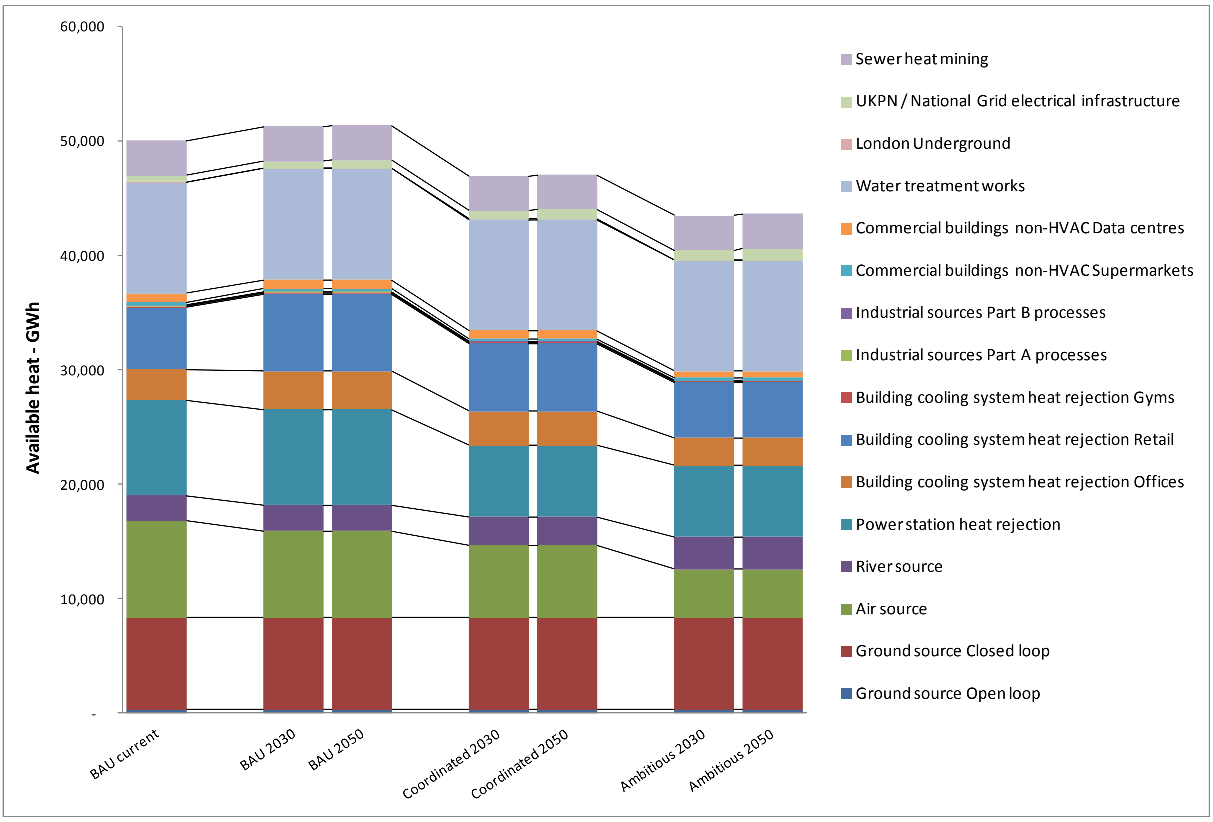


Figure 4-1: evolution of available secondary heat supply under different scenarios using percentage changes outlined in the tables in Appendix C

4.4 Results and discussion

4.4.1 Secondary heat utilisation in 2050

Based on the demand and supply scenarios outlined above, a further supply-demand matching exercise has been undertaken to for the Ambitious scenario in 2050. The filters described in Chapter 3 have been applied to this scenario as outlined in Table 4-7. In respect of heat end use, both space heating and domestic hot water have been included as being potentially supplied by the heat networks; and in respect of building efficiency, percentages have been extrapolated from the 2013 scenario, weighted by the % of upgraded housing stock in 2050.

Table 4-7: application of filters to total energy use to arrive at heat demand suitable for utilisation of secondary (low grade) heat

Filter 1	Heat end use	Space	DHW	Cooking	Process
	Domestic	1	1	-	-
	Non-domestic	1	1	-	-

Filter 2	Building efficiency rating	A	B	C	D	E	F	G
	Domestic	100 %	99%	95%	80%	76%	73%	69%

Filter 2	Building efficiency rating - EUI (kWh/m2)	0 to 100	100 to 200	200 to 300	300 to 400	400 to 500	500 to 600	600 to 700	700 to 800	800 to 900	900 to 1000	1000 +
	Non-domestic	99%	92%	86%	85%	82%	82%	73%	65%	57%	53%	39%

The results of applying these filters to the extrapolated demand in 2050 is given in Table 4-8 and the results of supply and demand matching exercise are shown in Table 4-9.

Table 4-8: heat demand suitable for utilisation of secondary (low grade) heat after application of filters

User type	Total (MWh)	Demand which is suitable for utilisation low grade heat (MWh)	Suitable for use (%)
Domestic	50,229	33,305	66%
Non-domestic	30,596	18,016	59%
Total	80,825	51,321	63%

Under the Ambitious scenario there are many more buildings suited to low temperature heat networks and so the emphasis of useful heat supply shifts from Central London to those areas that have a potentially high supply into the network such as Barking and Dagenham (Barking Power Station) and Kingston upon Thames (modelled location of a Thames river heat recovery station).

In 2050 the proportion of London's heat demand which can be met by secondary heat sources is around 38%. In this case the limitation is primarily a supply one, both in the magnitude of supply and its spatial distribution. Due to assumption of significant improvements in building thermal efficiency along with the ability to supply domestic hot water, it is forecast that much more of the building stock will be suited a secondary heat source network in 2050. Excluding the constraints of supply, the 'restricted' demand would represent 63% of the total forecast heat demand.

Table 4-9: amount (MWh) and percentage of current heat demand met by secondary (low grade) sources of heat for each London borough sorted in order of percentage, Ambitious scenario, 2050

Borough	Heat demand (MWh)	Heat demand met by secondary sources of heat	
		MWh	%
Barking and Dagenham	1,297,762	764,136	59%
Kingston upon Thames	1,437,518	804,420	56%
Tower Hamlets	2,014,853	1,058,516	53%
Islington	2,015,227	1,035,390	51%
Richmond upon Thames	1,958,939	994,378	51%
Greenwich	2,816,480	1,376,327	49%
Bexley	2,515,222	1,171,478	47%
Enfield	2,714,657	1,173,484	43%
Newham	3,098,180	1,316,051	42%
Havering	2,008,796	851,347	42%
Merton	1,766,526	745,322	42%
Southwark	2,620,001	1,089,877	42%
Redbridge	2,129,517	863,916	41%
Lewisham	2,047,859	830,571	41%
Hounslow	2,286,596	923,862	40%
Hackney	1,595,663	638,000	40%
Kensington and Chelsea	2,265,061	869,582	38%
Waltham Forest	1,852,406	707,322	38%
Hammersmith and Fulham	1,936,355	722,090	37%
Camden	3,185,789	1,180,480	37%
City of London	1,216,297	450,009	37%
Westminster	5,020,784	1,838,377	37%
Wandsworth	2,804,683	993,887	35%

Borough	Heat demand (MWh)	Heat demand met by secondary sources of heat	
		MWh	%
Sutton	1,639,212	537,687	33%
Brent	2,633,942	818,618	31%
Bromley	3,051,410	935,434	31%
Ealing	3,025,470	906,464	30%
Hillingdon	3,782,852	1,101,527	29%
Lambeth	2,760,884	786,231	28%
Croydon	3,137,790	840,924	27%
Barnet	3,494,761	914,394	26%
Haringey	2,054,428	529,100	26%
Harrow	2,535,665	515,631	20%
Total	80,721,584	30,284,834	38%

Figure 4-2 shows a visualisation of the results of the supply and demand match for the 2050 Ambitious scenario. This is for 10 iterations of redistributed supply to surrounding MSOAs within 5,000m. Areas that are blank have had all of their gross restricted demand[34] met either by supply in that MSOA or surrounding highlighted MSOAs. Remaining demand is the demand suited to secondary heat networks (total demand is not shown on this map) These blank areas provide a high level indication of regions that would suit a secondary heat network in 2050 and will be explored further in the following phase.

[34] Demand restricted to that suited to secondary heat sources, but including network losses

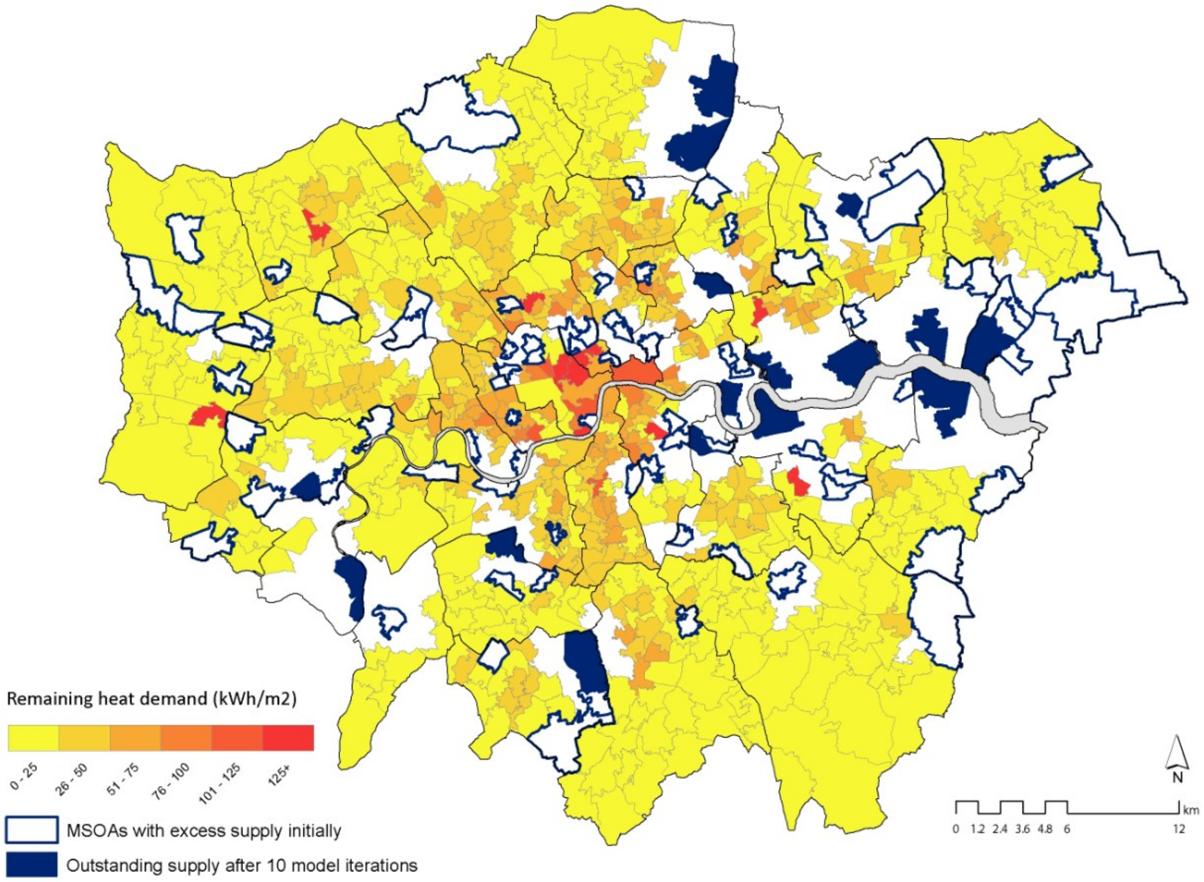


Figure 4-2: supply and demand match for the 2050 Ambitious scenario

5 Conclusions and next steps

This report and its associated maps and models represent the first phase in the study into the potential for utilisation of secondary (low grade) sources of heat within London. This section sets out the conclusions of this phase of the study and key questions for the subsequent phase.

5.1 Conclusions

A detailed model for representing the potential heat supply from 14 separate heat sources has been developed, along with a methodology for filtering heat demand based buildings' abilities to utilise low grade heat. Taking this supply and demand data together and applying a GIS based spatial distribution model supply and demand can be matched using supply and demand results for three potential scenarios for 2030 and 2050.

The research and analysis to date demonstrates that secondary heat sources have significant potential to contribute towards meeting London's heat demands.

The analysis shows that the total amount of heat *available* in London from secondary sources is around 49,974 GWh/yr. This is equivalent to 76% of London's total heat demand in 2010. Total *delivered* heat is 71,330 GWh requiring an additional 21,356 GWh of electrical input from heat pumps.

The three highest sources of supply for delivered heat are air source (23%), water treatment works (20%) and ground source (19%). The environmental sources tend to dominate as they are effectively only constrained by demand, notwithstanding the high potential impact on electricity networks of large increases in demand. In practice the constraints applied to air source and ground source in particular are likely to significantly overestimate available supply.

Sources which appear to have limited potential (<0.1% of total heat demand) at a macro scale include London Underground ventilation (0.02%), small industrial processes (0.04%) and larger industrial sources (0.12%). Note this does not mean that these sources could not be used on a project specific basis. They are available in relatively concentrated quantities which makes them easier to recover than ground or air source recovered energy.

Matching supply to demand suggests that around 35% of London's heat demand can be met using secondary sources. However, this proportion is largely driven by the constraints restricting the amount of total heat demand which can utilise secondary sources. This is limited to around 38% of overall demand in 2010 due to the poor thermal efficiency of London's building stock, and the need to supply domestic hot water at relatively high temperatures for Legionella disinfection.

In 2050 the proportion of London's heat demand which can be met by secondary heat sources is around 38%. In this case the limitation is primarily a supply one, both in the magnitude of supply and its spatial distribution. Due to assumption of significant improvements in building thermal efficiency along with the ability to supply domestic hot water, it is forecast that much more of the building stock will be suited a secondary heat source network in 2050. Excluding the constraints of supply, the 'restricted' demand would represent 63% of the total forecast heat demand.

It is likely that modelling the economic potential for heat networks would greatly reduce the proportion of heat able to be supplied by heat networks. The *London Decentralised Energy Capacity Study* suggested that only 22% of London's total energy demand (around 17% of heat demand) could be met by decentralised energy sources by 2031. This suggests that the potential of secondary sources is likely to be constrained by the deployment of heat networks.

5.2 Next phase

The overall study seeks to answer a broader range of questions building on those addressed here. These include:

- What are the impacts on network and energy systems of utilising secondary (low grade) sources of heat?
- How do the viability and environmental benefits of each heat source vary in the context of meeting London's heat demand?
- What are the implications of the development of low temperature heat networks for investment and employment?
- What spatial and project opportunities might emerge in respect of low grade heat network development?
- What are the policy, regulatory and project implications of seeking to utilise secondary sources of low grade heat?

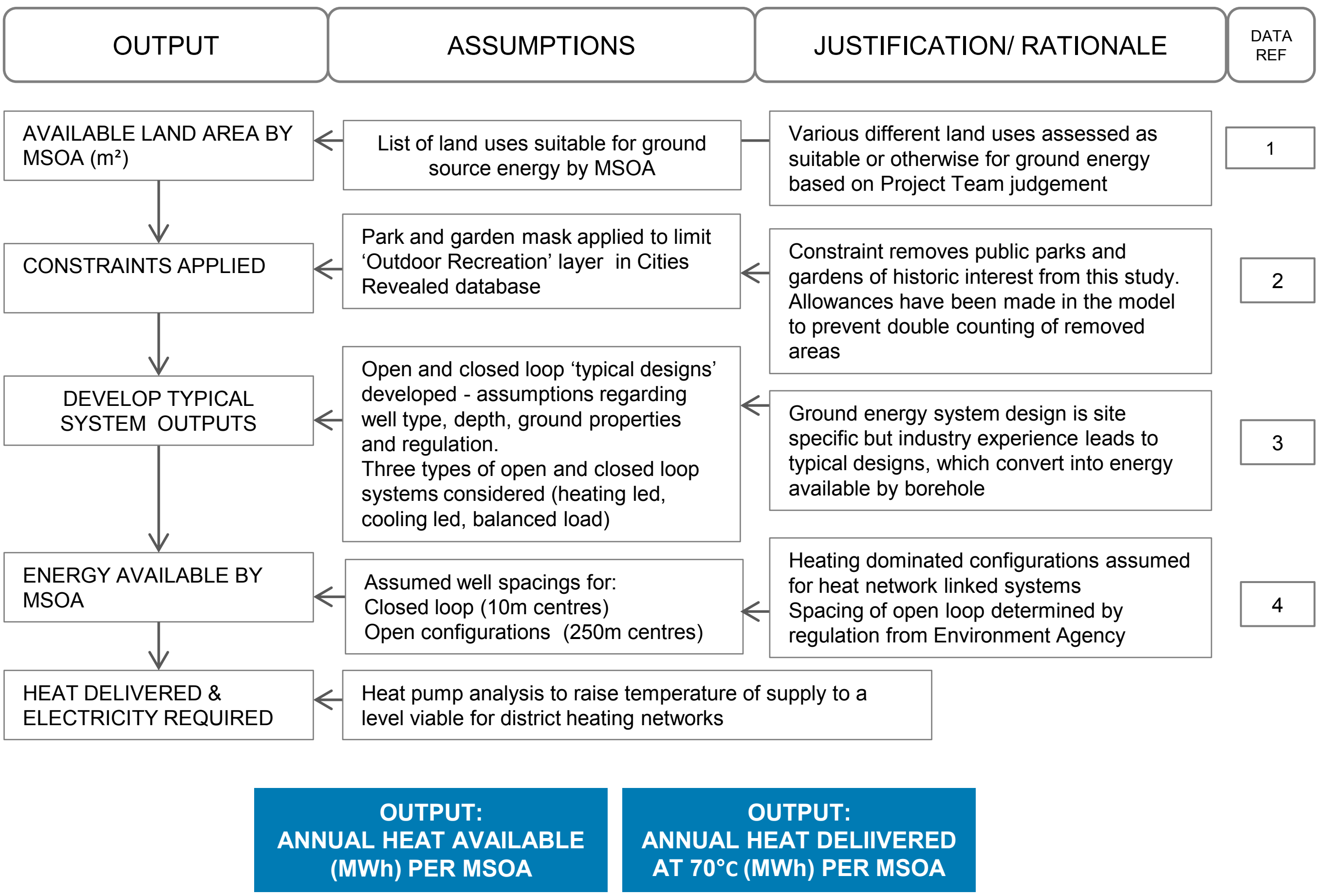
These questions will be addressed in the next phase of the study based in particular on an in depth analysis of a pilot study area.

APPENDIX A – HEAT SOURCE METHODOLOGIES

APPENDIX A

Heat Source	Ground Source
Advisory Group	n/a
Date	11.01.13
Rev	01

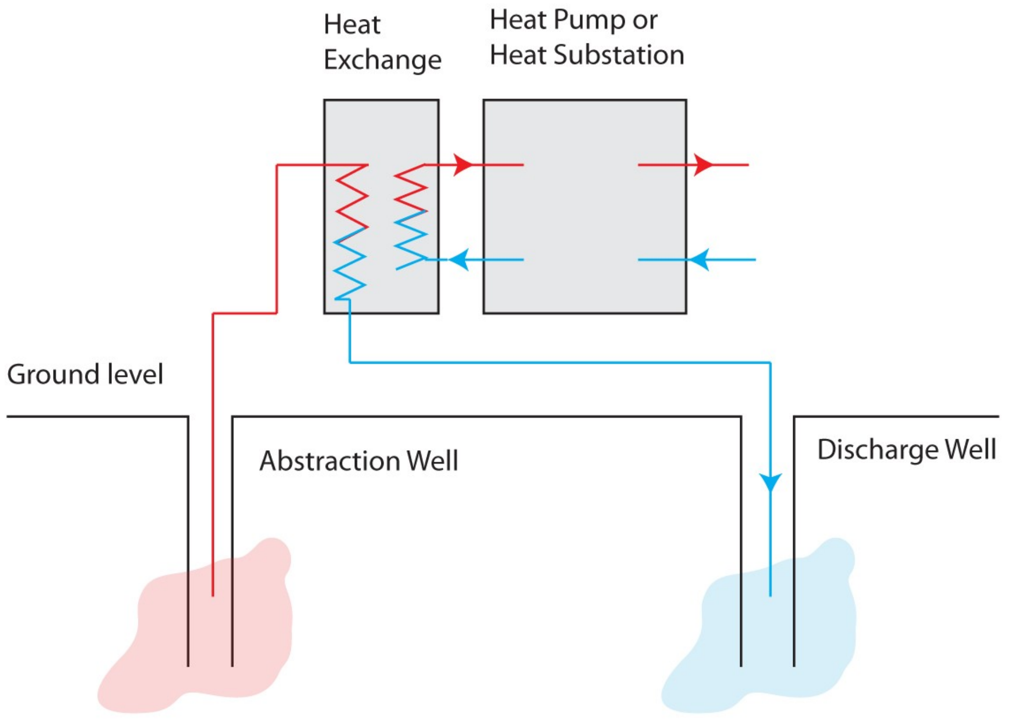
METHODOLOGY



DATA SOURCES

Ref	Source	Comment
[1]	GLA (2007) Cities Revealed Database	CONFIDENTIAL NOT FOR CIRCULATION
[2]	English Heritage (2012) Registered Parks and Gardens: http://magic.defra.gov.uk/datadoc/metadata.asp?dataset=59	
[3]	Project Team assumptions	Detailed assumptions sheet included in Calculation Sheets
[4]	Project Team assumptions	Detailed assumptions sheet included in Calculation Sheets

SCHEMATIC



SUPPLY MAP

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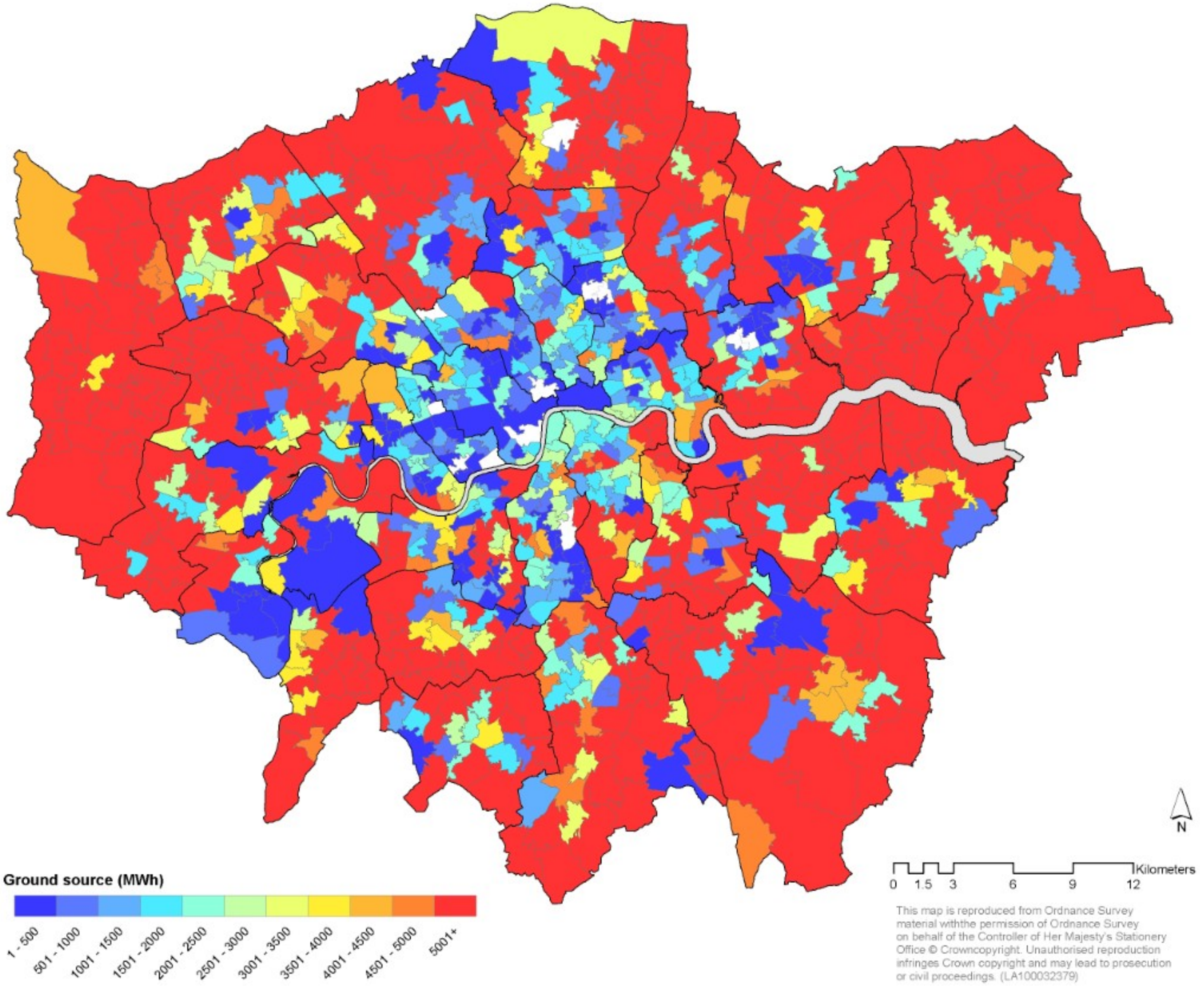
HEAT DENSITY MAP (Closed and open loop systems combined – 2013 available supply)



SEASONAL VARIATION

The effect of external air temperature on groundwater temperature decreases with depth below ground. At the depth that vertical boreholes have been specified (50m/100m) this is assumed to be minimal and therefore no seasonal variation has been modelled.

CLOSED LOOP - Mean bulk temperature at 50m below ground level - 12.8°C
OPEN LOOP - Mean Groundwater Temperature at 100m – 14.3°C

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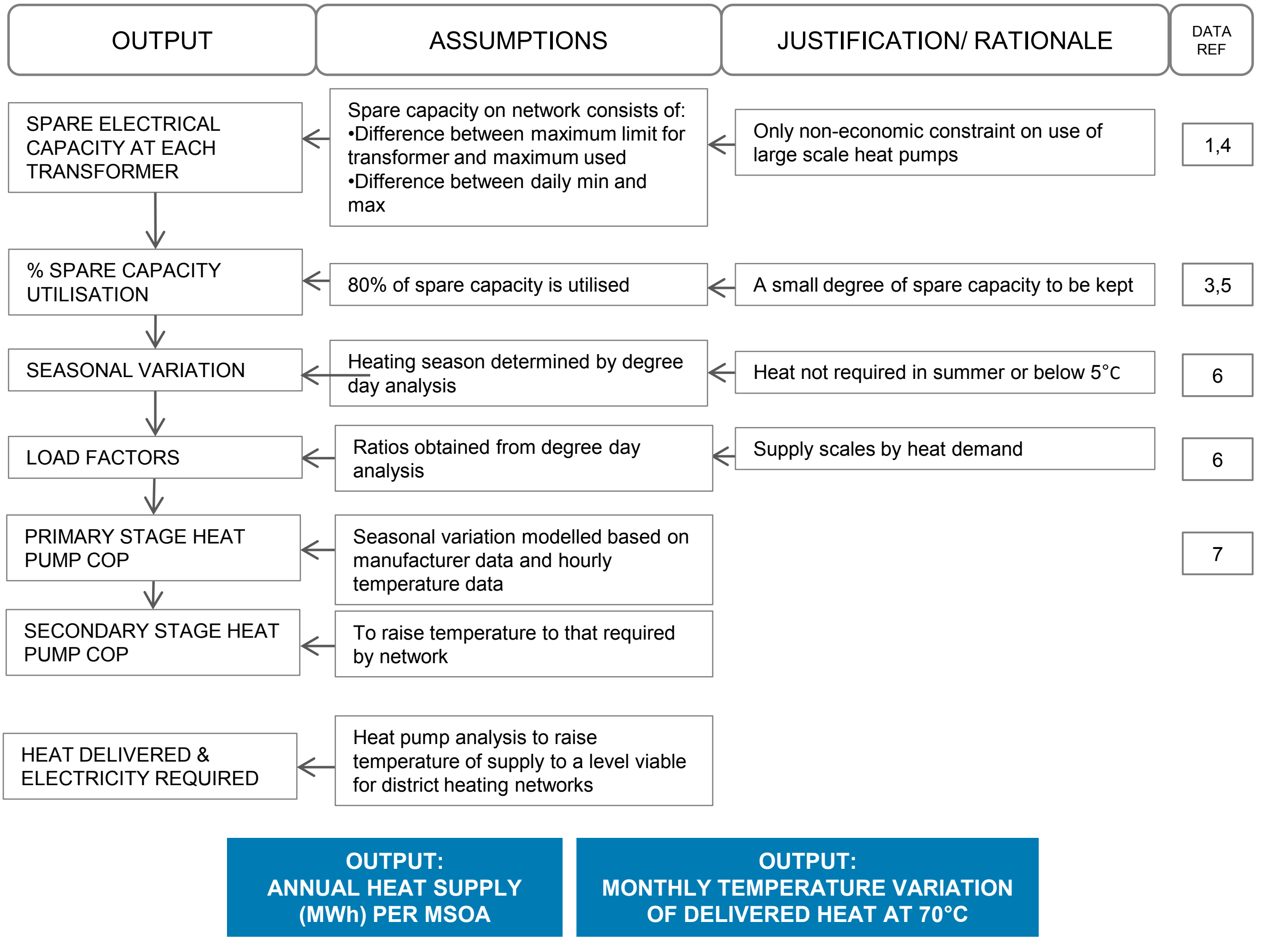
APPENDIX A

Heat Source	Large scale air source heat pumps
Advisory Group	n/a
Date	18.02.13
Rev	02

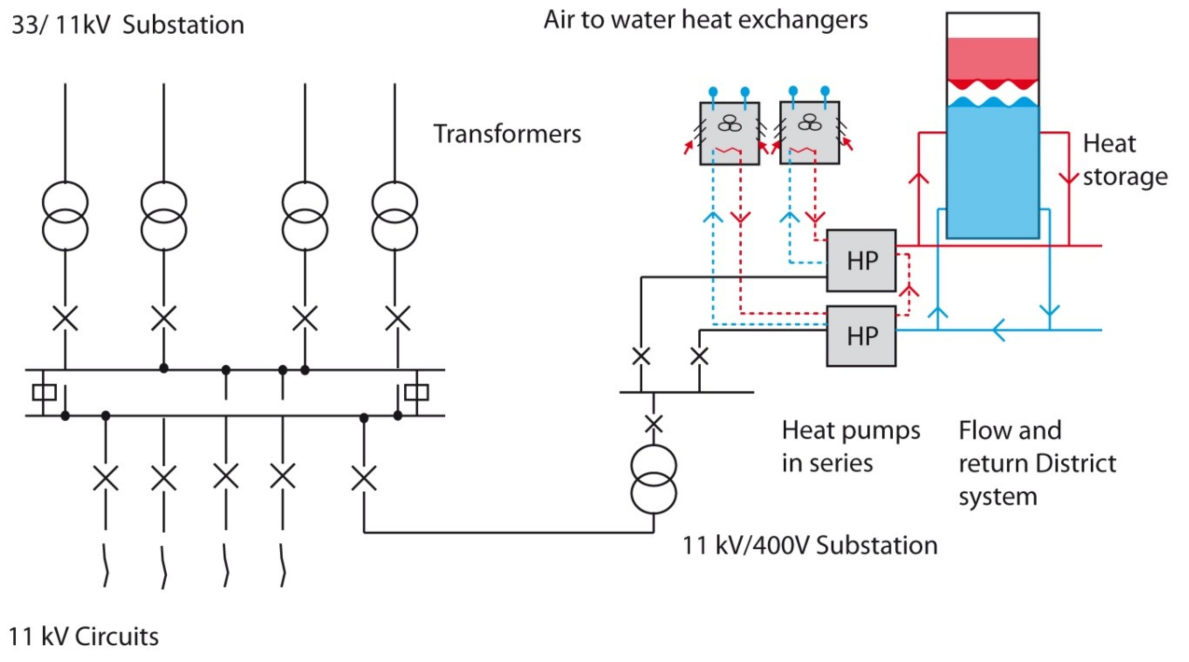
METHODOLOGY



DATA SOURCES

Ref	Source	Comment
[1]	UKPN (2012) Long Term Development Statement for London Power Networks: http://www.ukpowernetworks.co.uk/internet/en/about-us/regulatory-information/	Data for London transformers provided including used winter capacity and firm capacity.
[3]	Project team assumption	
[4]	DECC (2010) Energy trends, September 2010, p51: http://www.decc.gov.uk/assets/decc/Statistics/publications/trends/558-trendssep10.pdf	
[5]	Project team assumption	assume frost coils needed below 5°C
[6]	Weather data, Heathrow	
[7]	Ciat Heat pump feasibility study. Aquaciat Power LD1800V	Refrigerant on large scale heat pump restricts flow temperature to 55°C

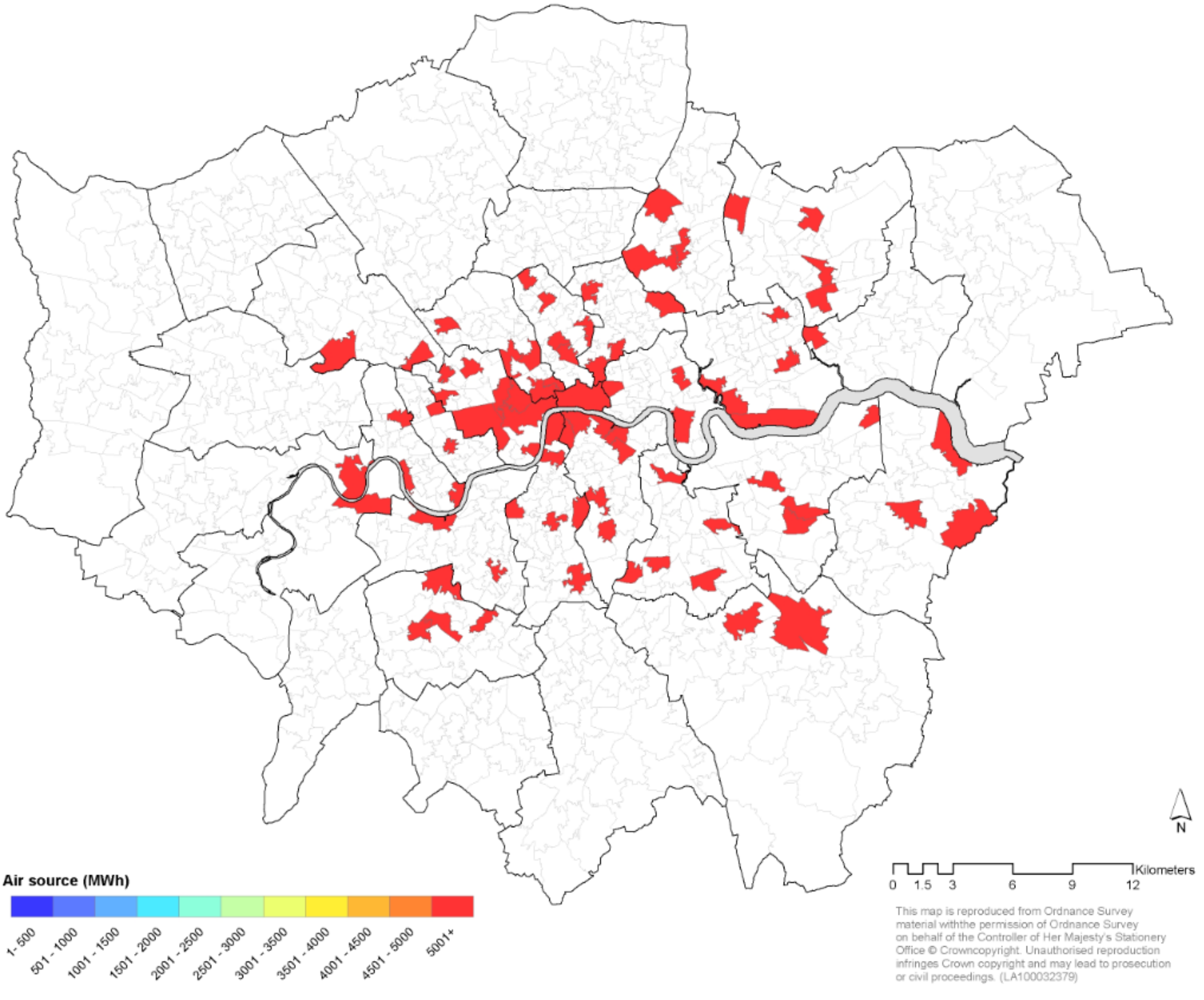
SCHEMATIC



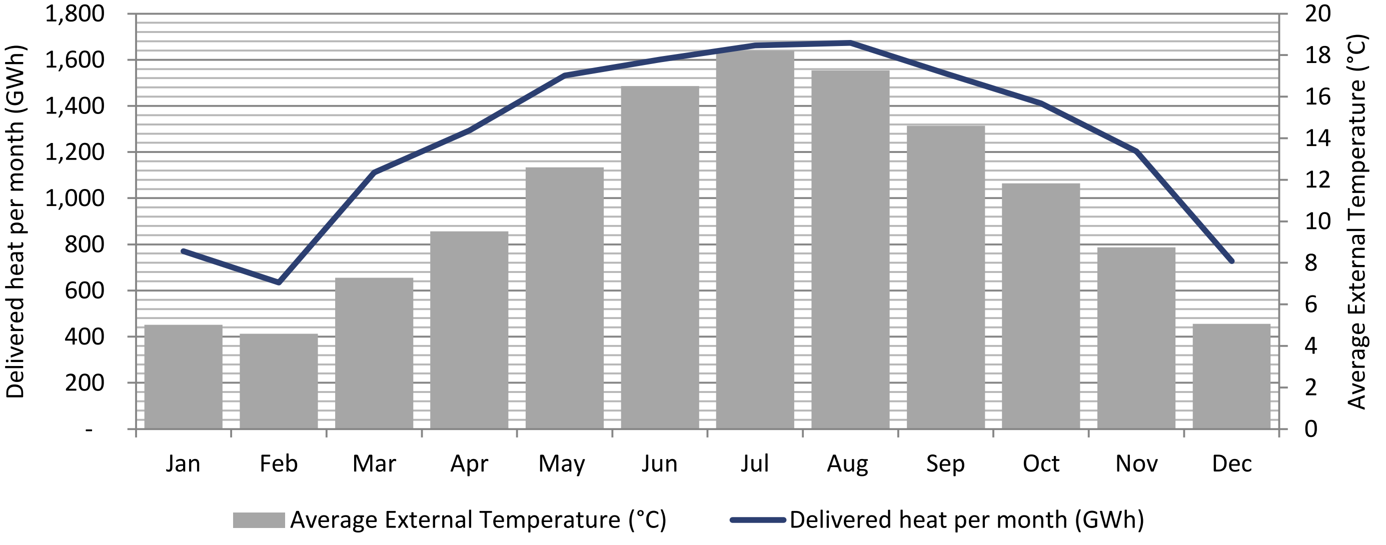
SUPPLY MAP

Air source heat pumps are located adjacent to UKPN substations. Locations are therefore confidential and not published

HEAT DENSITY MAP 2013 Available Heat



SEASONAL VARIATION



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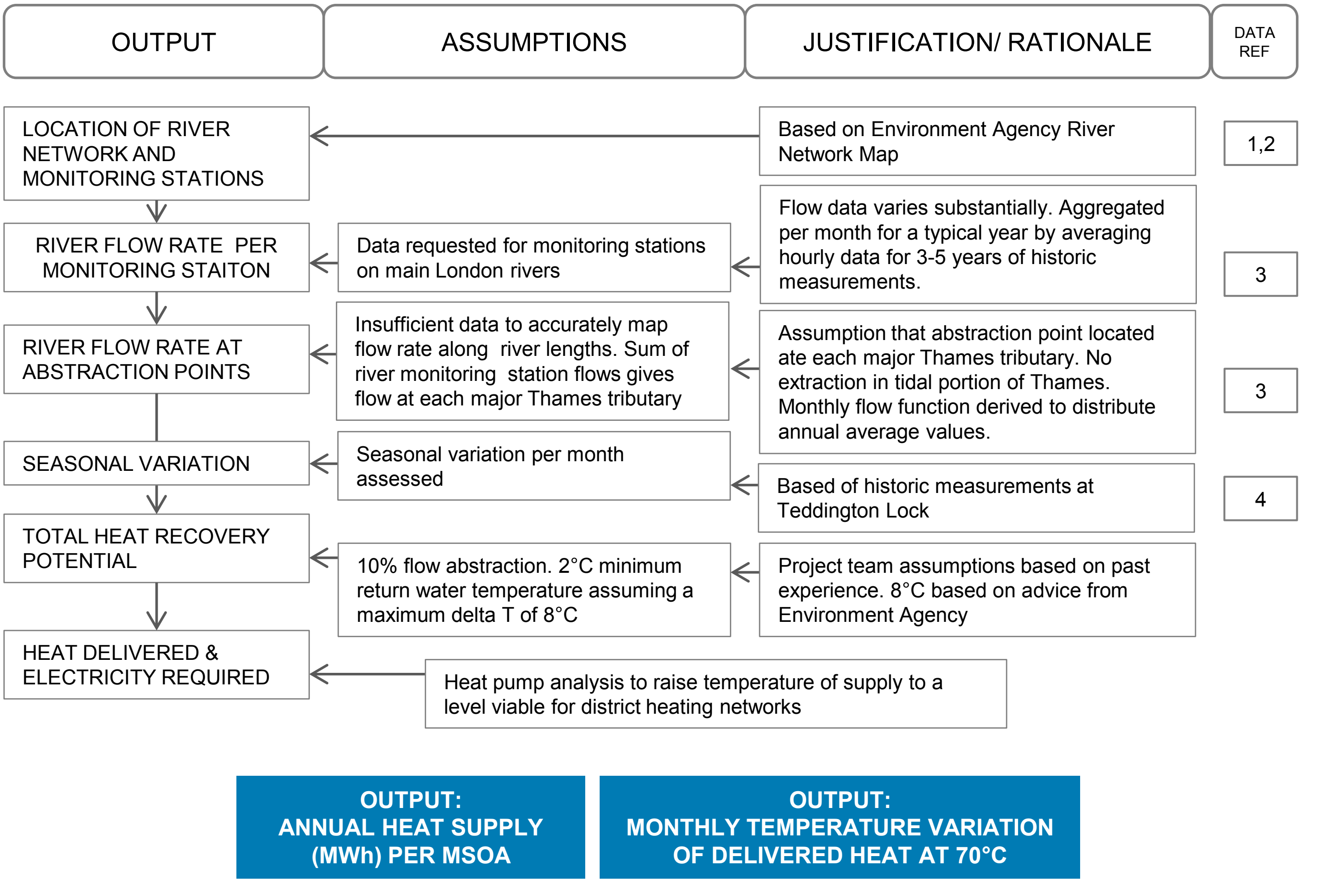
APPENDIX A

Heat Source	River Sources
Advisory Group	Environment Agency
Date	11.01.13
Rev	01

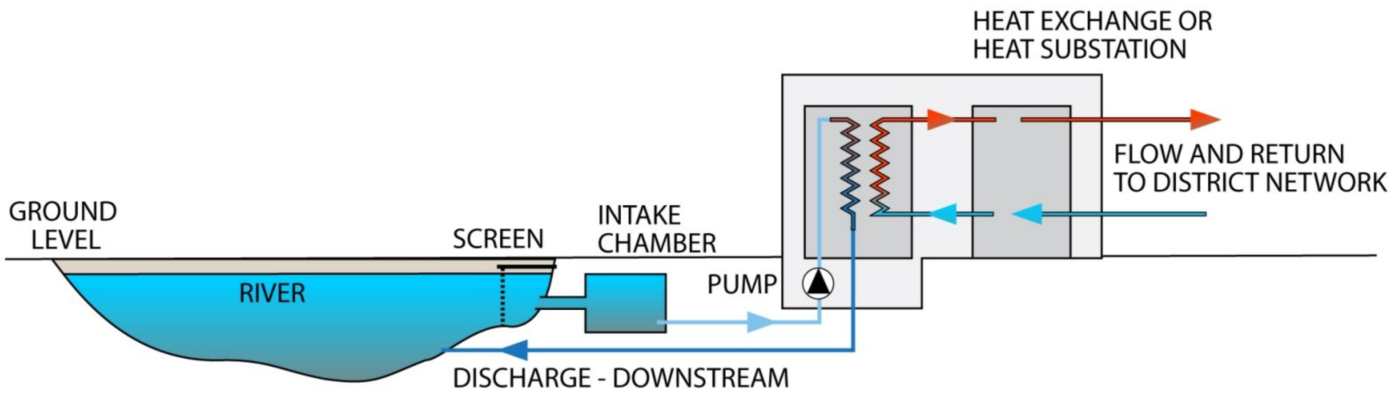
METHODOLOGY



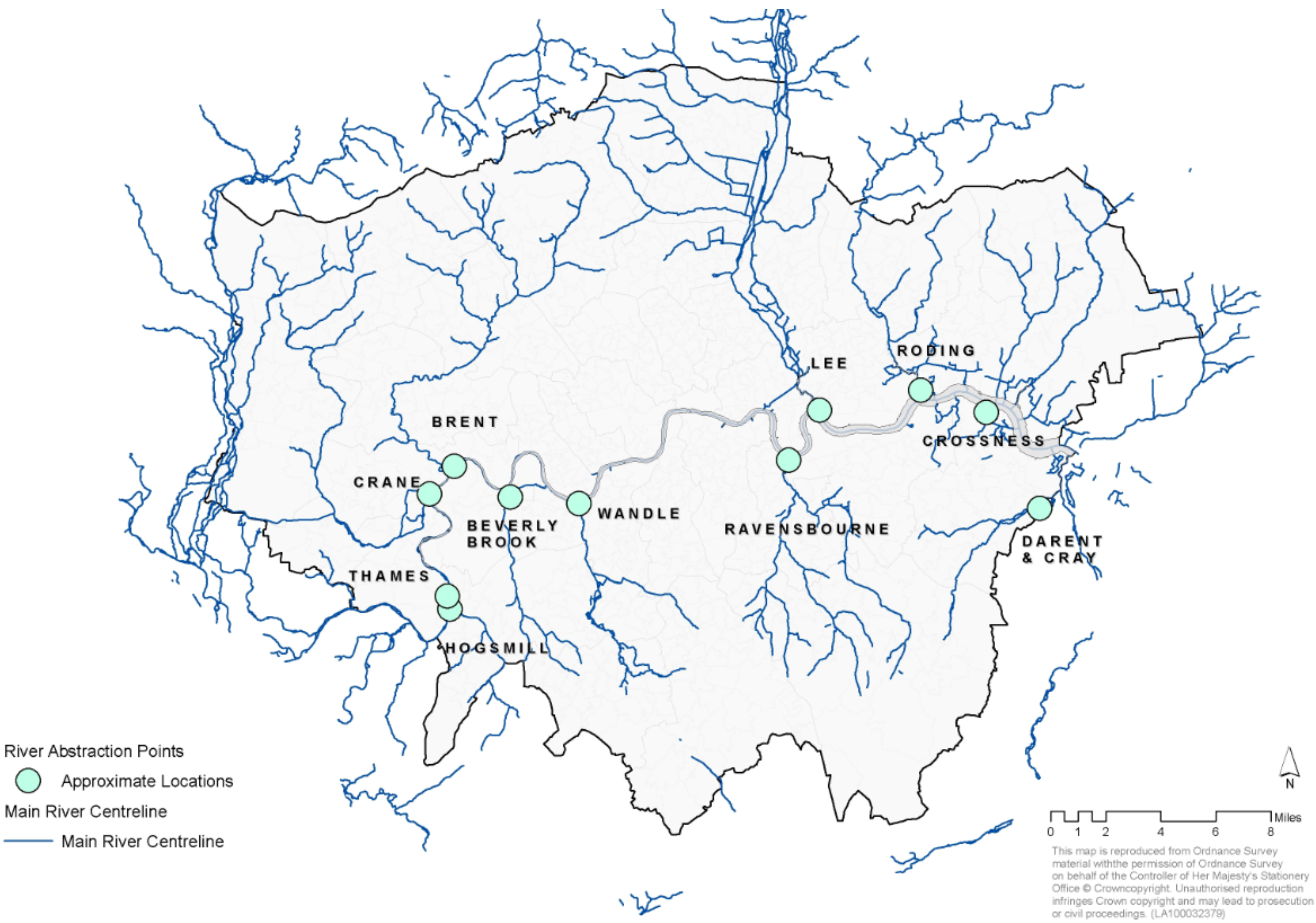
DATA SOURCES

Ref	Source	Comment
[1]	Environment Agency: main river locations	GIS vector file
[2]	Environment Agency: flow station locations	GIS shapefile
[3]	Environment Agency: flow data	Historic monthly means for requested sites
[4]	Environment Agency: river temeperature data	Historic monthly means for teddington lock

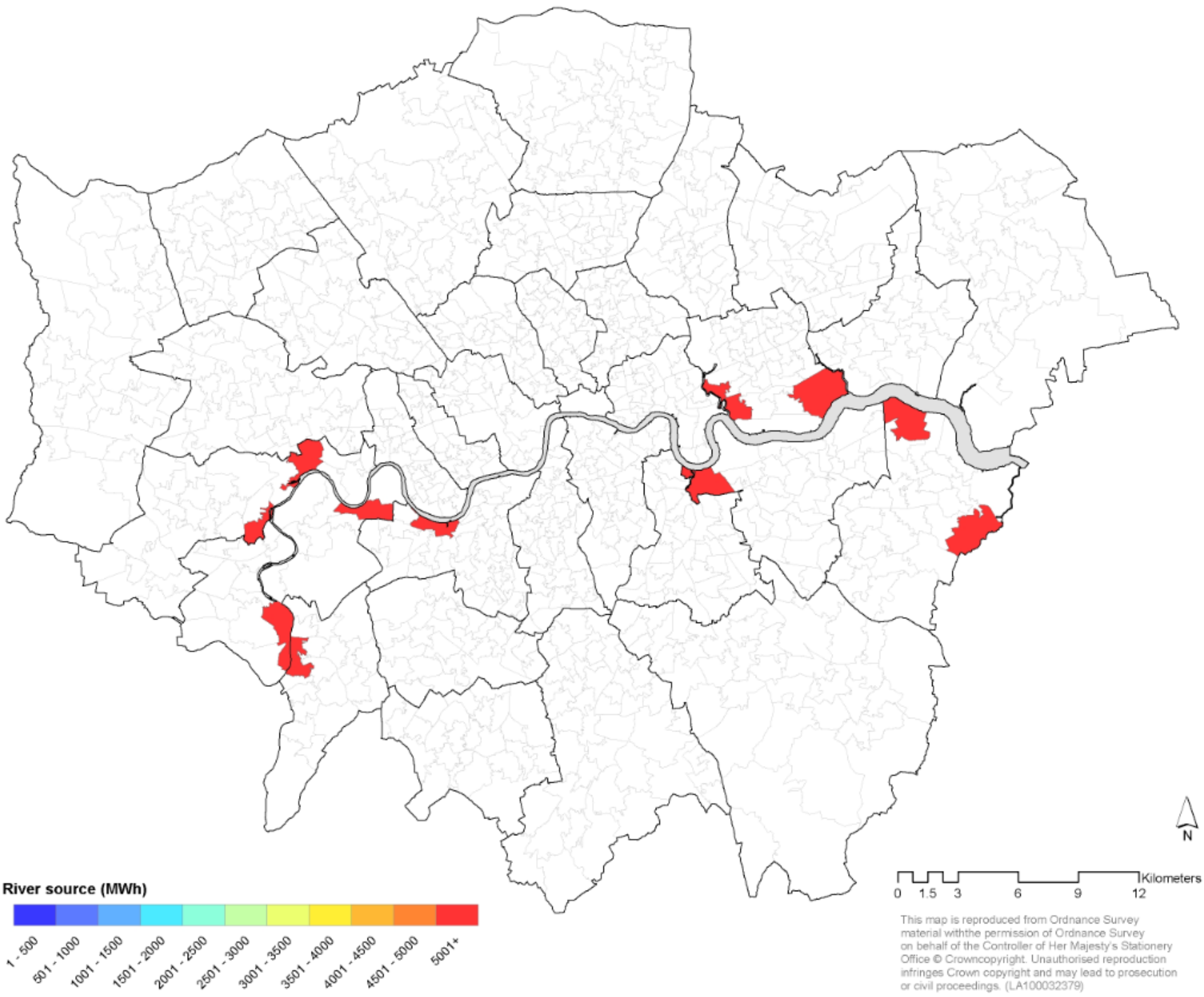
SCHEMATIC



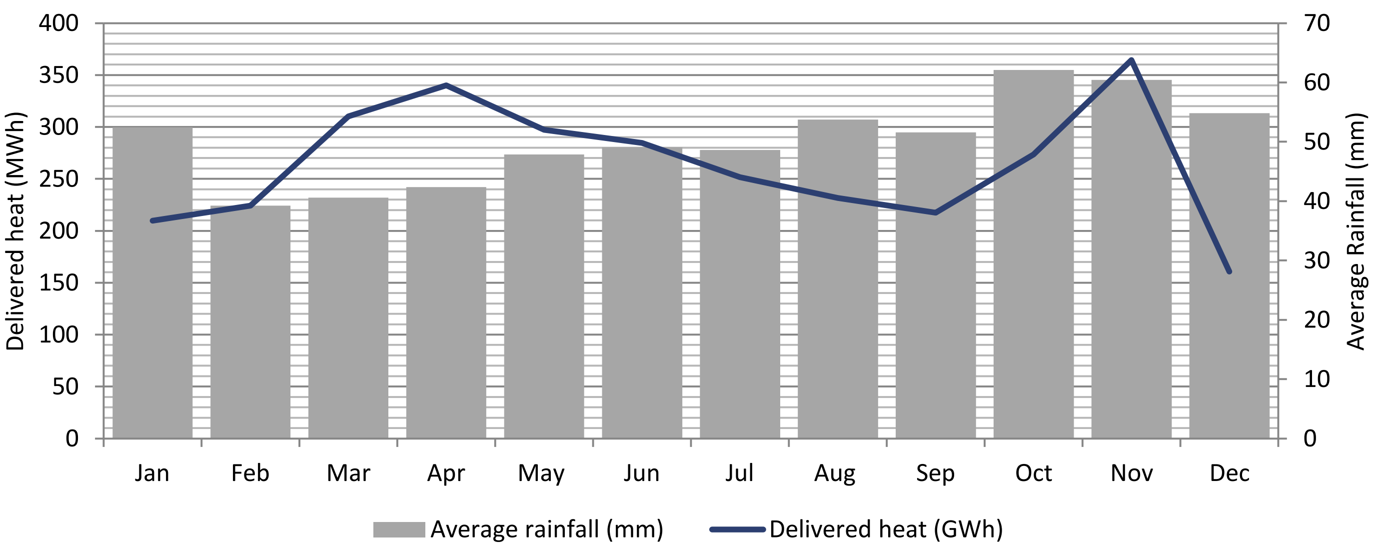
SUPPLY MAP



HEAT DENSITY MAP 2103 Available Heat



SEASONAL VARIATION



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APPENDIX A

Heat Source	Power station heat rejection
Advisory Group	n/a
Date	11.01.13
Rev	01

METHODOLOGY

OUTPUT	ASSUMPTIONS	JUSTIFICATION/ RATIONALE	DATA REF
LOCATION OF ALL POWER STATIONS IN LONDON	Heat sources considered where energy is generated anyway for other purposes. Waste heat recovery cannot impact power station electrical output. CHP schemes are not included	CHP plant potential capacity has already been established.	11,12, 13
POWER OUTPUT			
LOAD CONDITIONS	(see table below)	Power Stations categorised under various types with respective conditions	1-10
HEAT RECOVERY POTENTIAL	(see table below)		
ASSESS SEASONAL VARIATION	Assume only steam cycle plant vary temperature seasonally due to use of condensers using river water, cooling tower or dry condeners		#
GIS SPATIAL ANALYSIS	Sum capacities per MSOA	London MSOA shapefile	
HEAT DELIVERED & ELECTRICITY REQUIRED	Heat pump analysis to raise temperature of supply to a level viable for district heating networks		

	Power/heat ratio	Ref.	Thermal efficiency		Electrical efficiency		Load Factor	
Existing power plant	167%	[1]%	30%	[1]	50.0%	[1]	62.8%	[2]
Energy from waste - incineration	50%	c	40%	[3]	20.0%	[3]	90.0%	
Sewage Gas (anaerobic digester)	70%	c	33%	[3]	23.1%	[4]	90.0%	[6]
Landfill Gas	100%	c	35%	[8]	35.0%	[8]	90.0%	[7]
OCGT	143%	[9]	25%	c	35.0%	[9]	11.4%	[9]
STW Sludge powered generator	33%	[10]	60%	[10]	20.0%	[10]	90.0%	[10]

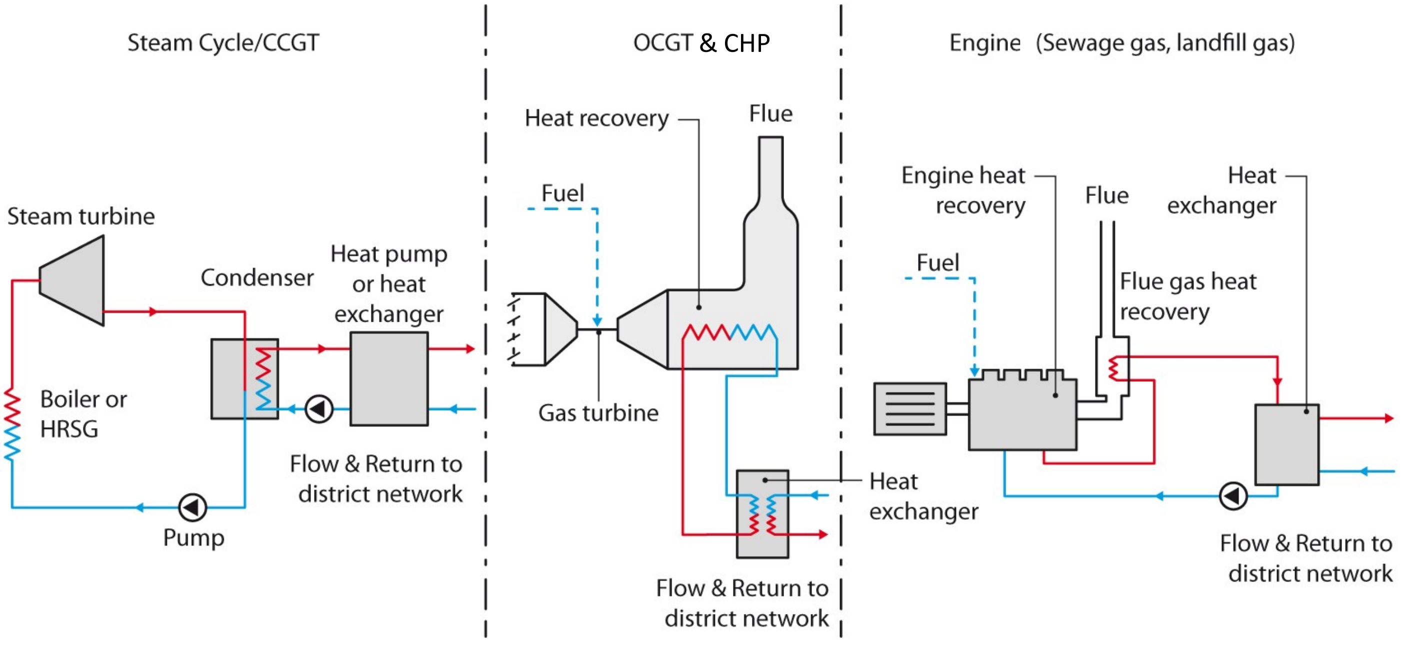
OUTPUT: ANNUAL HEAT AVAILABLE (MWh) PER MSOA

OUTPUT: ANNUAL HEAT DELIIVERED AT 70°C (MWh) PER MSOA

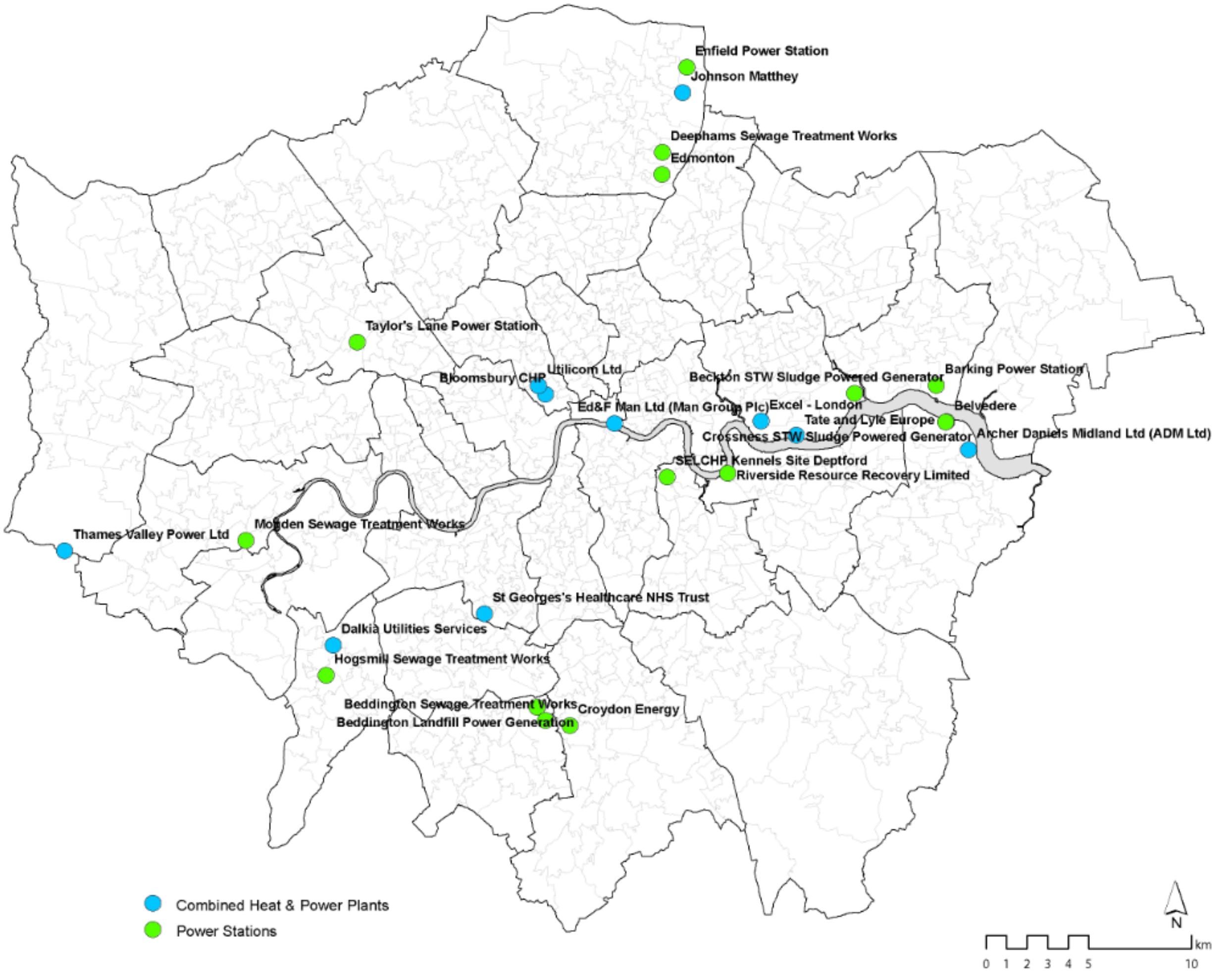
DATA SOURCES

Ref	Source
[1]	Project team assumption
[2]	DECC (2010) Digest of UK energy statistics, 2009 Table 5.10, Average power plant load factors
[3]	GLA (2009) Environment Committee site visit notes, Appendix X: https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CDcQFjAA&url=http%3A%2F%2Flegacy.london.gov.uk%2Fassembly%2Fenvmtgs%2F2009%2Fenvjul09%2Fminutes%2Fappendix-c.rtf&ei=N17UUKaGAdKwhAff4oC4BQ&usg=AFQjCNEiy7qki1SEAf42noLxlb84mxMVEg&sig2=-LYo-j1tmbZQfrcekJzfXw&bvm=bv.1355534169,d.ZG4
[4]	DEFRA (2007) Incineration of municipal solid waste http://archive.defra.gov.uk/environment/waste/residual/newtech/documents/incineration.pdf
[5]	AEA Technology (2007). Residual waste treatment in Cornwall. An assessment of costs and environmental impacts of single and multiple facilities. Harwell: 52.
[6]	DECC (2011) Decentralised Energy Capacity Study
[7]	Project team assumption
[8]	U .S. Environmental Protection Agency (2009) Project Technology Options: LFG Energy Project Development Handbook: http://www.epa.gov/lmop/documents/pdfs/pdh_chapter3.pdf
[9]	AECOM (2009) Croydon Decentralised Energy Study: http://www.londonheatmap.org.uk/Content/uploaded/documents/Croydon_DE-study-complete.pdf
[10]	Project team assumption
[11]	DECC (2010) Digest of UK energy statistics, 2009
[12]	GLA (2012) London Heat Map
[13]	Renewable Energy Foundation (2012) REGO database - obtained via private communication with project team

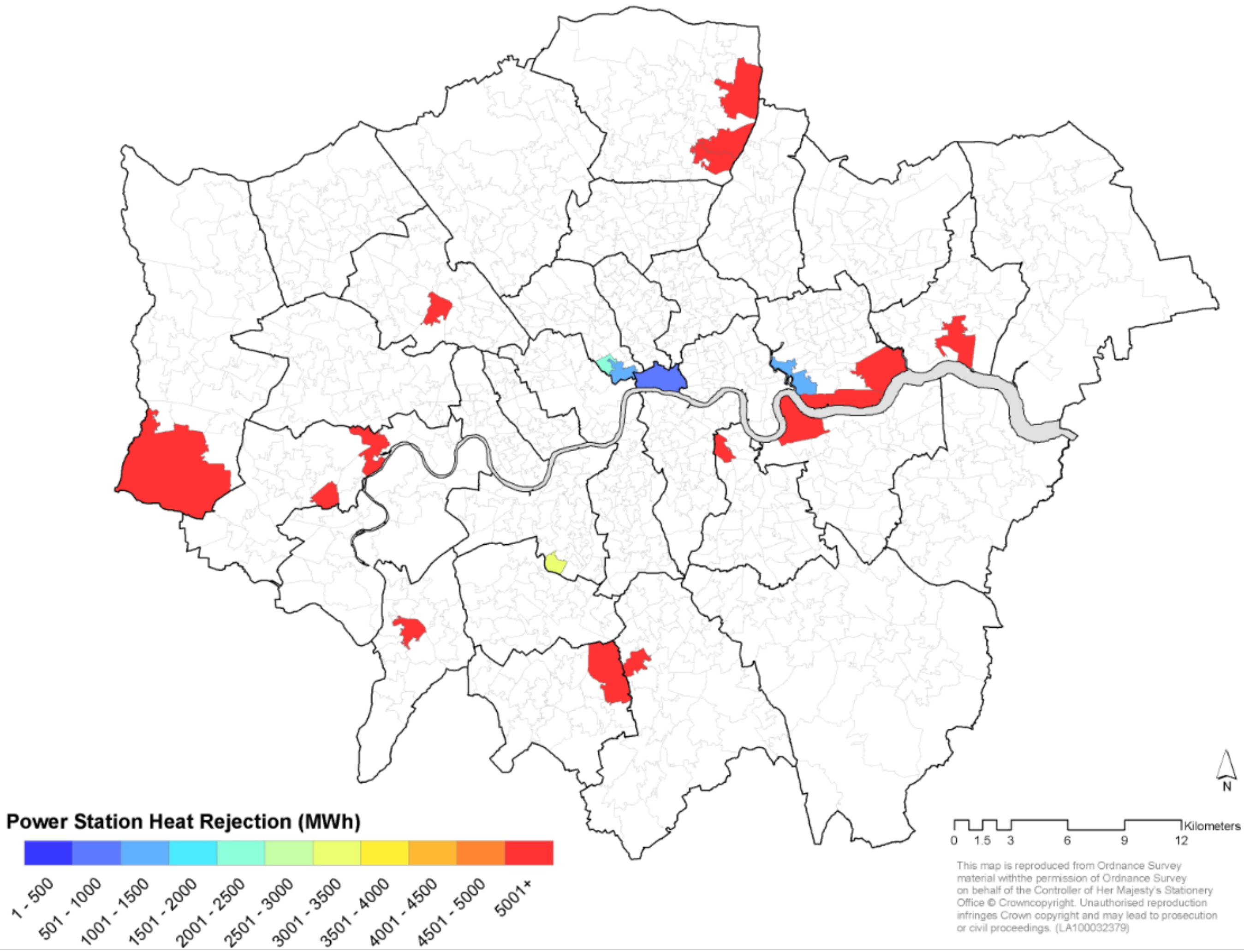
SCHEMATIC



SUPPLY MAP



HEAT DENSITY MAP 2013 Available Heat



SEASONAL VARIATION

No seasonal variation has been modelled

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APPENDIX A

Heat Source	Building Cooling System Heat Rejection
Advisory Group	n/a
Date	11.01.13
Rev	01

METHODOLOGY

OUTPUT	ASSUMPTIONS	JUSTIFICATION/ RATIONALE	DATA REF
BUILDING FLOOR AREA	Based on VOA floor space data per MSOA for office and retail spaces. Gyms based data extracted from the London heat map. Assessed as point with benchmarks applied per gym	Warehouses, factories and other process buildings have been excluded – office and retail are key sources of building cooling system heat rejection	1,2,5
AIR CONDITIONED FLOOR AREA	Assigned to VOA floor areas based on rateable value. % of air conditioned floor space distributed across rateable range	Rateable value provides estimate of type of building. EPC data pending for more accurate distribution analysis	1
SEASONAL VARIATION	Seasonal variation per month assessed	Based of effect of ambient air temperature on chiller heat rejection	#
HEAT RECOVERY POTENTIAL	Rejected heat (MWh per MSOA) as a function of installed capacity and chiller COP	Run hours and load factor applied based on best available data	2,3,4
HEAT DELIVERED & ELECTRICITY REQUIRED	Heat pump analysis to raise temperature of supply to a level viable for district heating networks		

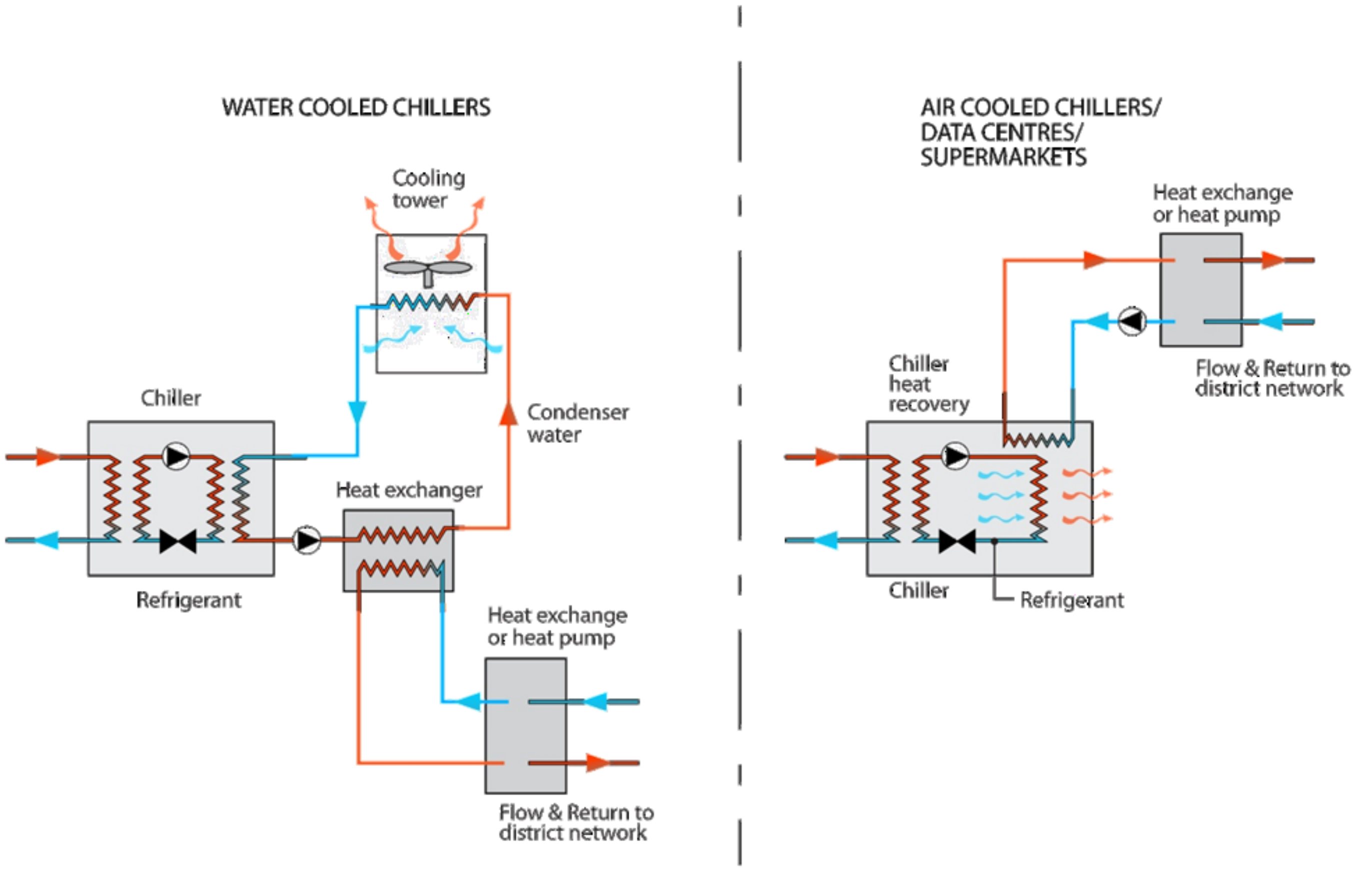
**OUTPUT:
ANNUAL HEAT SUPPLY
(MWh) PER MSOA**

**OUTPUT:
MONTHLY TEMPERATURE VARIATION
OF DELIVERED HEAT AT 70°C**

DATA SOURCES

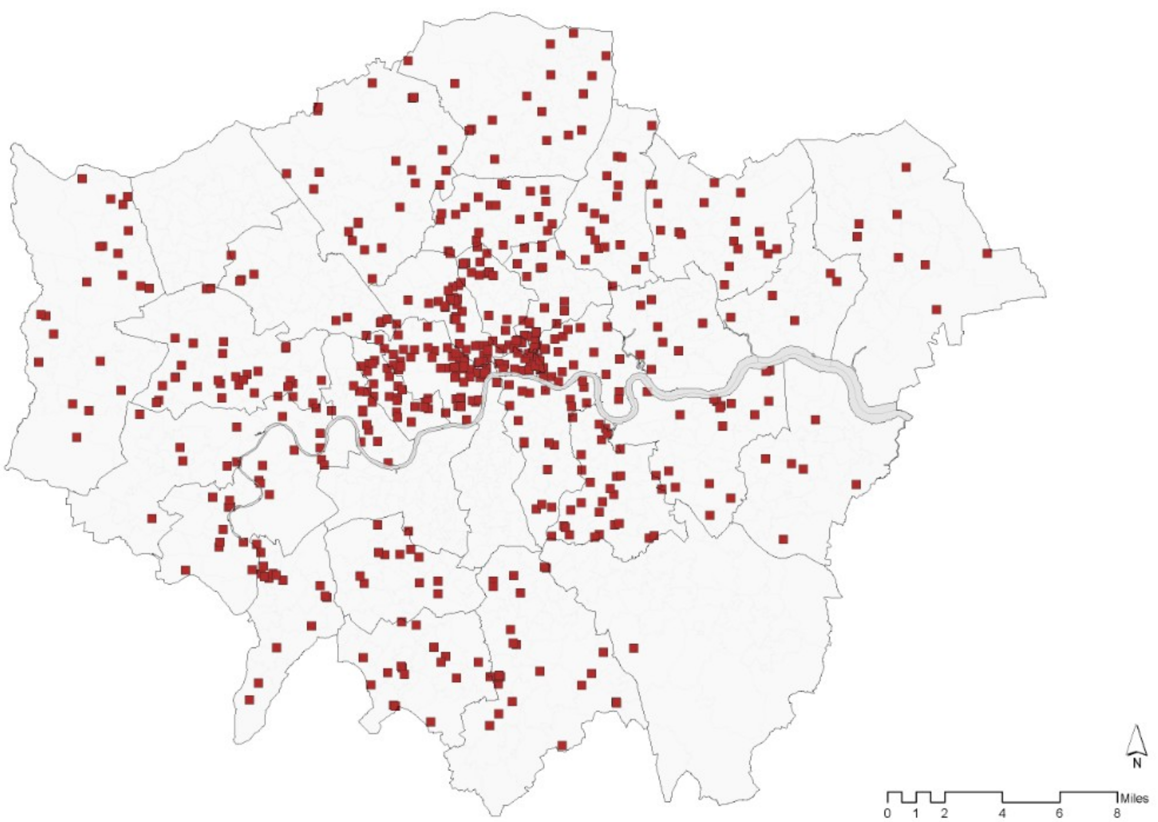
Ref	Source	Comment
[1]	Neighbourhood Statistics (2008): Valuation Office Agency - floorspace and rateable value	Data per MSOA for retail and office spaces
[2]	Project Team Assumptions	Based on Carbon Trust technologly Guide CTG005 (http://www.datumphasechange.com/Carbon%20Trust%20-
[3]	CIBSE Guide F: Table 8.1	Benchmarks of typical air coditioned standard office and air conditioned prestige office. Allocation based on rateable value
[4]	ECON Guide on Energy use in sports and recreation buildings. Energy Consumption Guide 78.	All gyms based on a type 5 fitness centre (suite of exercise rooms with exercise machines). All demands relate to gross floor area
[5]	London Heat Map, Sports and Leisure sites. Available at http://www.londonheatmap.org.uk/Content/HeatMap.as	Quality of data varies by borough. As such, only the point locations of each site have been abstracted from the heat map.

SCHEMATIC



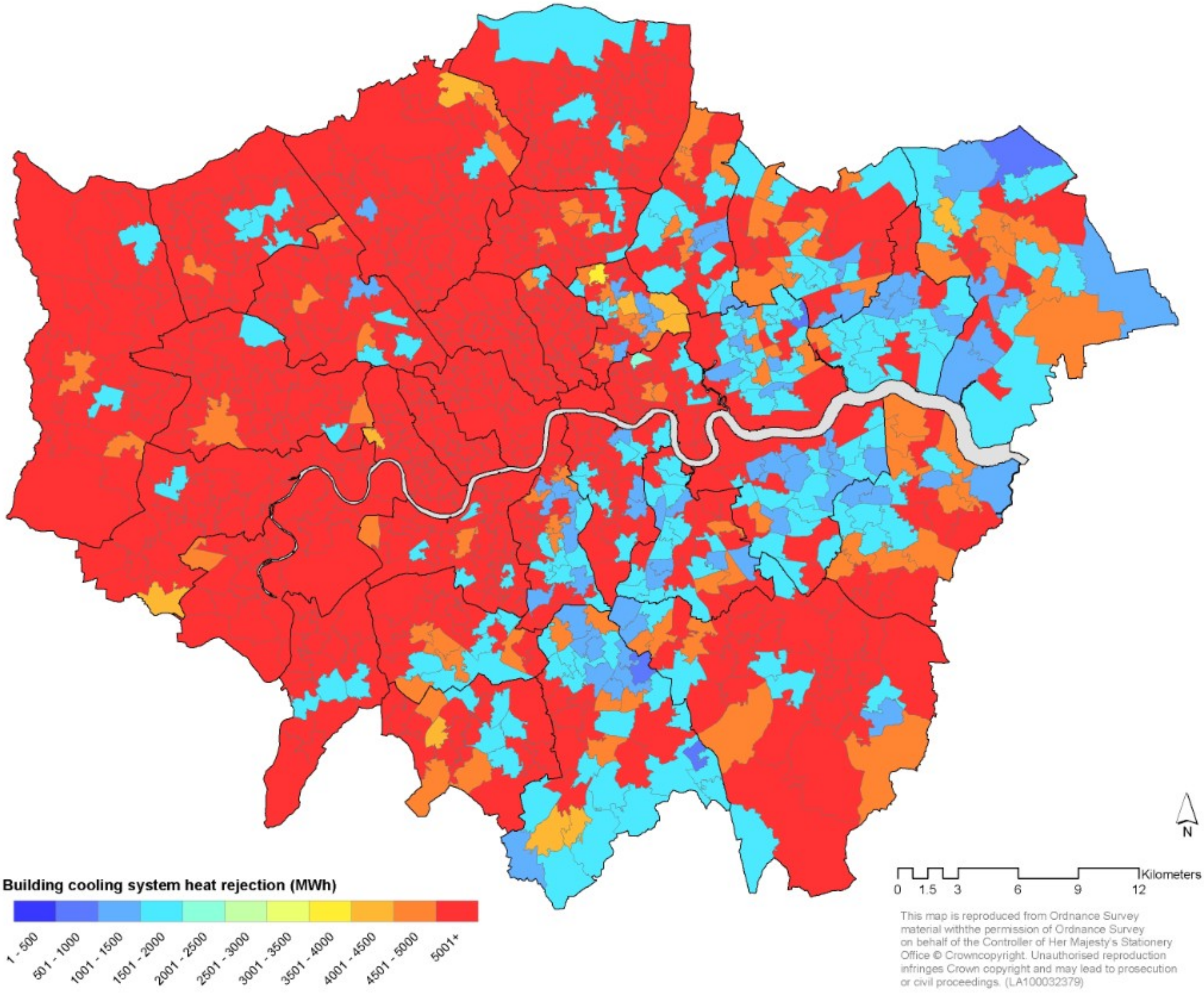
SUPPLY MAP

Office and retail floor space mapped for each MSOA (not shown in point location map below)

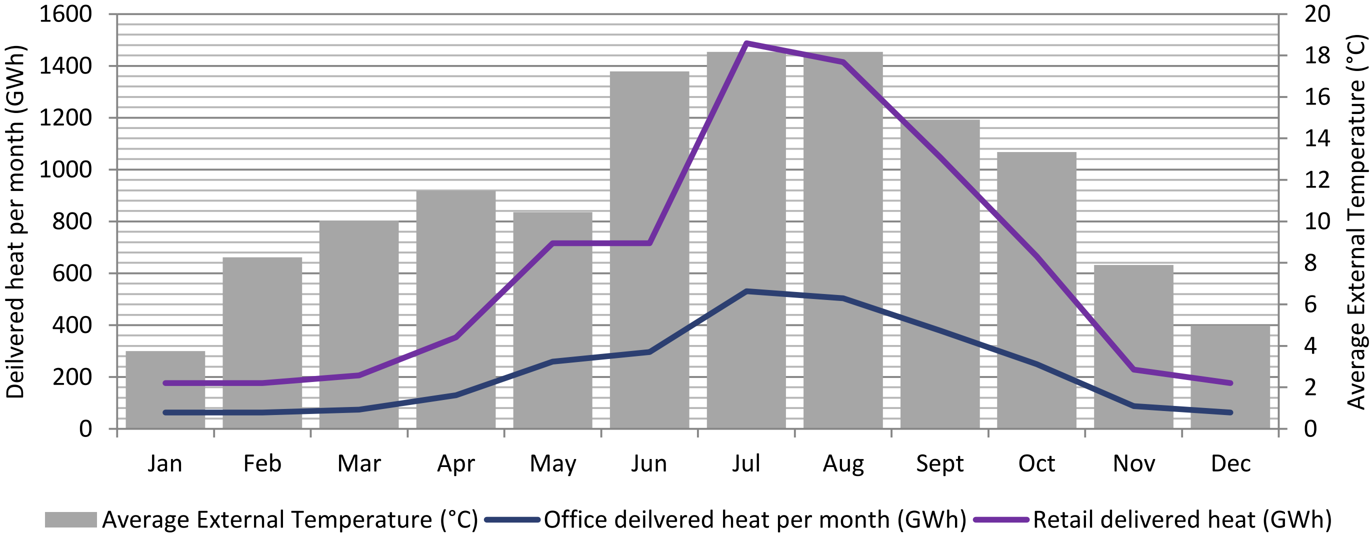


Major Gyms
■ All Gyms

HEAT DENSITY MAP 2013 Available Heat



SEASONAL VARIATION



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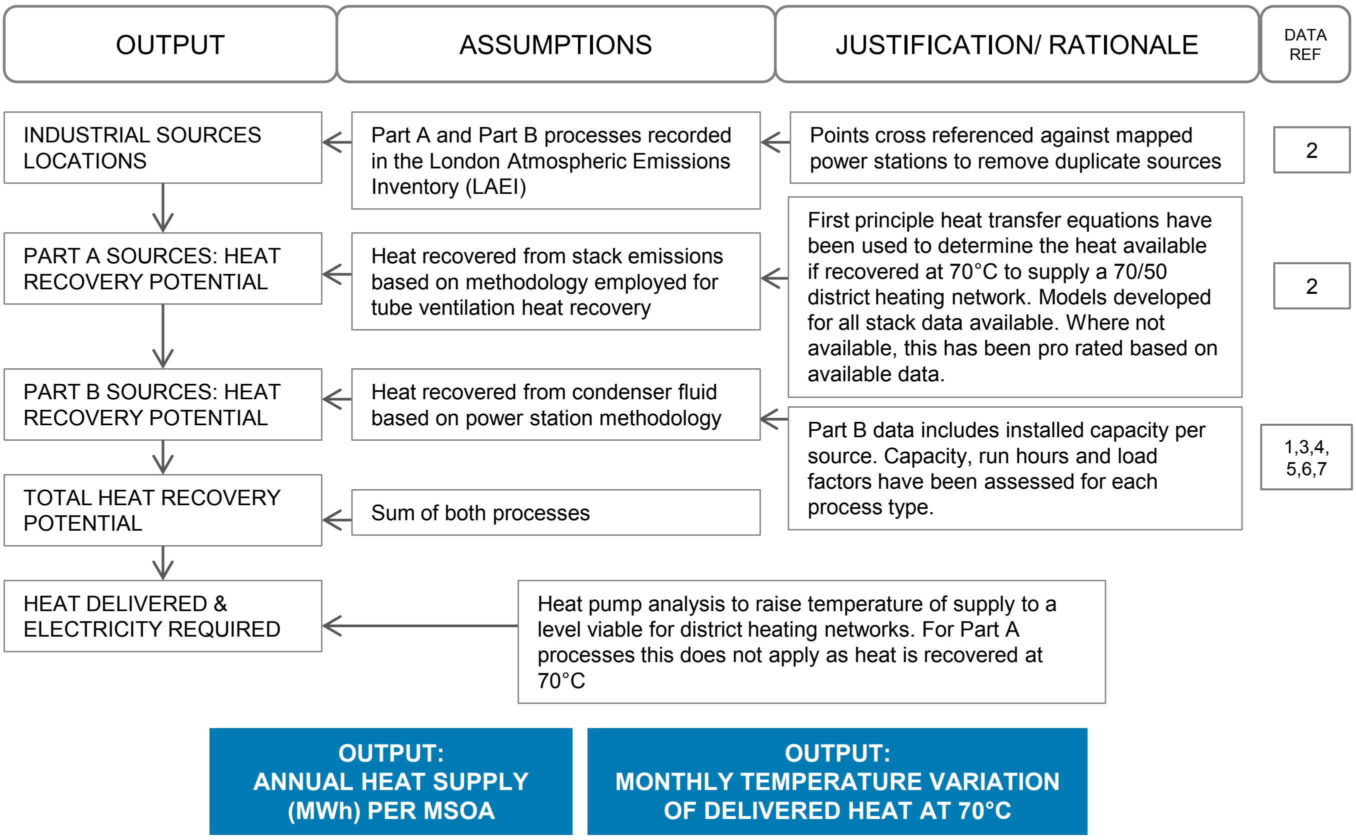
APPENDIX A

Heat Source	Industrial Sources
Advisory Group	n/a
Date	11.01.13
Rev	01

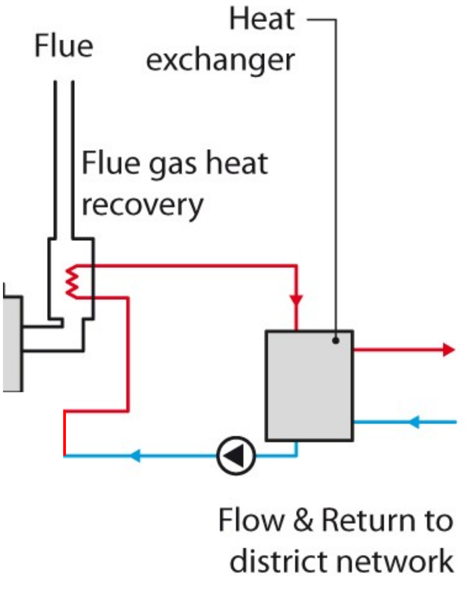
METHODOLOGY



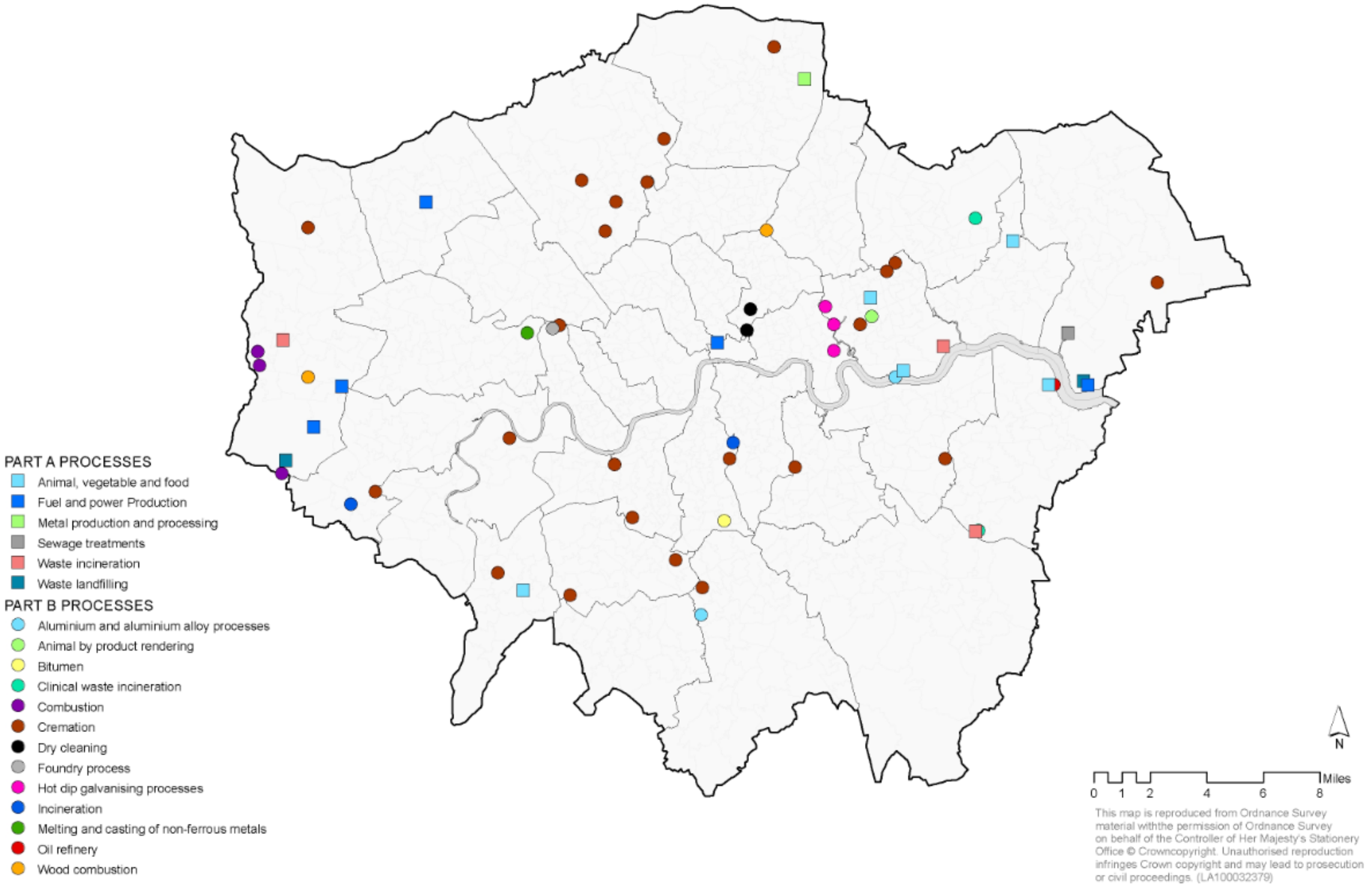
DATA SOURCES

Ref	Source	Comment
[1]	Reddich Council (2011): Crematorium Energy Recovery Project. Agenda Item 8	280kW per 80min cycle therefore 373 kW per cycle. 250 operating days, 8 hours. Assumption of 6 cycles per day
[2]	LAEI (2008): London Atmospheric Emmisions Inventory	200kg of cabon monoxide per annum per clinical waste incinerator 102 tonnes/annum wood combusted per wood combustion sites
[3]	EMEP/EEA (2009): Emission Inventory Guidebook 2009	2.8 kg of Carbon Monoxide /Mg waste for typical waste incinrator
[4]	Universiti Teknologi Malaysia (2008): Jurnal Teknologi, 49(F) Dis. 2008: 455–465,	Net Calorific value of hospital waste - 13.3 GJ per tonne of input fuel
[5]	Forestry Commision: http://www.biomassenergycentre.org.uk	Net calorific value of wood chip (30% moisture content) - 3.5 kWh per kg
[6]	Project Team Assumption	100 kW baseload assumed due to lack of available data. Includes : Bitumen, Animal by product rendering, Aluminium and aluminium alloy processes, Foundry process, Hot dip galvanising process, Incineration, Melting and casting of non-ferrous metals, Oil refinery
[7]	Aeropulse Incinerators - Kings College Hospital case study: http://www.aeropulse.com/incinerators.html	

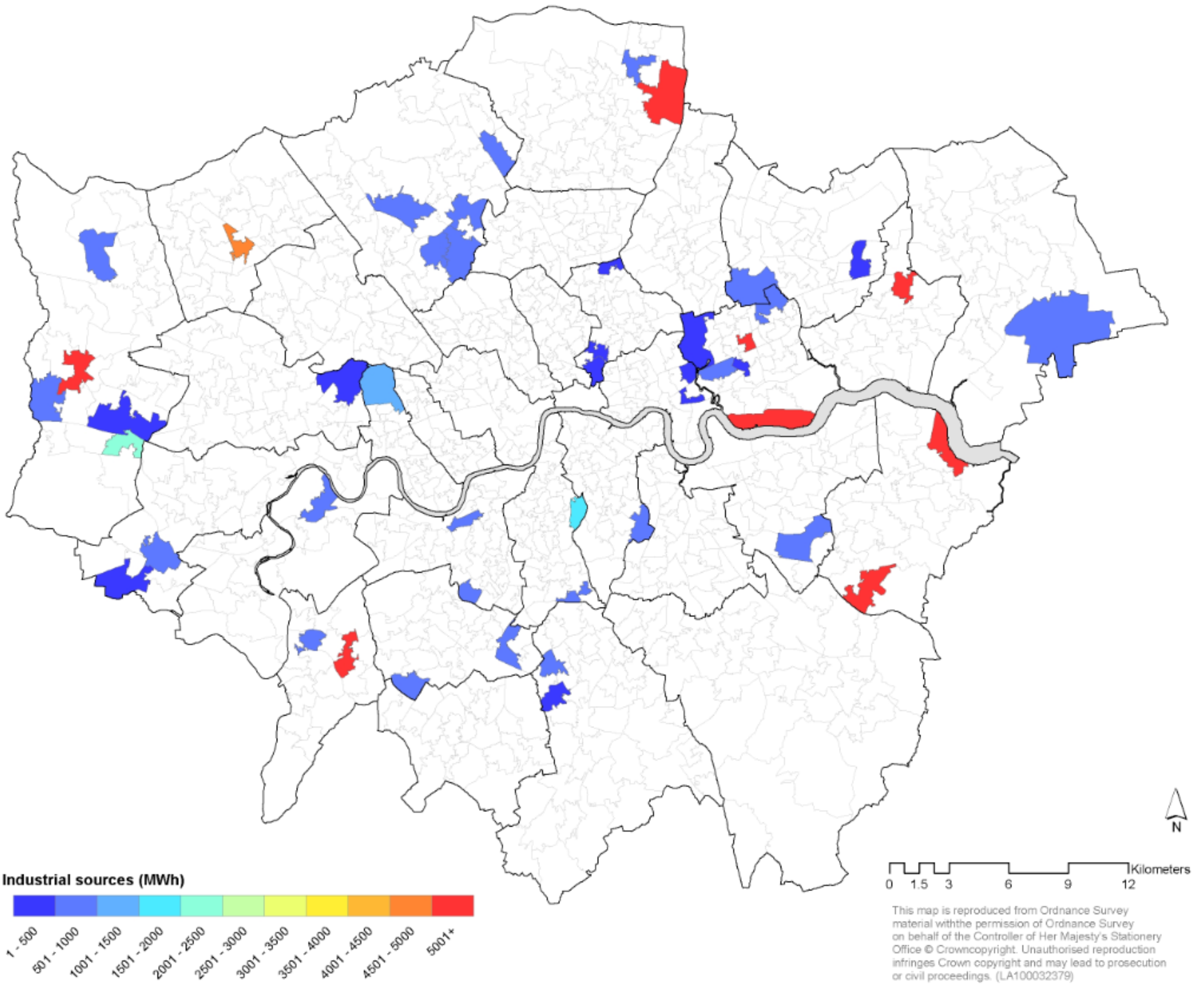
SCHEMATIC



SUPPLY MAP



HEAT DENSITY MAP 2013 Available Heat



SEASONAL VARIATION

No seasonal variation has been modelled

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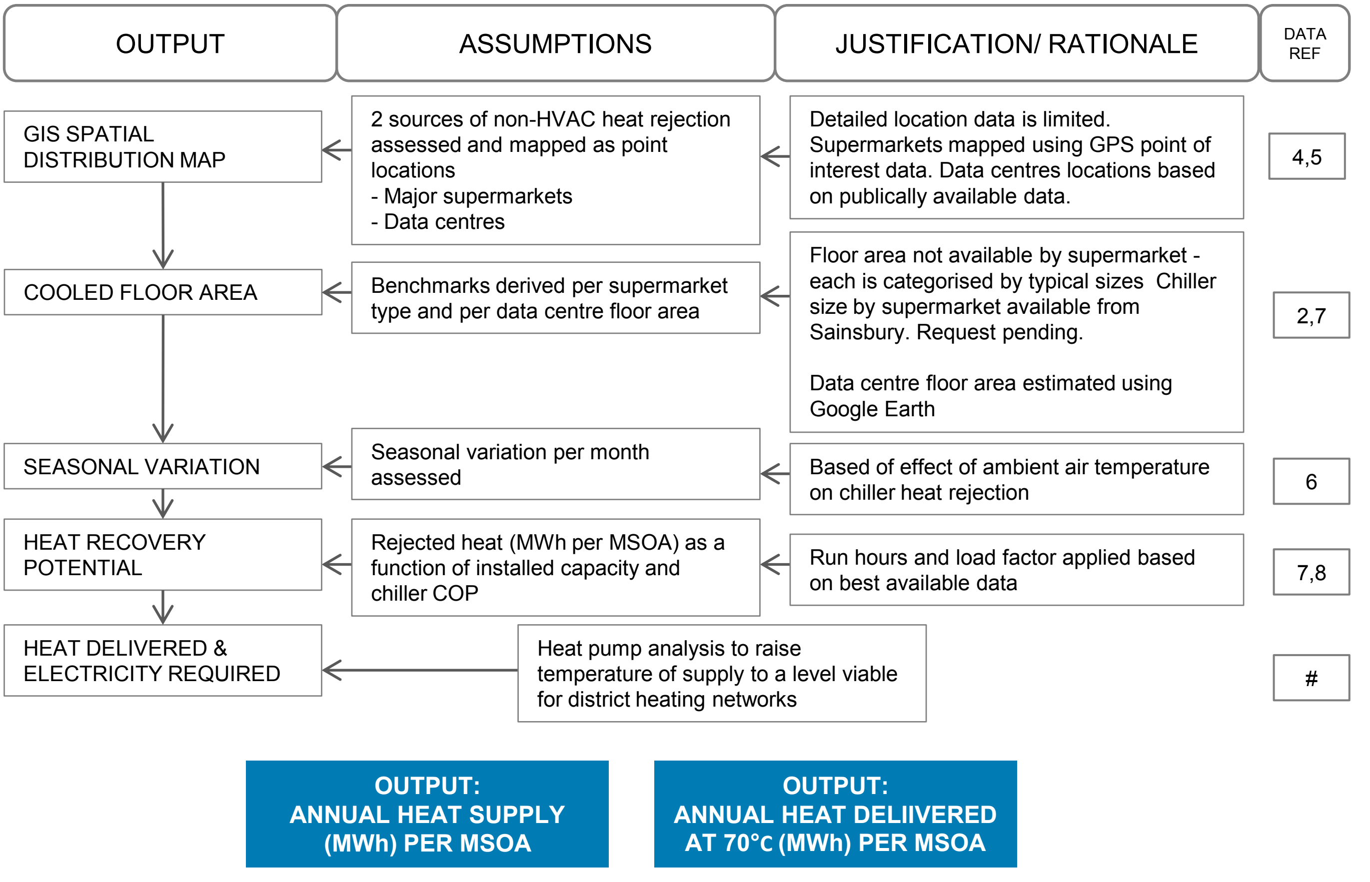
APPENDIX A

Heat Source	Commercial buildings non-HVAC
Advisory Group	n/a
Date	11.01.13
Rev	01

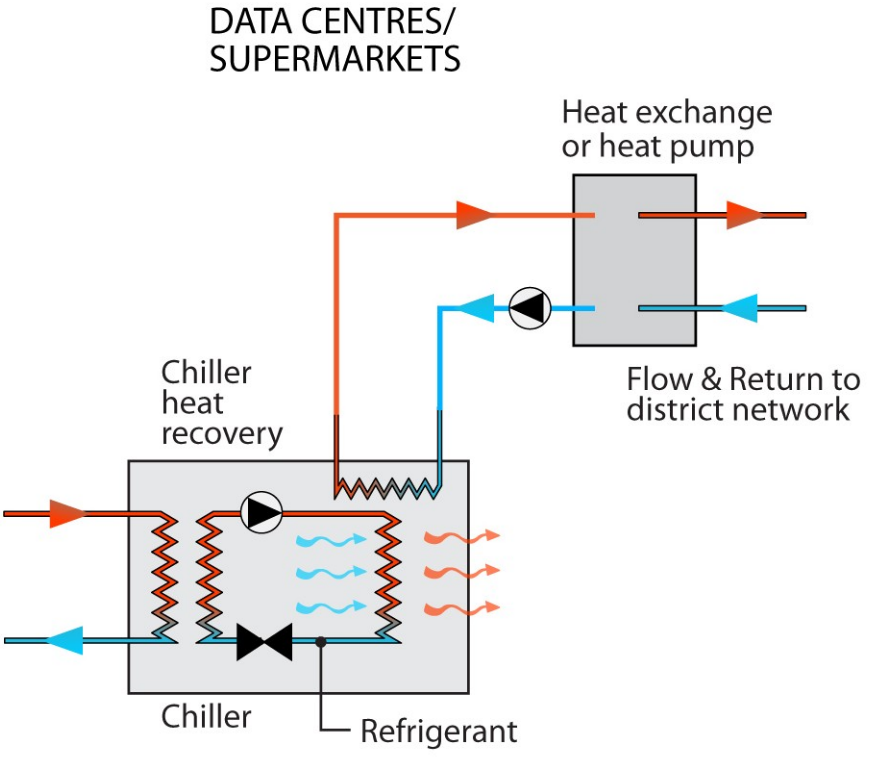
METHODOLOGY



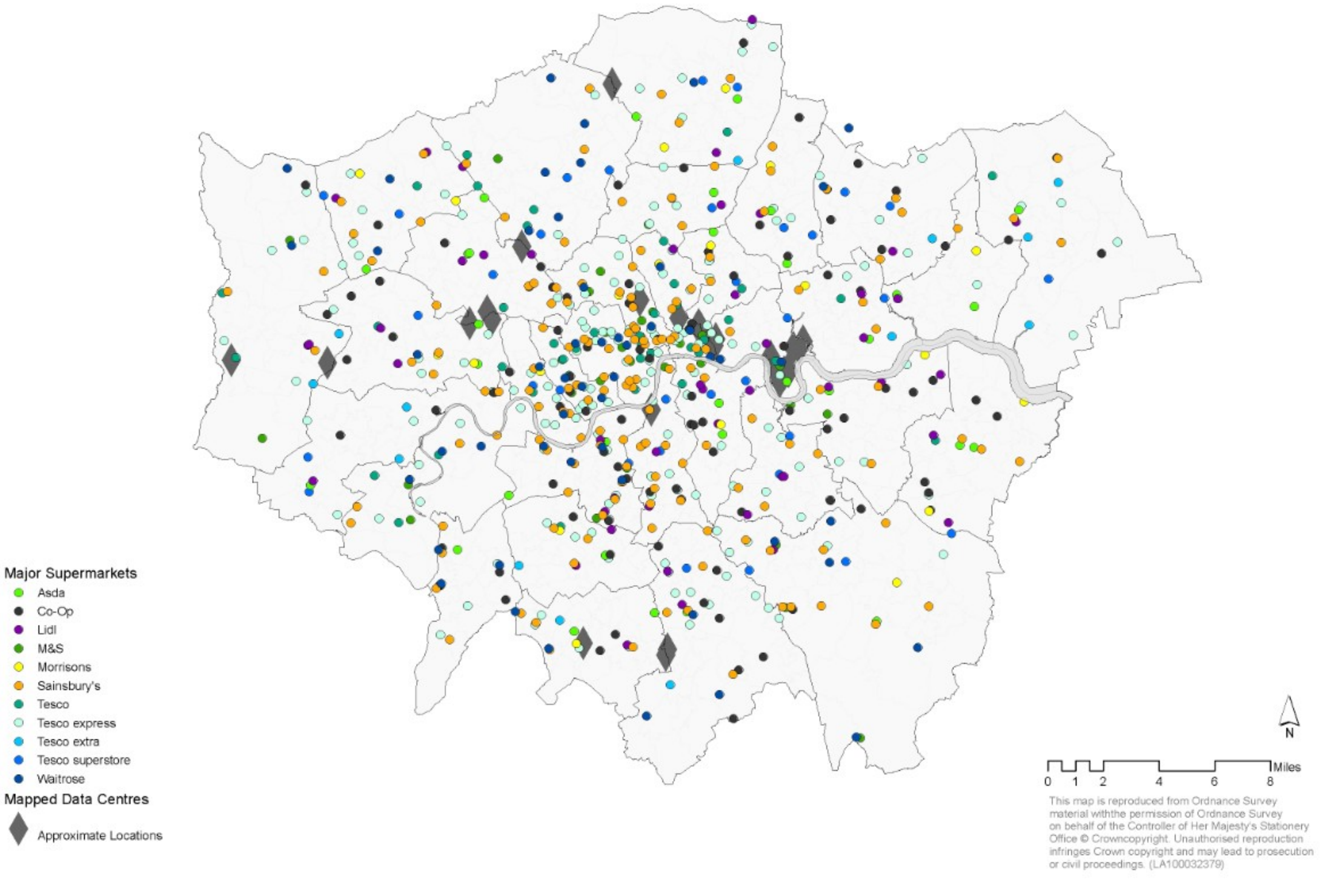
DATA SOURCES

Ref	Source	Comment
[1]	Review of calculation programs for supermarket DX refrigerating systems year-round energy consumption S.M. van der Sluis, M.Sc. IIR/IIF D1-subcommission “Refrigerated Display Cabinets” Glasgow (UK) Meeting, August 31st, 2004	Benchmarks given for annual consumption of refrigirated cabinets. Average values take for the uses given in [2]. All values in kW/m or kW/m². Assumption that all cabinets are 1m deep.
[2]	Project team assumption	Based on project team assumptions for typical store sizes. Walk in storage facilities sized to match frozen counter space.
[3]	Project team assumption	Based on typical air cooled chiller COP
[4]	Point of interest (POI) location data for GPS navigation, available from: http://poi.gps-data-team.com/	Sumpermarket mapping limited to M&S , Tesco, Asda, Lidl, Waitrose, Co-op, Morrisons and Sainsburys
[5]	http://www.datacentermap.com/	All data centre locations mapped however this is not an exhaustive list due to the confidential nature of some sites
[6]	Met Office	Historic weather data measurements at Heathrow Airport
[7]	BSRIA (2011): Rules of thumb. Guidlines for building services (5th edition)	Based on the net area of the data hall
[8]	Project team assumption	Factor reduces peak load for trater floor area to a baseload for gross floor area which can be assumed to run constantly

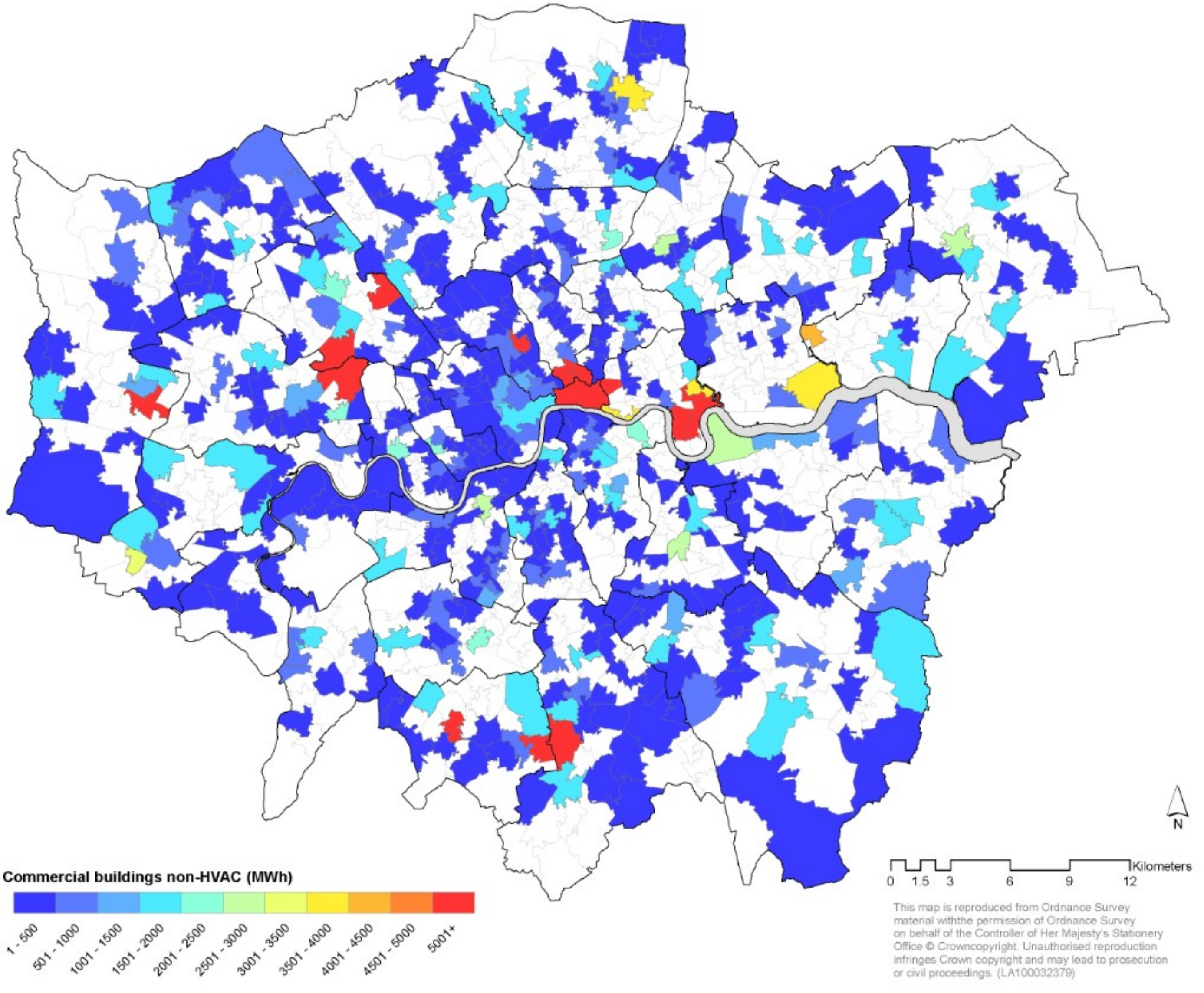
SCHEMATIC



SUPPLY MAP



HEAT DENSITY MAP 2013 Available Heat



SEASONAL VARIATION

No seasonal variation has been modelled

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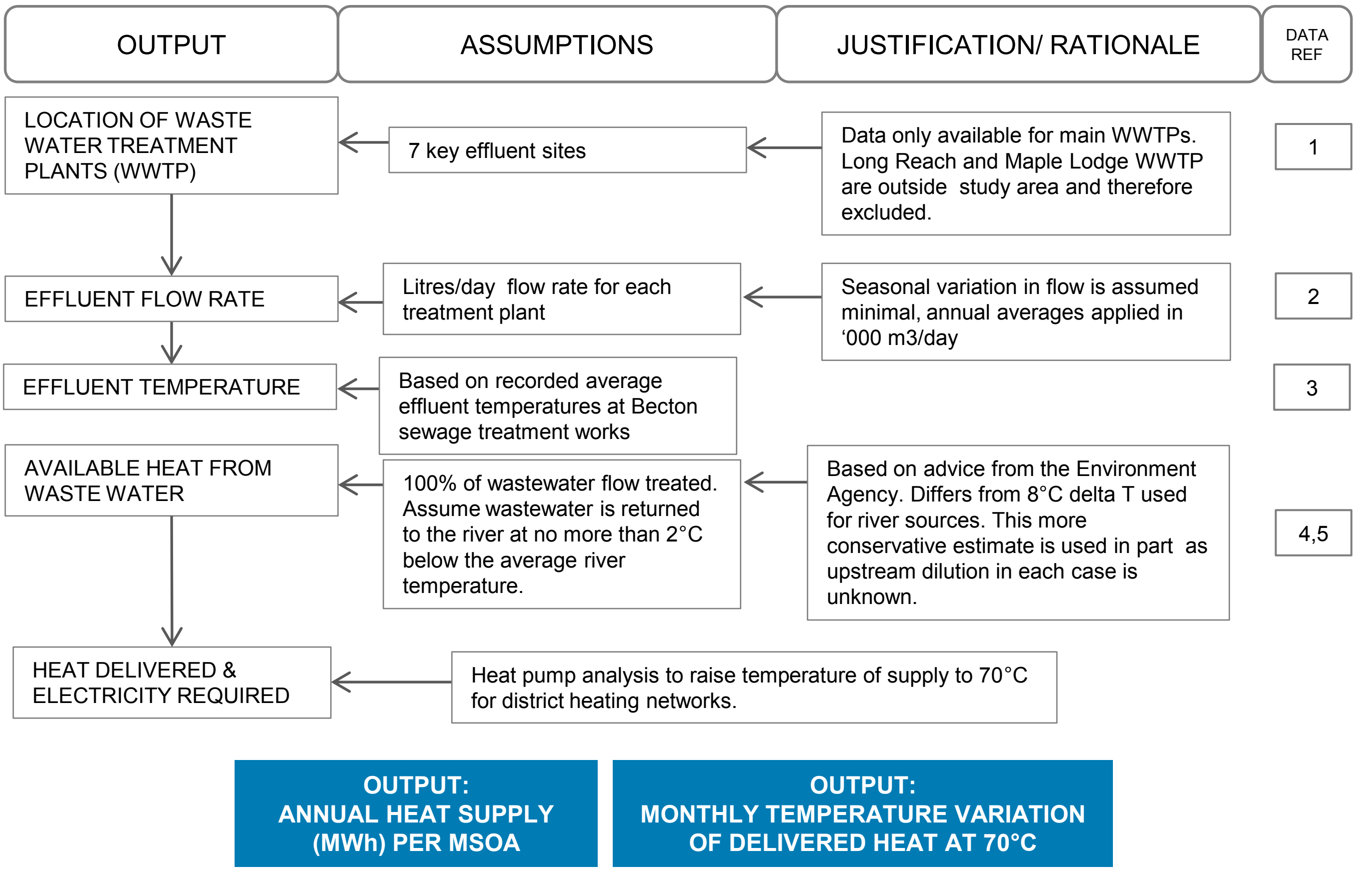
APPENDIX A

Heat Source	Water treatment works
Advisory Group	Thames Water
Date	11.01.13
Rev	01

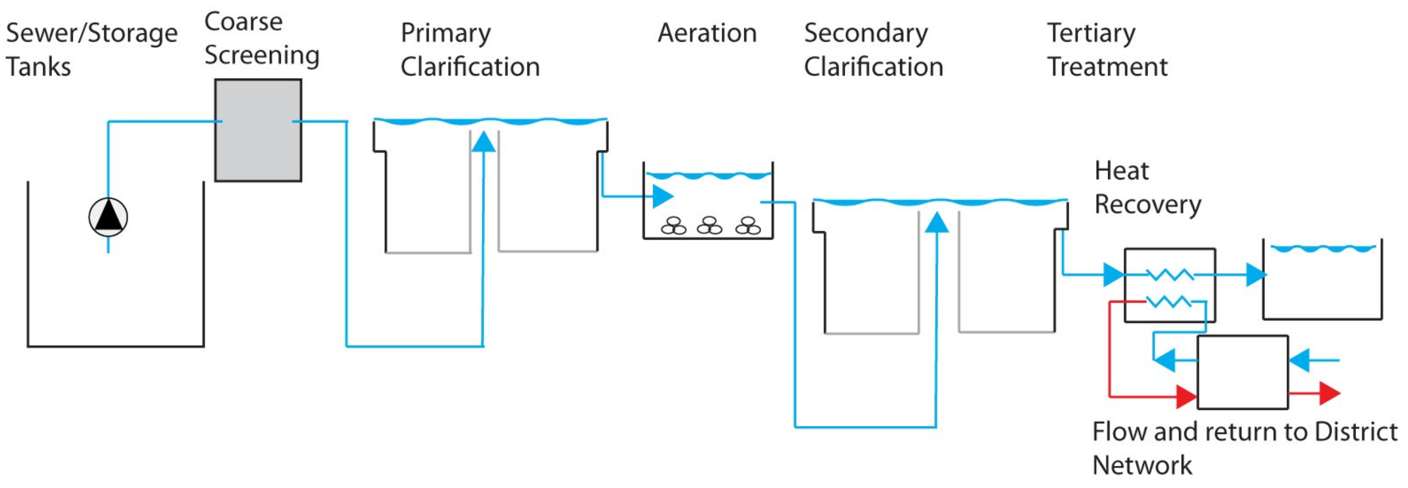
METHODOLOGY



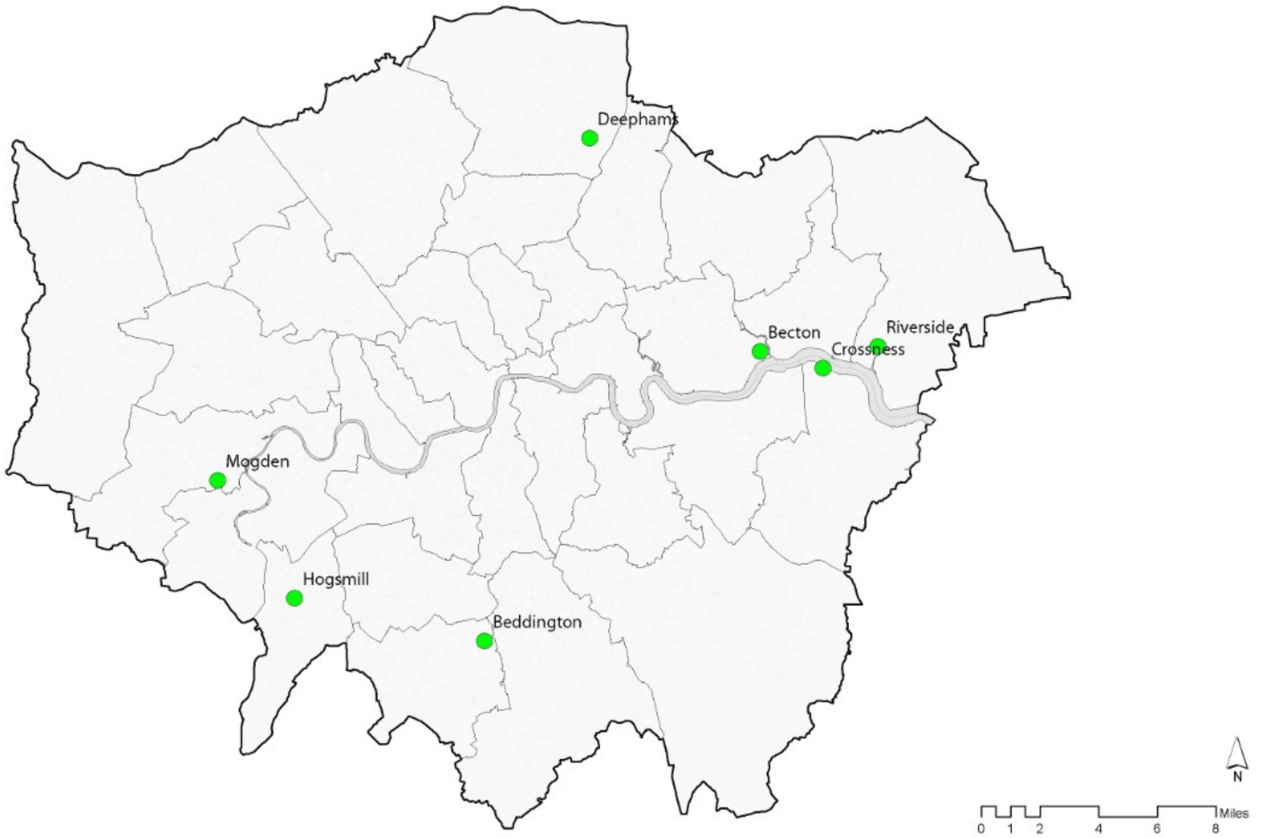
DATA SOURCES

Ref	Source	Comment
[1]	Thames Water:	GIS data files
[2]	Thames Water	Data supplied for average flow rates per site
[3]	Thames Water	Graph of recorded effluent temperatures at Becton sewage treatment works
[4]	Environment Agency: river temperature data	Historic monthly means for Teddington lock
[5]	Environment Agency	No minimum return temperatures exist: based on good practice recommendations

SCHEMATIC

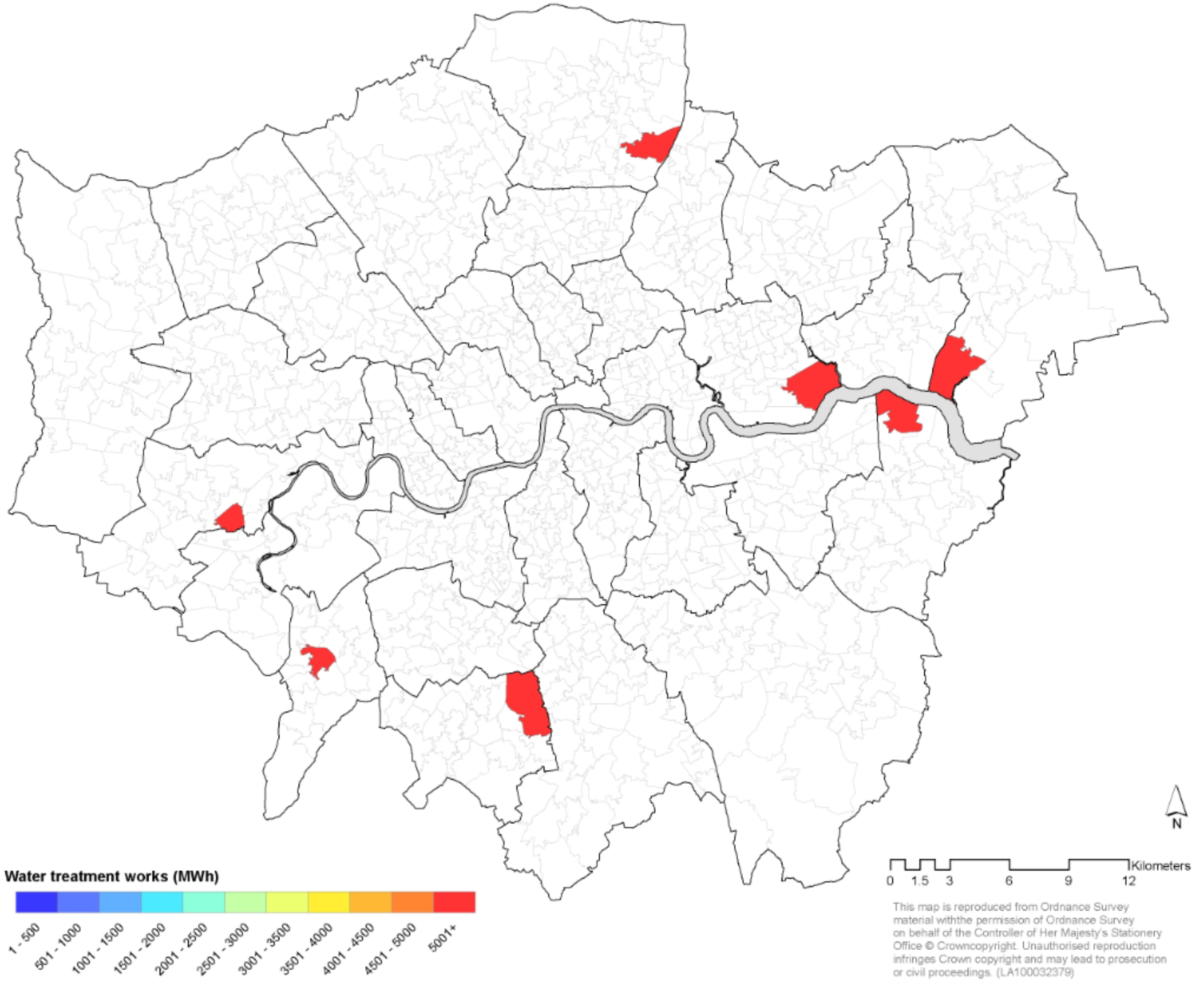


SUPPLY MAP

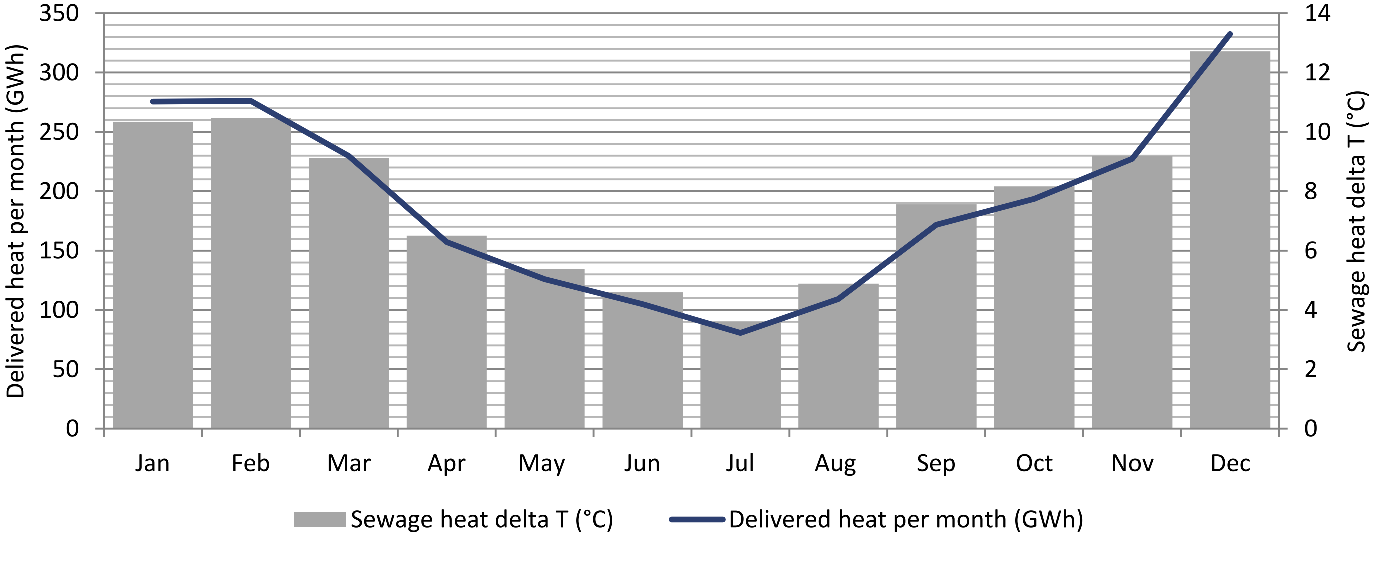


● Sewage Treatment Works

HEAT DENSITY MAP 2013 Available Supply



SEASONAL VARIATION



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APPENDIX A

Heat Source	London Underground
Advisory Group	Transport for London
Date	14.02.13
Rev	02

METHODOLOGY

OUTPUT	ASSUMPTIONS	JUSTIFICATION/ RATIONALE	DATA REF
IDENTIFY TUNNEL EXHAUST SHAFTS	Exclude: Station shafts, draught relief shafts and shafts used solely for fire safety and smoke control.	Station ventilation fluctuates between in- and outflow and so are excluded. Smoke shafts are excluded on safety grounds.	1
AIRFLOW CAPACITY OF TUNNEL SHAFTS	Airflow capacity given per shaft. Utilisation based on tunnel air velocity	Average velocity based TFL Report	2
TEMPERATURE OF WASTE HEAT	Temperature per shaft calculated	Shaft temperatures interpolated between data available for station temperatures. Station temperatures supplied by London Underground.	2
ASSESS SEASONAL VARIATION	Follows pattern of station platform seasonal variation	Included in London Underground station temperature database	2
SELECT HEAT CAPTURE METHOD	In-situ helix water pipes surrounding exhaust shaft perimeter. Negligible resistance on airflow through shaft.	Based on first principal heat transfer equations. For high level calculations other heat capture methods have been excluded in line with recommendations from TFL.	3
CALCULATION OF POTENTIAL			
HEAT DELIVERED & ELECTRICITY REQUIRED	Heat pump analysis to raise temperature of supply to 70°C for district heating networks.		

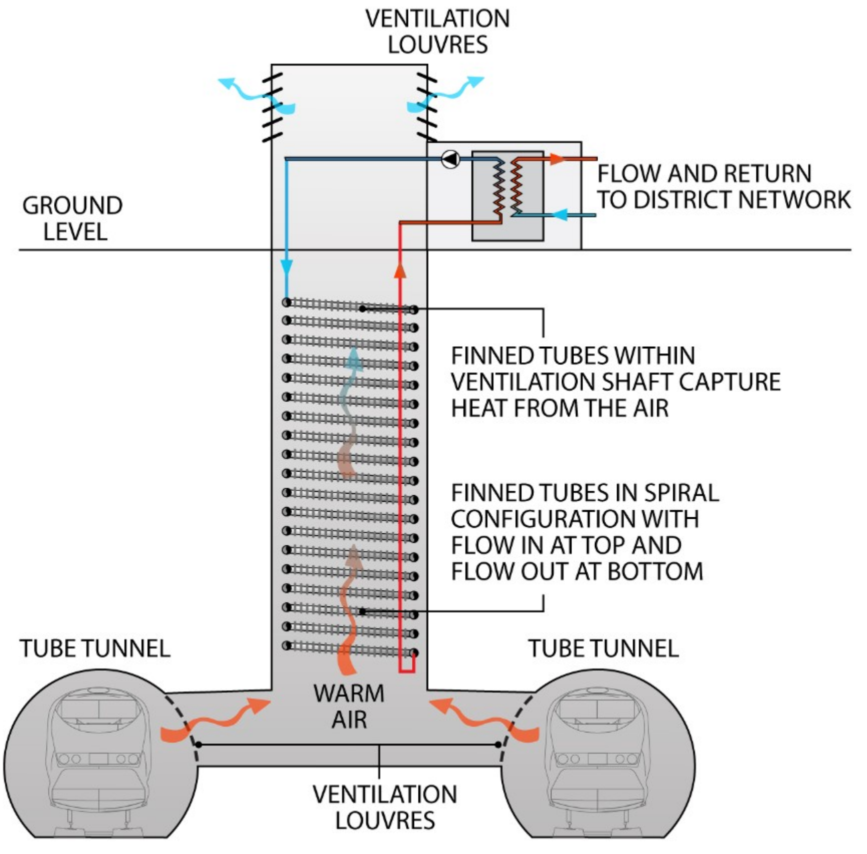
OUTPUT: ANNUAL HEAT SUPPLY (MWh) PER MSOA

OUTPUT: MONTHLY TEMPERATURE VARIATION OF DELIVERED HEAT AT 70°C

DATA SOURCES

[1]	London Underground	Location data confidential not for distribution
[2]	London Underground (2011): Heat Recovery Report	Detailed study on heat recovery from London Underground. Associated models provided for temperature data.
[3]	London Underground (2011): Heat Recovery Report	3m shaft diameter assumed

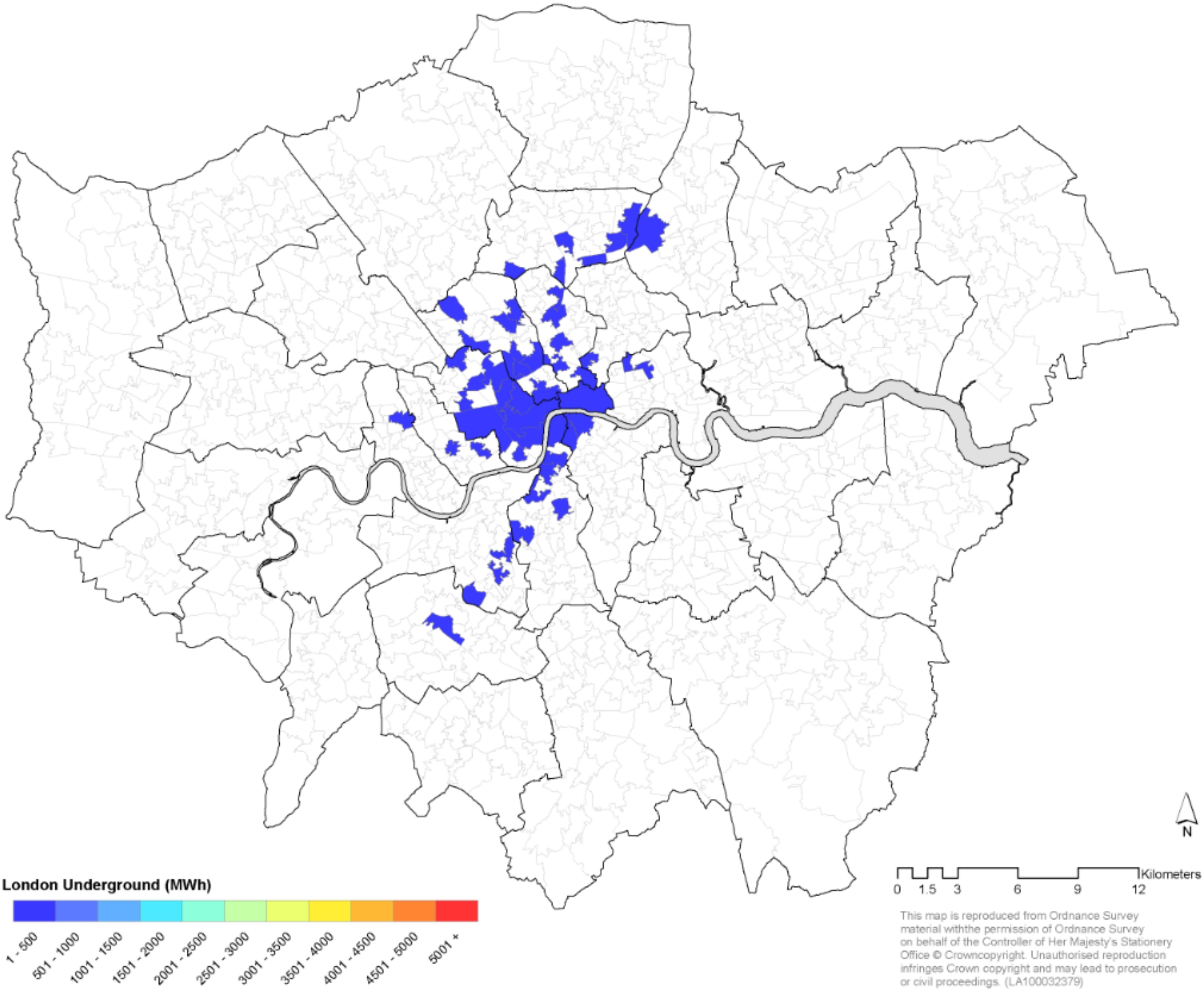
SCHEMATIC



SUPPLY MAP

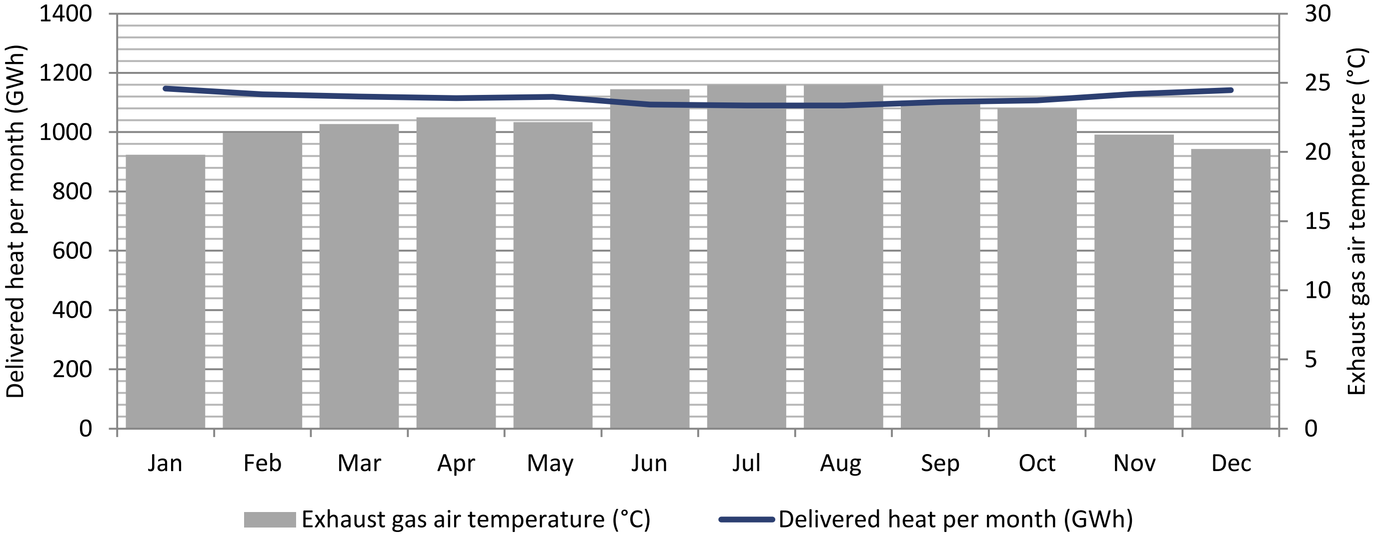
Due to sensitivity of raw data, supply map is not for redistribution

HEAT DENSITY MAP 2013 Available Heat



SEASONAL VARIATION

The amount of heat recovered in each shaft is not seasonally dependant, however the temperature available is and hence the delivered heat varies



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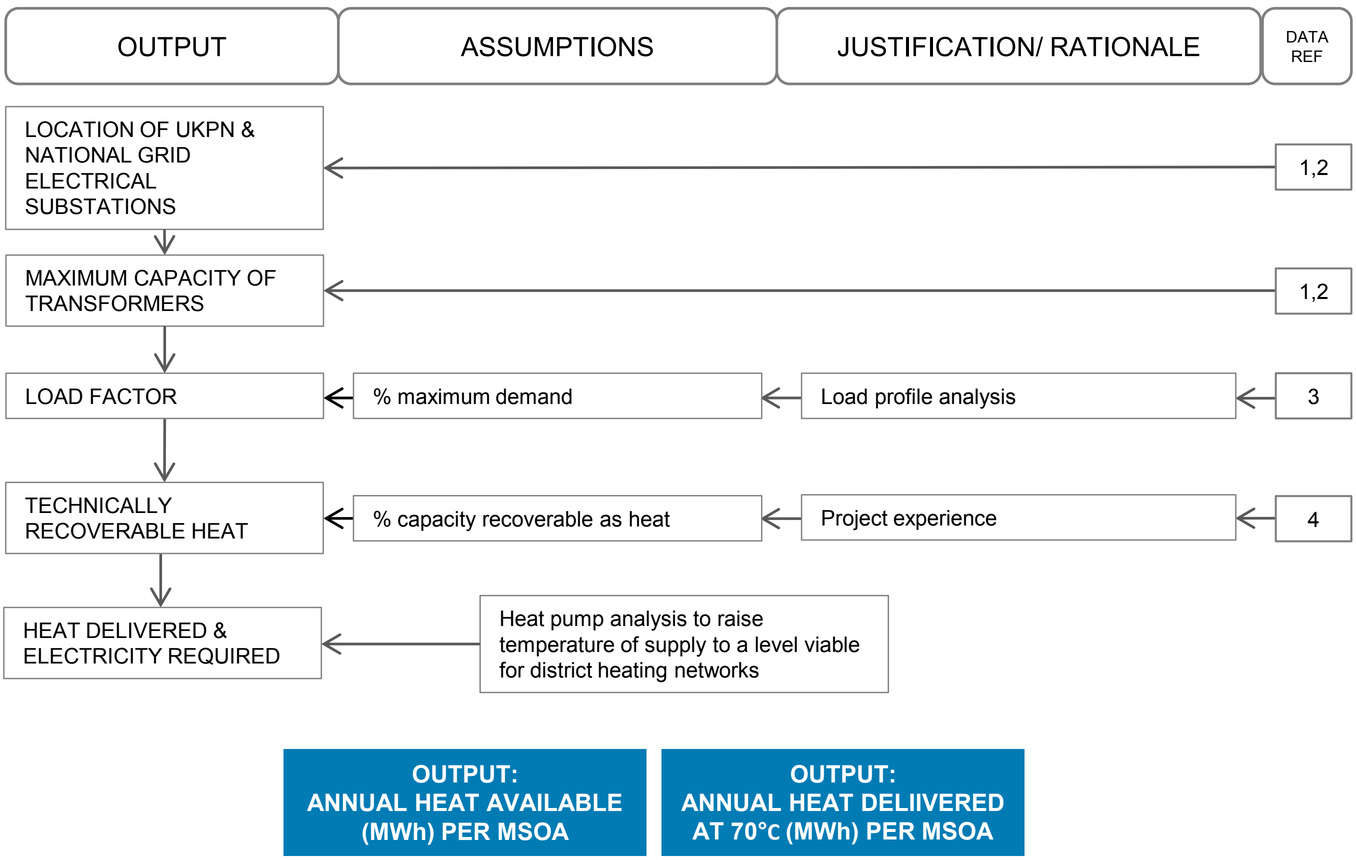
APPENDIX A

Heat Source	UKPN Electrical infrastructure
Advisory Group	UKPN
Date	11.01.13
Rev	01

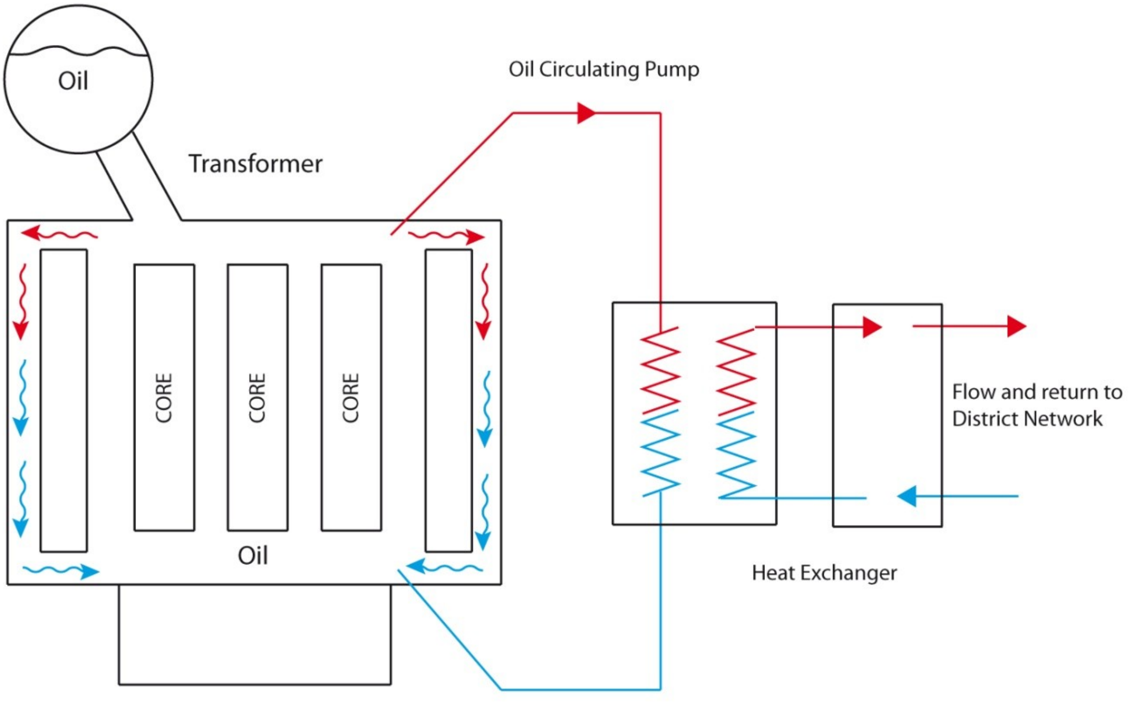
METHODOLOGY



DATA SOURCES

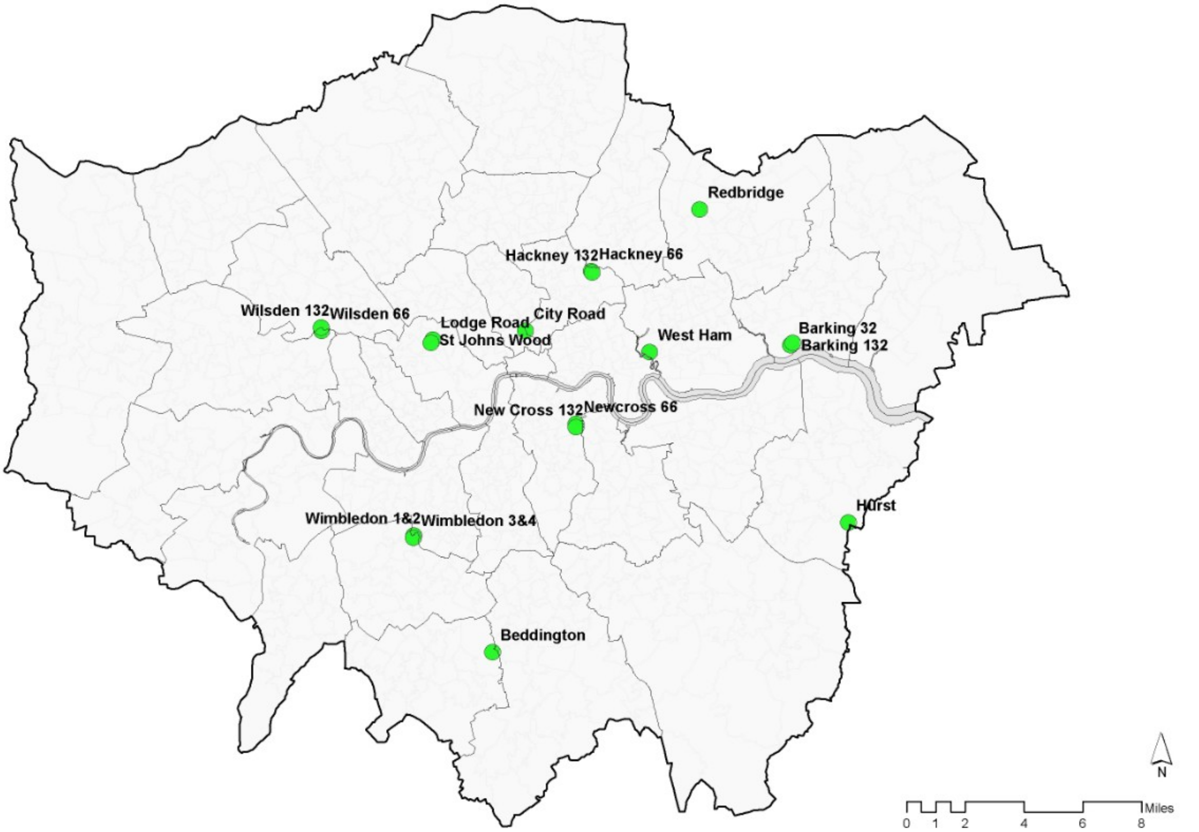
Ref	Source	Comment
[1]	UKPN (2012) Long Term Development Statement for London Power Networks: http://www.ukpowernetworks.co.uk/internet/en/about-us/regulatory-information/	Data for London transformers provided including used winter capacity and firm capacity.
[2]	National Grid	Substation Location GIS map
[3]	Various electricity profile data e.g.: DECC (2010) Energy trends, September 2010, p51: http://www.decc.gov.uk/assets/decc/Statistics/publications/trends/558-trendssep10.pdf	
[4]	Project team assumption	

SCHEMATIC



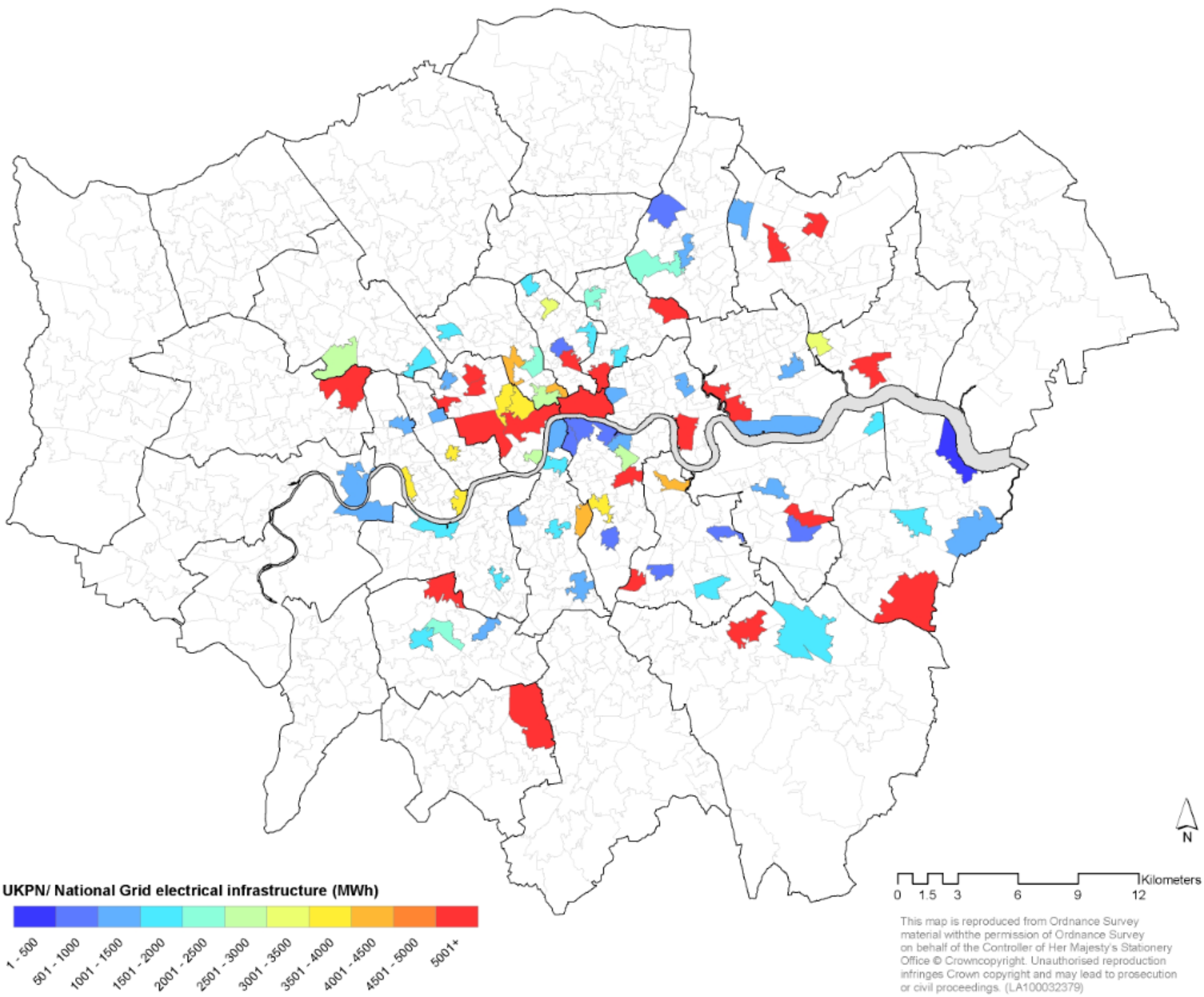
SUPPLY MAP

Due to sensitivity of raw data, supply map for UKPN is not for redistribution
(note NGT locations approximate only)



end

HEAT DENSITY MAP 2013 Available Heat



SEASONAL VARIATION

No seasonal variation has been modelled

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APPENDIX A

Heat Source	Sewer Heat Mining
Advisory Group	Thames Water
Date	18.02.13
Rev	02

METHODOLOGY

OUTPUT	ASSUMPTIONS	JUSTIFICATION/ RATIONALE	DATA REF
SEWAGE VOLUME PER MSOA	Calculated litres/person/day sewage.	Population and daily water usage (domestic & non domestic) by MSOA is known. 90% of water assumed captured as sewage.	2,3,5
LOCATION OF MAIN TRUNK SEWERS	Smaller sewers and combined sewer overflows (CSO) are excluded. All MSOAs containing trunk sewers are targeted for heat abstraction	Sewers present everywhere. Logistical restrictions limit consideration to main trunk sewers. CSO only operational in storm water flow therefore not suitable.	1
ABSTRACTION METHODOLOGY	MSOAs containing trunk sewers determined and assigned sewage from their MSOA population. MSOAs without trunk sewers are assigned to nearby trunk sewers based on spatial distribution and catchment areas	Methodology prevents double counting of sewerage availability in any one MSOA.	1
TOTAL HEAT RECOVERY POTENTIAL	Maximum 5°C abstraction from sewage energy. Minimum of 11°C	Delta T is assumed based on existing schemes. No set limit for minimum temperature. 11°C advised by Thames water and to not impact Wastewater treatment plant or double count heat abstraction after plant.	4
HEAT DELIVERED & ELECTRICITY REQUIRED	Heat pump analysis to raise temperature of supply to a level viable for district heating networks		

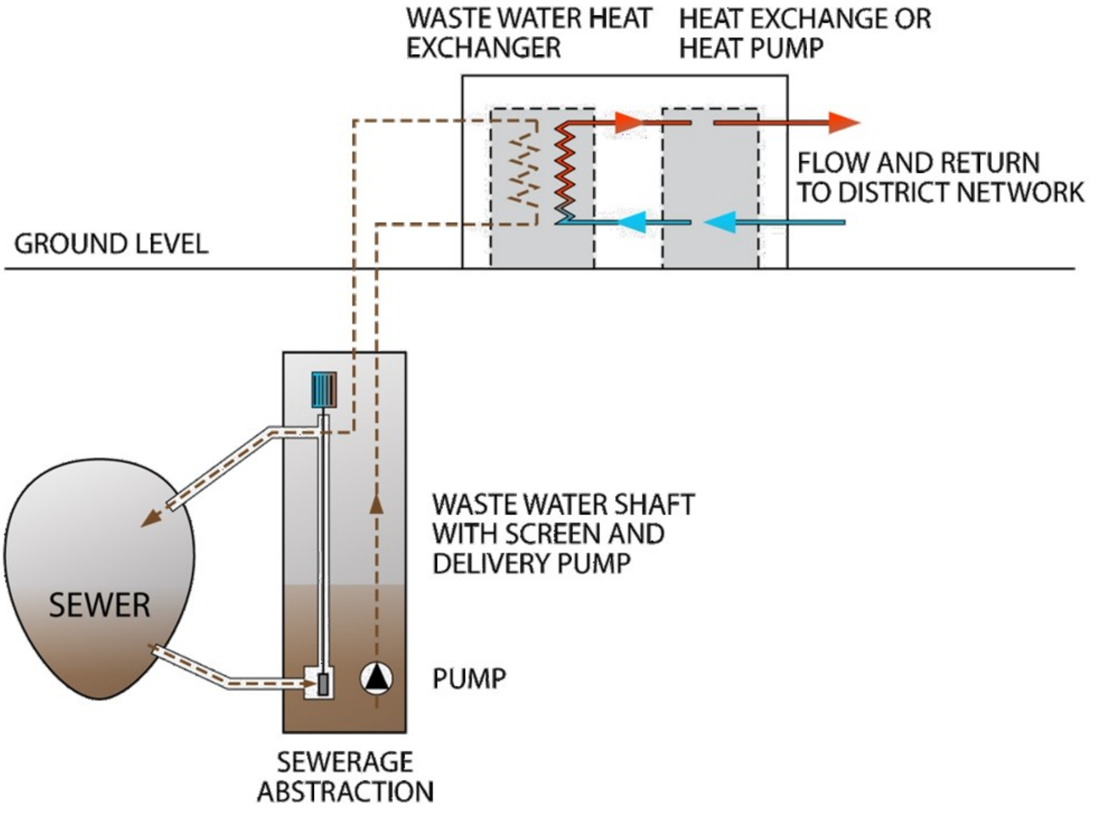
OUTPUT:
ANNUAL HEAT SUPPLY (MWh) PER MSOA

OUTPUT:
MONTHLY TEMPERATURE VARIATION OF DELIVERED HEAT AT 70°C

DATA SOURCES

Ref	Source	Comment
[1]	Thames Water: Sewer Map	Trunk sewers points abstracted from raw data and overlain as lines in GIS
[2]	Environment Agency (2010): State of the environment report (http://www.environment-agency.gov.uk/research/library/publications/41051.aspx)	Daily domestic and nonm-domestic water use per person
[3]	Office for National Statistics: 2010 Mid Year Estimates	Census population data per MSOA
[4]	Based on discussion with the designer of the sewage heat recovery system in Athlete's Village, Whistler	Delta T of 5°C
[5]	Project Team Assumption	Proportion of water usage which is captured as sewage: 90%

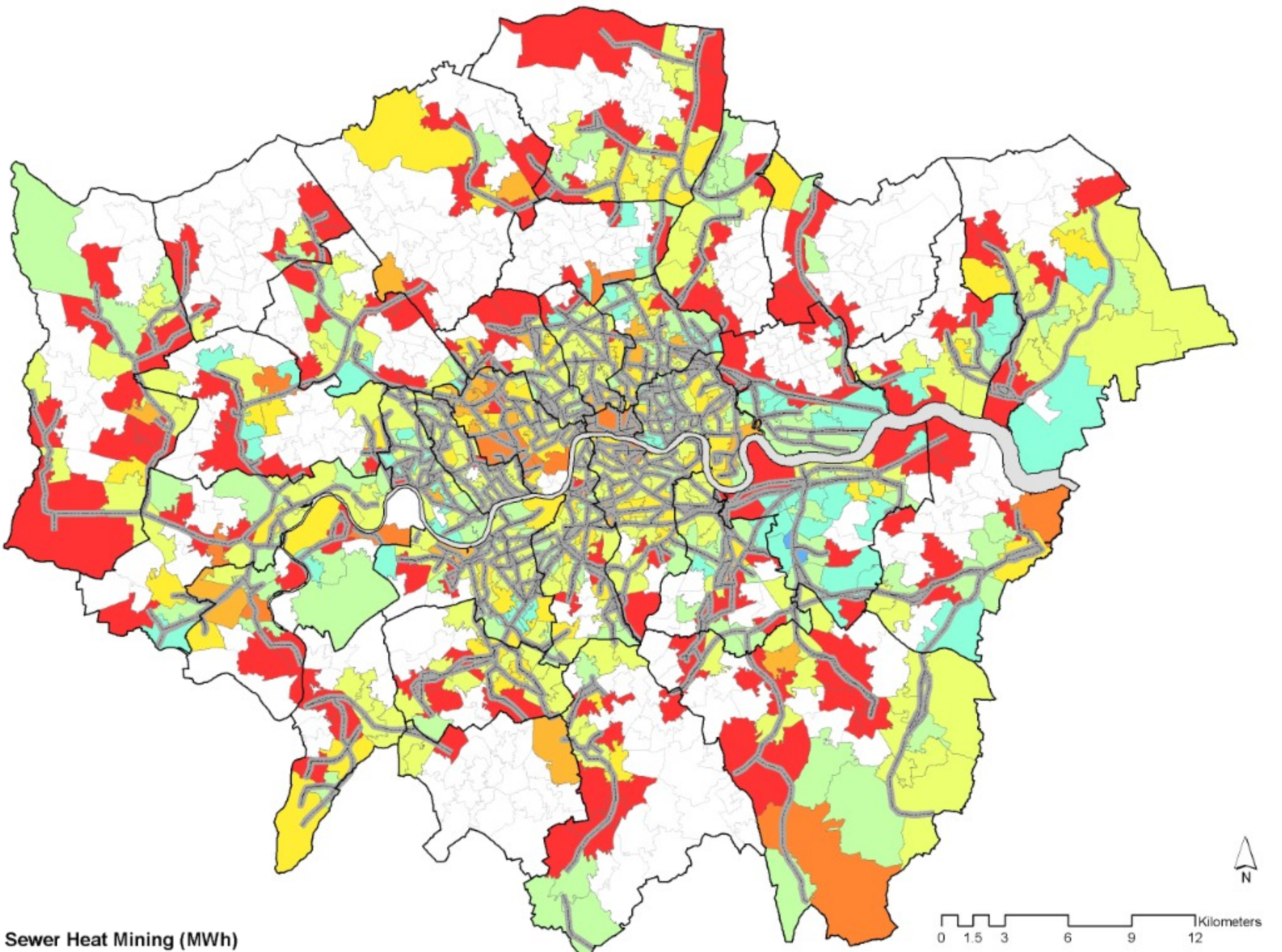
SCHEMATIC



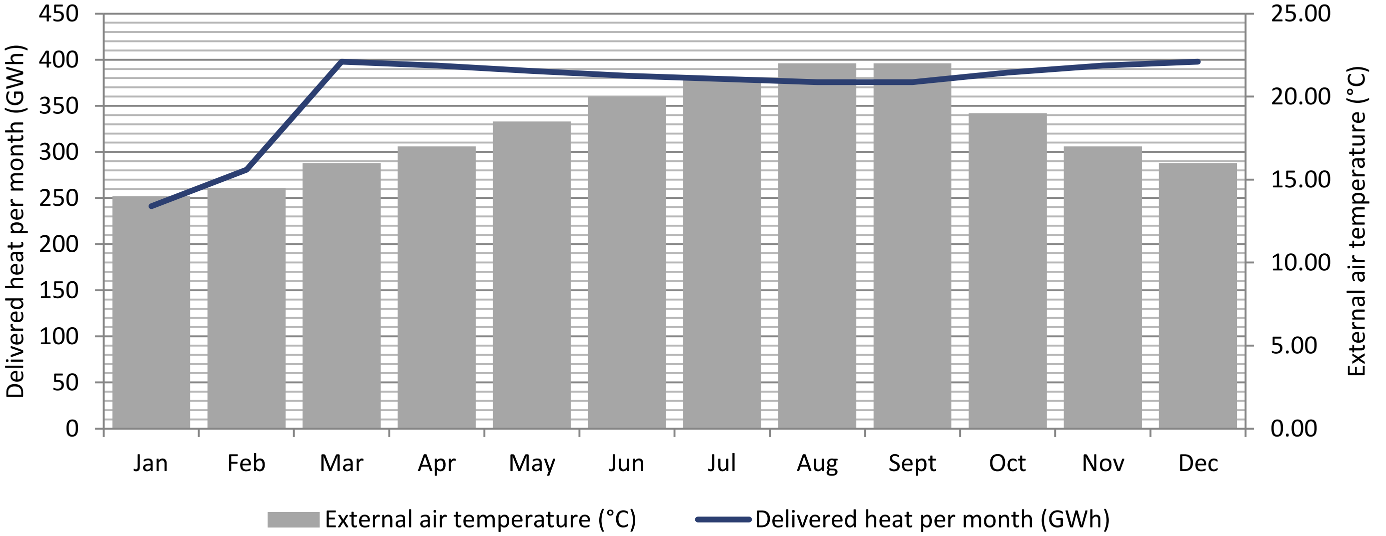
SUPPLY MAP

Due to sensitivity of raw data, supply map is not for redistribution

HEAT DENSITY MAP 2013 Available Heat



SEASONAL VARIATION



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APPENDIX B – HEAT PUMP CASE STUDIES

Case Study1: Bjerringbro Varmeværk/ Grundfos

Prepared by COWI, Denmark

CASE STUDY KEY FEATURES	
Location	Bjerringbro, Danmark
Start date	November 2012
Operated by	Bjerrringbro Varmeværk amba.
No / type of customers	Mixed, extensive existing district heating system.
Capacity (MW)	2 MW with 50 % redundancy allowed for.
Approximate network length (km)	Supplies heat to the existing extensive district heat network in Bjerringbro.
Heat source(s)	Excess heat from the cooling of production plant.
Temperature – network (flow and return, °C)	Two different temperatures for the flow (6 and 12 °C). The return is at 18 °C.
Heat pump technology	Bespoke design for this installation.
Heat pump refrigerant	R717 (NH_3)
Heat pump evaporator and condenser temperatures (°C)	Evaporator temperature 4-12 °C Condenser temperature 54-72 °C
Heat pump performance – in use (COP)	4,6
Heat pump performance – manufacturer's performance (COP)	4,6
Load factor (%) / annual operating hours (hrs/yr)	Load factor is 100 % Operation for 5840 hrs/yr

COWI

Project history / back ground

As one of the world's leading suppliers of energy efficient pumps Grundfos are keen to ensure that their main headquarters lives up to their ethos by being as efficient and as environmentally sustainable as possible. Also, as a large local employer in the area of Bjerringbo, Denmark, Grundfos are keen to be a part of the local community and actively seek opportunities to engage further with local companies.

Bjerringbo already has a district heating network, which is operated by the local heat provider, Bjerringbro Varmeværk. Bjerringbo Varmeværk were keen to work with Grundfos to deliver an efficient and more sustainable way of delivering affordable heat to the existing network.

Engineering approach

The heat pumps use the low temperature waste heat from the Grundfos manufacturing plant and upgrade it to heat which can be utilised in the district heat network.

It is planned that the heat pumps will provide heat to the Bjerringbro district heat network for 8 months of the year. During the 4 months over the summer the district heat network cannot use the heat, so the heat pumps will be turned off. During this time Grundfos will use the ground as a heat store by distributing waste heat via a network of underground pipes. During the 8 months of operation, the heat pumps not only provide a sustainable use for Grundfos' waste heat but also extract the stored heat from the ground so that the ground is cooled for the next summer.

The system is based on 5No. reciprocating compressors arranged in two groups: one group of 2-step heat pumps and a group of single step heat pumps. The plant operates so that the single step heat pumps raise the temperature of the water from approx. 38 degrees to approx. 46 degrees. Then the 2-step heat pumps further increase the temperature of the water to 68 degrees. Both evaporators and compressors are connected in series so that each heat pump meets part of the pressure differential, but does not need to meet all of it. This set up results in a significantly better COP than if they were connected individually.

The refrigerant in all of the heat pumps is ammonia (NH_3) and all of the three heat pumps have a closed refrigerant cycle to ensure that there is some security of supply should one of the heat pumps fail.

The connection to the district heat network is designed to allow a flexible temperature to the network from the heat pumps. There is a CHP and boilers on the same connection, and so the water from the heat pumps can be mixed up to the required flow temperature of the network.

The heat pumps have a fully automated management system that is integrated with the controls of the overall district heating network. This allows the operation of the different heat production units on the network to be optimised at all times.

Economic issues

This is a commercial project implemented by Grundfos in partnership with Bjerringbro Varmeværk. Whilst it is designed to be an environmentally sustainable showcase, it is also based on am economic model which make s it viable for both parties.

Success factors

For both Grundfos and Bjerrignbro Varmeværk the key success factor is to prove that waste heat can be used in an economically and environmentally sustainable way as a viable heat source for input to an existing district heat network.

One of the largest barriers to implementation of this project was to work out how the administration fits with the legal and tax laws. Both regarding supply of heat to a district heat network and the methods by which waste heat is dealt with from industry.

Case Study 2: Frederikshavn

Prepared by COWI, Denmark

CASE STUDY KEY FEATURES		
Location	Frederikshavn, Denmark	
Start date		
Operated by	Forsyningen Frederikshavn	
No / type of customers	Existing extensive district heat network providing heat to the town of Frederikshavn.	
Capacity (MW)	1 MW heat pump capacity	
Approximate network length (km)	Existing extensive town-wide system.	
Heat source(s)	Sewage water. Average temperature of 12 °C (cooled down to 8 °C by the heat pump)	
Temperature – network (flow and return, °C)	Forward temperature in the DH network: 80 °C. Return temperature 40 °C.	
Heat pump technology	Transcritical CO_2 heat pump	
Heat pump refrigerant	CO_2	
Heat pump evaporator and condenser temperatures (°C)		
Heat pump performance – in use (COP)	2.8	
Heat pump performance – manufacturer's performance (COP)	2.8	
Load factor (%) / annual operating hours (hrs/yr)	App. 6,000 hours per year	

Project history / back ground

In 2006 Frederikshavn was designated as an "Energy City" by Danish experts, with an aim to make it fully sustainable by 2015. A task force was set up in order to identify relevant projects to meet this aim, with participants including Aalborg University, Forsyningen Frederikshavn and DONG Energy. One of the identified projects was to establish a 1 MW heat pump at the sewage plant to utilise the heat from this waste water stream into the existing district heating network.

Like many towns in Denmark, Frederikshavn already has an extensive district heating network throughout the town. In Frederikshavn the heat is provided by a combination of natural gas fired CHP, traditional boilers and a waste to energy plant. The total capacity of the plant on the network is approximately 65 MW, and approximately 224,460 MWh of heat every year is supplied to buildings across the town.

It was important that the heat pump ran on sustainable energy and it was therefore set up to run using electricity directly from DONG Energy's nearby offshore wind test site. The district heating system is controlled to ensure that the most viable fuel is used at any one time so whenever there is adequate wind resource and heat demand the heat pump will run to offset heat produced using natural gas. This works effectively and the heat pump runs on average 6,000 hours per year.

Engineering approach

The heat pump utilises the waste water flow from the sewage plant as a low temperature heat source. The sewage has an average temperature over the year of 12.8 °C, with a minimum of 7.6 °C and a maximum of 18.1 °C.

The heat pump itself produces 1 MW of heat with a COP of 2.75 (when the sewage flow is 12.8 °C). It uses a transcritical cycle with CO_2 as the refrigerant. The temperature of the return line from the district heat network is raised from 40 °C to 80 °C by the heat pump. Since it is used only for providing heat to the district heat network, the heat pump is not intended to be reversible.

As mentioned above the heat pump is one of a number of production technologies used to provide heat to the district heating network in Frederikshavn. Due to the nature of its operation the waste-to-energy plant provides the base load and the gas-fired CHPs and boilers to provide additional heat where necessary. The heat pump is always run to replace heat which would otherwise be produced by natural gas and, since it runs on renewable energy, therefore directly offsets the carbon from the burning of gas. Control of the entire network is via a SCADA system.

Economic issues

The idea behind an 'energy town' such as Frederikshavn is to provide a test bed for different sustainable technologies. However, it is important that the technologies are viable from a technical and economic viewpoint and replicable elsewhere.

For this project a feasibility study was carried out and the result was that the heat pump would have a simple pay back time of approximately 5 years. The reason for this is that the heat from the heat pump substitutes heat production at a gas fired CHP plant and a gas fired heat only boiler at relatively high costs.

Note that, in Denmark, district heating companies have a responsibility to supply a service to the customers at the best price possible and are not permitted to make a profit. Any profit must be re-invested in the network (on projects which are approved by the municipality) or used to reduce the price of heat to consumers. It is worth keeping this in mind when considering the financial viability of projects undertaken in Denmark as the measurement of economic success may be different to elsewhere.

Success factors

Frederikshavn has an established and extensive district heating system with a number of heat production plants of different types. The introduction of a 1 MW heat pump into a network with a capacity of 65 MW and a number of different plants is therefore relatively easy to manage in terms of security of supply, since the entire network does not rely on the effective operation of the heat pump. This is a very good example of utilising and integrating different sources of supply to fully utilise the energy available from each different source at a different time.

This project highlights the importance of a district heat network in terms of flexibility of supply. With a heat network the useful product is delivered directly to the customer and how that product is produced can be flexible. This allows the supply of heat to become increasingly more environmentally sustainable over time as further renewable technologies are integrated into the network.

An effective control system of the entire network makes this project viable both from a sustainability point of view and also economically. The control system needs to be able to control the network according to the demand and available heat sources. To maximise sustainability the system needs to use the most sustainable fuel available and to maximise economic viability the cheapest fuel available is preferable. These factors need to be constantly monitored to ensure the system is optimised at all times.

Perhaps the largest technical challenge with the utilisation of heat from waste water is the fouling of the heat exchangers. This has presented great challenges in the implementation of this project.

Case Study 3: North Saanich WWTP Heat Recovery

Prepared by DEC Engineering, Canada

CASE STUDY KEY FEATURES	
Location	North Saanich, British Columbia, Canada
Start date	June 2011
Operated by	Capital Regional District
No / type of customers	1 Rec Centre (possible expansion to school, 100 homes, greenhouses)
Capacity (MW)	2.35
Approximate network length (km)	0.9
Heat source(s)	Treated effluent heat exchange
Temperature – network (flow and return, °C)	10/15 °C Winter/Summer Supply 8/13 °C Winter/Summer Return
Heat pump technology	Commercial water to water
Heat pump refrigerant	R410a
Heat pump evaporator and condenser temperatures (°C)	10/15 °C Winter/Summer EST 50 °C LLT
Heat pump performance – in use (COP)	5.7
Heat pump performance – manufacturer's performance (COP)	3.4
Load factor (%) / annual operating hours (hrs/yr)	77%

Energy Centre

Valve Chamber

Mini-Plant

One of Two Heat Pumps in Mini-Plant

Project history / back ground

This project was a pilot to demonstrate the potential of recovering thermal energy from clean effluent for the Capital Regional District (CRD). The CRD is the regional government for the 13 municipalities and three electoral areas that are located on the southern tip of Vancouver Island, including Victoria the capital of British Columbia, Canada.

DEC was selected to design this project due to its proven experience, designing and constructing Whistler Athletes Village District Energy Sharing System (DESS) that also recovers energy from clean effluent for heating and cooling the village. A DESS is a two-pipe ambient temperature system that allows the use of either extracted or contributed energy. Residential buildings requiring heating during winter days can be supplied by office buildings that require cooling during occupancy. Meters in each building track as to whether the client is contributing or using energy from the DESS.

DEC designed the thermal energy from effluent system at the Saanich Peninsula Wastewater Treatment Plant (WWTP). The project consists of a low temperature DESS that recovers heat from the WWTP and circulates the heat through a two pipe closed loop system to the surrounding facilities. These facilities include an existing pool, school, residential neighbourhood, greenhouses, and the waste water treatment process building. This type of system will displace the consumption of natural gas and is projected to reduce GHG emissions by over 95% compared to conventional heating technologies.

The budget drove a phased system with allowance for future expansion. The current DESS includes a heat exchange plant with capacity to utilize most of the waste heat available from the effluent. Building size, piping headers and electrical feeds are all sized for the future capacity to feed all the intended buildings, but only 50% of the pump and heat exchange capacity is included in the first phase. There is space within the heat exchange building for the installation of the other 50% of the pump and heat exchange capacity.

The DESS piping is also sized to handle all the potential connected buildings and the valve chamber is arranged to allow future connection to the Kelset elementary school and Dean Park.

Funding was received from the federal Gas Tax Agreements Innovations Fund for construction of a system to recover thermal energy from the effluent of the Saanich Peninsula WWTP to serve the following facilities:

a) Saanich Peninsula WWTP (building heating);
b) Panorama Recreation Centre (PRC) pool facility;
c) Centre for Plant Health (CPH);
d) Kelset Elementary School;
e) Dean Park residential neighbourhood (approximately 500 single family dwellings).

The system is also designed to recover the remaining waste heat from the PRC ice rink refrigeration system to augment the heat available from the WWTP and provide a greater reliability and efficiency. A portion of the available waste heat is already being utilized by the pool, but this accounts for only about 20% of the total available.

The following diagram Figure B-0-1 shows the phasing of the North Saanich WWTP DESS. Phase 1 is completed and fully operational.

In 2012 the Union of British Columbia Municipalities awarded the project an Honourable Mention in the Best Practices category.

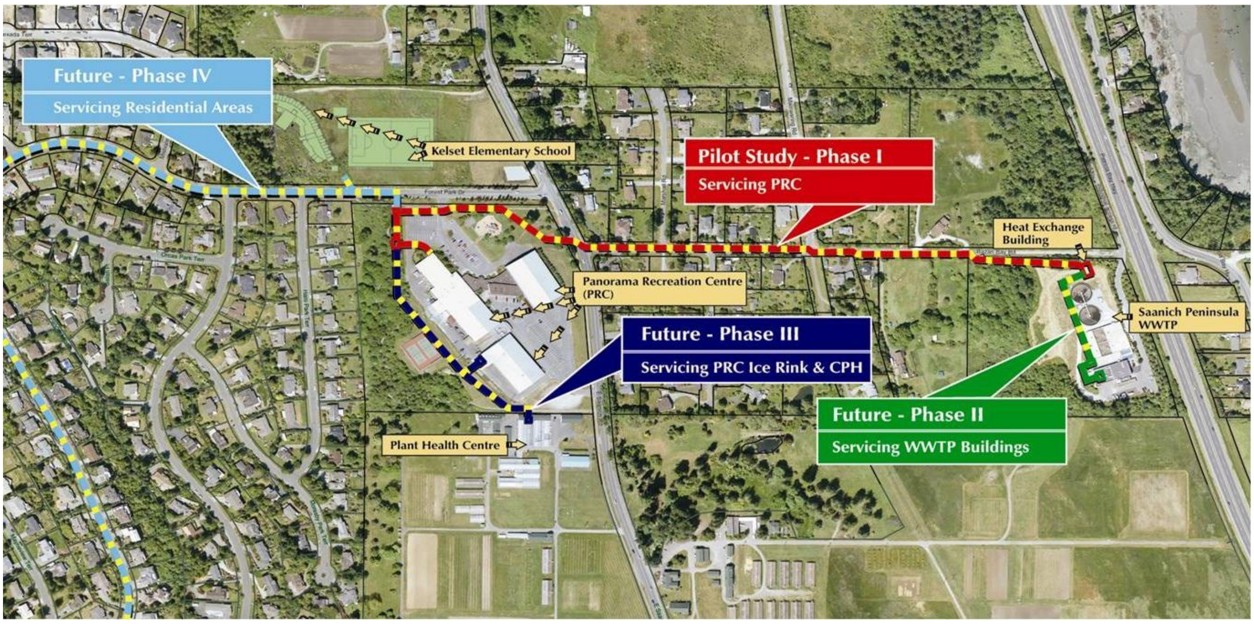


Figure B-0-1: Scheme phasing

Engineering approach

Off the shelf (TRANE) heat pumps have been designed to run autonomously based on a call for heating or cooling from the building needing heating or cooling and drive the circulating pumps and control valves that are connected to the energy source. The heat pumps are equipped with pre-packaged Direct Digital Controls (DDC) and logic that is optimized to get the best efficiency out of the heat pumps and protect them against a variety of conditions. For example, ensuring proper flows and temperatures are maintained to prevent the heat pumps from tripping out.

It is important to note that the efficiency of a heat pump is dependent on the supply side water temperature and the output load side water temperature being demanded by the building calling for heating or cooling. Heat pumps also have specific constraints related to the flow rate and temperature drop across both the supply and demand side of the heat pump. This limits the ability of the DES to provide any more than the required flow rate to the heat pump. However, increasing the loop temperature may improve the efficiency at which the heat pump runs during heating mode, as long as that temperature does not exceed the maximum inlet temperature for the heat pump.

For the Panorama Recreation Centre the heat pumps have been placed in a pre-packaged container referred to as a mini-plant. The primary reason a mini-plant was used is due to the lack of space and structural support within the pool building being serviced to support the required heat pump. The mini-plant provides a pre-packaged enclosure for the heat pumps with all the circulating pumps, plumbing, and wiring pre-connected and are a natural extension of the building control systems. As noted above, the (pool) buildings connected to the mini-plant drives the call for heating (or cooling) and does not require any external oversight or control.

The TRANE Multi-Stack heat pumps use R410a as the refrigerant and have achieved an annual average COP of 5.7.

Control

The primary functions of the CRD DESS control system are to maintain a DESS supply temperature and maintain a pressure difference between the supply and return pipes. The secondary function is to optimise the efficiency of the system. The temperature is controlled by varying the flow rate of the effluent through the heat exchangers. The pressure difference is controlled by varying the speed of the circulating pumps. A critical technique in maintaining efficiency is using energy from the effluent when effluent flow rates are high by increasing the DESS temperature to provide thermal storage within the DESS pipes for use when building loads are high.

When there is no energy demand from the system, the bypass control valve opens wide and the two heat exchanger control valves are closed.

The control system for the heat exchange building interoperates with the all the equipment within the connected buildings based on sensors located within the buildings and remote sensors located in the valve chamber in the Saanich WWTP DESS piping. The controls will also respond to signals from buildings attached to the DESS as well as other plants that will be added to the system in later phases. These sensors and controls have been integrated into the CRD's SCADA control system, with a gateway to communicate with the DDC controls.

This system is the first stage of a network of systems that will communicate to share thermal energy and optimize energy use on a continuous basis, 24 hours per day and 365 days per year.

Economic issues

The first phase of the CRD district energy sharing system—distributing reclaimed heat to the Panorama Recreation Centre swimming pool--was commissioned in June 2011. In the first four months of operation, the system delivered 173 MWh of recovered heat from the effluent, saving 32 tonnes of CO_2 equivalent GHG emissions. The net annual savings in the first year of operation are projected to be $77,000 with a further $14,000 saving in Greenhouse Gas Credits for a total annual savings of $91,000.

The following table outlines the cost savings associated with the DESS utility and projected savings of the future system.

LOADS	EXISTING			NEW				
CURRENT DESS UTILITY								
BUILDING	Annual gas kWh	Annual htg kWh @ 80% efficiency	Gas cost	% of heating from HP	HP electricity cost	Pump electricity cost	Gas cost	Net savings
HX BUILDING						$9,000		-$9,000
OLD POOL	1,814,000	1,451,200	$80,539					
NEW POOL	3,265,200	2,612,160	$161,078	95	$28,910	$2,891	$8,054	$121,223
FUTURE DESS UTILITY								
WWTP	787,400	629,920	$41,300	95	$6,972	$697	$2,065	$31,566
GREENHOUSE	1,384,000	1,107,200	$67,024	90	$11,609	$1,161	$6,702	$47,552
SCHOOL	235,000	188,000	$12,390	95	$2,081	$208	$620	$9,482
DEAN PARK	5,500,000	4,400,000	$250,000	95	$48,697	$4,870	$12,500	$183,933
TOTALS	11,171,600	8,937,280	$531,792		$98,268	$18,827	$29,941	$384,756

Success factors

For the CRD the key success factor was to demonstrate that heat can be recovered from a wastewater treatment plant and used to displace natural gas in existing buildings in an economically and environmentally sustainable way.

There are over 10MW of thermal energy available at the Saanich Peninsula Wastewater Treatment Plant, of which approximately 2.35MW are currently used. One of the largest challenges for this project was to establish the phasing of this project in such a way as to minimize the first phase capital cost, without limiting the ability of the system to recover the full 10MW. A simple supply and return distribution system was setup for the first phase with a valve chamber connecting the primary load to the source.

The second challenge was to recognize that although the first phase was entirely heating, that the subsequent phases including the school and the residential neighbourhood would need both heating and cooling. Therefore the valve chamber was setup in such a way as to allow the future development to be configured as a two pipe DESS with a warm and a cool pipe. Buildings in heating draw off of the warm pipe and discharge chilled water to the cool pipe, buildings in cooling draw off of the cool pipe and reject warm water to the warm pipe. If the future DESS needs heating, it simply draws off the warm supply line, and if it needs cooling it draws off the cool return line. Controls manage the net balance between the heat exchange building and the rest of the network.

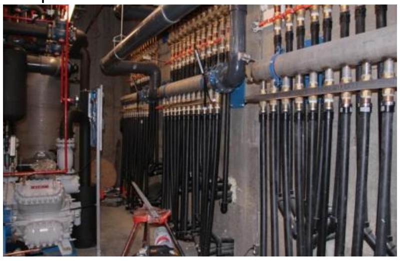
These principles have been integrated into two other projects including Westhills and Capital City Centre.

Case Study 4: Westhills District Energy Sharing System

Prepared by DEC Engineering, Canada

CASE STUDY KEY FEATURES	
Location	Langford, British Columbia, Canada
Start date	April 2010
Operated by	Sustainable Services Ltd.
No / type of customers	250 houses + 68 condominiums (expanding to 500 homes)
Capacity (MW)	1.9
Approximate network length (km)	3
Heat source(s)	Geoexchange vertical borefield and heat pump, ice rink heat recovery, natural gas boilers
Temperature – network (flow and return, °C)	13 – 18 °C Warm Pipe 8 – 15 °C Cool Pipe
Heat pump technology	HOMES: a) Commercial, water to air reversible with water to water for DHW b) Commercial, water to water heating only DESS: Custom water to water
Heat pump refrigerant	HOMES: R410a DESS: Ammonia
Heat pump evaporator and condenser temperatures (°C)	HOMES: 15 °C EST 50 °C LLT (Heating) DESS: -5 to 12 °C EST 15 °C LLT
Heat pump performance – in use (COP)	HOMES: n/a DESS: 8.3
Heat pump performance – manufacturer's performance (COP)	HOMES: Space Heating: 4.2 DHW: 3.8 DESS: n/a
Load factor (%) / annual operating hours (hrs/yr)	System: 100% DESS Heat pump: 48%

Geoexchange headers in Energy Centre and ammonia compressor at left



In building heat pump for heating, cooling and domestic hot water

Built Phase 2A with cut away showing warm (red) and cool (blue) pipes

Reclaimed water line (Purple Pipe) ties into DESS cool line

Project history / back ground

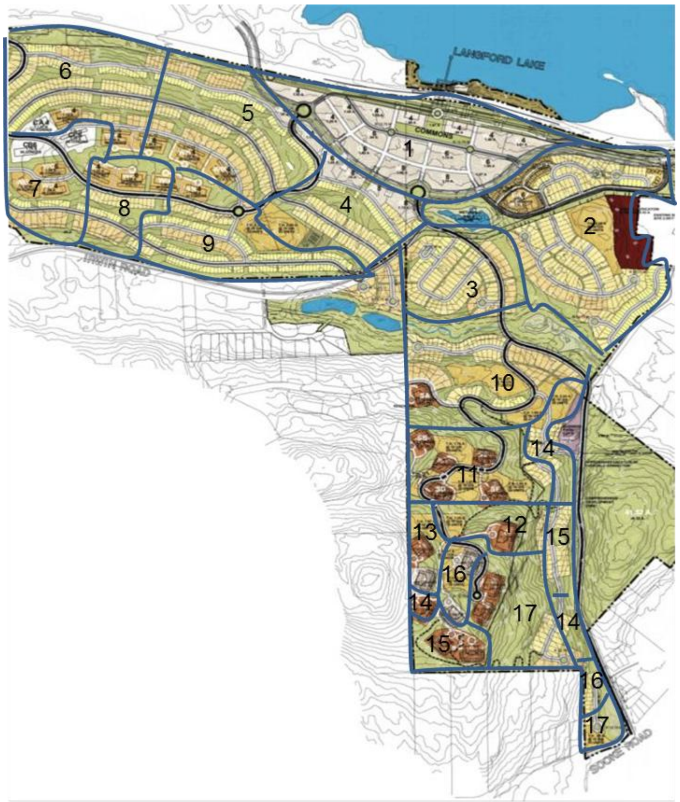
Westhills is a 210-hectare master planned community under development in Langford, a suburb of Victoria, British Columbia, Canada. Upon completion, the community will be comprised of approximately 6,000 residential units and 5,000,000 square feet of commercial, retail, educational, and cultural buildings.

Originally Westhills was planned to be one of Canada's first LEED-ND pilot's. LEED-ND is the Canadian Green Building Council's standard for Leadership in Energy and Environmental Design for Neighbourhood Design. Overtime, the costs and administrative overhead associated with LEED proved too high, and Westhills and the City of Langford adopted a LEED equivalency program.

In fact, it was the costs of developing green communities caused Westhills to engage Erik Lindquist and SunGen Sustainable Developments Inc. (SunGen) to find a way to design, build and finance Westhills green energy and water infrastructure in a manner that would protect the profitability of the development. These financial constraints, ultimately demanded the integration of three key design requirements, in everything that was designed:

1. Demand Side Management: Minimize energy and water consumption at the consumer level.
2. Fitness for Purpose: Provide on-demand, temperature-appropriate quantities as required.
3. Waste Chain Recovery: Recover and reuse wasted energy and water wherever possible.

From these constraints a patent pending integrated district heating, cooling and water recovery systems was developed. This system has become known as a District Energy Sharing System (DESS). A DESS is a two-pipe ambient temperature system that allows the use of either extracted or contributed energy. Residential buildings requiring heating during winter days can be supplied by office buildings that require cooling during occupancy. Meters in each building track as to whether the client is contributing or using energy from the DESS.



After identifying the most promising opportunities, a detailed analysis was carried out to assess and prioritize the various energy sources, including:

- Biomass (construction wood waste)

- Wastewater Heat Recovery

- Municipal Solid Waste (on-site and onsite/offsite solid mix)

- Closed loop or open loop geo-exchange.

- Closed and open loop geo-exchange using adjacent lake water

- Solar heat and power

A closed loop geo-exchange bore-field was selected as the first energy source due to the ability to provide heating and cooling. The vertical bore-field is located under a soccer pitch at the entrance to the community and boasts 212 boreholes that are 410 ft deep. Lake geo-exchange is planned for the development of the commercial centre (Phase 2), located next to Langford Lake.

Westhills began with Phase 2 and the DESS has been in operation since April 2010. Currently, there are over 250 single family dwellings and 10 town homes connected to the DESS. A 68 unit condominium is also connected to the DESS.

Phase 3 is presently under construction and Phase 1 (Commercial Core) is being cleared for up to 5,000,000 square feet of commercial mixed use development.

Engineering approach

Fundamental Design Requirements

The engineering approach at Westhills was based on three fundamental design requirements:

- Demand Side Management: Minimize energy and water consumption at the consumer level.

- Fitness for Purpose: Provide on-demand, temperature-appropriate quantities as required.

- Waste Chain Recovery: Recover and reuse wasted energy and water wherever possible.

Demand Side Management

At Westhills the energy goal for the buildings was to reduce the overall energy supply for the community by attempting to balance the buildings' internal gains (people, equipment, lighting and solar gains) with the building's heating losses through both natural means and the use of reversible heat pumps to reduce the energy required to heat and cool the buildings.

At Westhills residents, further demand side management has been achieved by teaching home owners to bring their homes to a comfortable temperature and allow the building to come up to that temperature and stay at that temperature (i.e. no setbacks). This allows the buildings to maximize the efficient use of their thermal mass and minimize the amount of time the heat pump may come on throughout the day. This is very similar to brining a car up to 60kmh, once it is at 60kmh it does not take a lot of energy to keep the car at 60kmh, however if you are constantly changing the speed of a vehicle, you will use much more energy.

To keep construction costs reasonable the second step was to recover and reuse any imbalances in building heating and cooling.

Recovery and Reuse

Westhills DESS is based on modern building principles, making a DESS a logical extension of those building systems. The DESS technology enables Westhills to connect buildings to a network that actually allows them to use the surplus heating or cooling to help the rest of the community balance its energy needs. That is, we take the imbalance (surplus) in heating or cooling, and distribute it out into the community. The imbalances in heating in one building are made up by imbalances in cooling in another building, reducing the amount of energy the community needs and the costs associated with improving the efficiency of the buildings. By reducing the overall community energy consumption, the size of any purpose built energy sources within the community can also be reduced resulting in reduced capital and operating costs.

Fitness for Purpose

Modern buildings do not need high temperatures to maintain their space heating or domestic hot water temperatures. Even domestic hot water, only requires 55C, which makes up less than 20% of a residential building's demand, and even less in a commercial building. Delivering 100% of the supply to meet 10-20% of the load was deemed wasteful at Westhills, recognizing waste costs money.

An optimal distribution temperature at Westhills was determined by considering all the energy sources within and adjacent to the community that would maximize the reduction in energy supply requirements through energy sharing within the community (25-35% in a typical mixed use community) and subsequently the other sources of energy within a community (wastewater, solar, geoexcange, biomass, etc.). It also recognizes the differences in temperature differentials when heating or cooling is required and the manufacturer's temperature differentials between the supply side entering and leaving water temperatures. Through this process, the optimum distribution temperatures for the warm pipe were determined for several off the shelf heat pumps.

At Westhills the current operating temperatures for the residential neighbourhoods are:

- Warm pipe: 13-18°C
- Cool pipe: between 8-15°C.

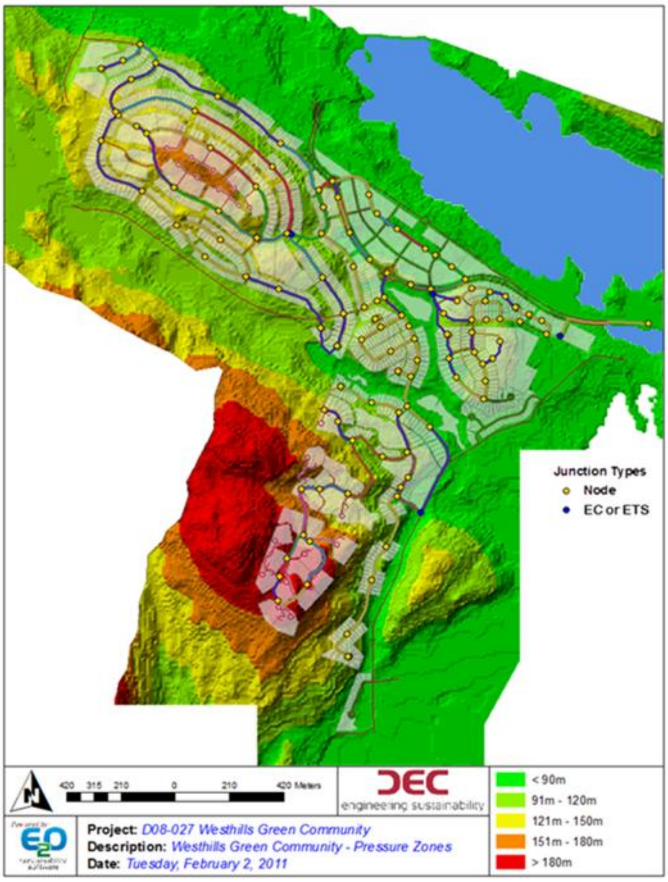
It is important to note that different communities and even different zones within a community may have different temperature ranges. By breaking Westhills down into zones and local service areas that deliver energy to specific buildings or groups of buildings at temperatures that best match the building needs, energy can be used most efficiently and costs can be minimized. To further improve the efficient use of energy across Westhills and into the neighbouring community, Energy Transfer Stations are used to tie service areas together and modulate loop temperatures to balance the efficient transfer of energy from one service area to another. This will help to minimize the size of large centralized thermal energy systems, and associated line losses, and allow for smaller localized energy sources that can be used to better match energy supply to demand and the capital and operating costs to the service area revenues.

Features of Westhills DESS

Specific features of the system that were designed to meet the three design requirements include:

- Grid Based Design
- Development of a "Thermal Capacitor"
- Integrated Water and Energy Recovery
- Eductor Stations

Grid Based Design



From the beginning, Westhills was broken down into grids and local service areas that deliver energy to specific buildings or groups of buildings at temperatures that best match the buildings' needs. In this way, energy can be used most efficiently and costs can be minimized. Local service areas are connected using Energy Transfer Stations, which efficiently transfer energy between zones in a grid. This allows for the recovery and distribution of waste heat and chilled water from one zone to another, minimizing the size and energy provision from a central source and minimizing line losses by reducing distribution temperatures. By interconnecting Energy Transfer Stations a grid can be developed which will improve the reliability of the district energy system, helping to ensure energy can always be delivered to where it is needed, when it is needed. This grid approach creates modular systems that can be staged to incrementally add new sources and/or connect new service areas as required. This allows the cost of the infrastructure and to be balanced with the revenues and environmental benefits. A spin off benefits of the DESS grid includes reduced and standardized delivery pipe sizes to local service areas and DESS trunk pipes between Energy Centres and Energy Transfer Stations.

Development of a "Thermal Capacitor"

The DESS is made up of a warm pipe and a cool pipe. Buildings in heating draw off of the warm pipe and discharge chilled water to the cool pipe, buildings in cooling draw off of the cool pipe and reject warm water to the warm pipe. This creates a temperature differential between the warm and cool pipe. This temperature differential is maintained based on the thermal storage of the pipe network and energy added to the warm pipe or removed from the cool pipe at an Energy Centre or Energy Transfer Station. The purpose of the Energy Centre is to maintain the temperature and pressure differentials between the warm and cool pipes. Energy Transfer Stations perform the same function across zones in a DESS network. When the community is in thermal balance a temperature differential is maintained between the warm and cool pipes. As a greater percentage of buildings draw from the warm pipe and discharge to the cool pipe, the relative pressure on the cool pipe rises and vice versa when the majority of buildings are in cooling. The advantage of the thermal capacitor is the DESS Energy Centres and Energy Transfer Stations only have to provide energy based on the difference between the peak heating and peak cooling across a local service area or across the community to manage the temperature and pressure differentials. This greatly reduces the overall amount of energy supply required, and associated cost of infrastructure for a community. An additional benefit of the thermal capacitor is that when there is energy sharing within the community energy sources are only needed to meet the net difference between the peak heating and peak cooling loads, and then only after the thermal storage has been used. At Westhills a geoexchange borefield is used as the initial energy source and long term thermal storage. When the commercial area is built out and we have a greater diversity of heating and cooling loads, the lake can also be used for much shorter duration and faster responses to differences in heating and cooling throughout the day, minimizing the impact on the lake.

Eductor Stations

The purpose of Westhills eductor station is to reduce the physical size and costs (capital and operating) of pumping requirements by constructing small modular pumps that take a small sidestream of water and boost (or drop) the pressure in a pair of DESS warm and cool pipes to either overcome the friction loss in long distribution lines or instil a flow direction in loops where there is no direct control over the flow. The eductors stations at Westhills are located in standard manholes.

Integrated Water and Energy Recovery

One of the benefits of the ambient temperature distribution was the low temperature of the cool loop. Since a water reclamation plant was part of the overall design scheme and finding a way to reuse the reclaimed water was key to improving the feasibility of the tertiary treatment plant; it was quickly realized that the DESS could act as a conveyor of both the thermal energy and the reclaimed water. For Westhills it was also recognized that the overall draw of reclaimed water for toilet flushing and irrigation was significantly less than the overall flow for heating and cooling and therefor the pipe diameters were only marginally increased.

Energy Analysis

Consideration was given to energy loading and supply profiles, distribution pipe material, back-up energy sources and control systems. Energy requirements vary from season to season and from morning to night and the DESS was designed with storage capacity sufficient to take care of these occasions.

For the residential area, Westhills DESS is designed based on 40% of the peak heating load providing 90% of the average energy, and 100% of the cooling energy. During extreme winter temperatures, natural gas fired boilers provide the back-up to meet peak demands.

A bore-field was incorporated into the system as the receptacle for excess energy in summer and for back-up heating in the winter. The borefield is made up of 212 boreholes that are 410 feet deep. The borefield is further broken into a 3x3 grid or nine zones designed to allow for the independent storage and retrieval of heating and cooling to maximize the recovery and reuse of energy within the community.

As an ambient temperature DESS, the system has the ability to store energy in the distribution. Currently there is approximately 6 hours of thermal storage in the distribution piping. This is sufficient to pre-condition the system to take care of peak heating or cooling periods.

Control

To the extent possible the DESS has been designed to be self-balancing. Since DESS is simply an extension of the building mechanical systems, the overall DESS control system has been based on Direct Digital Controls (DDC) and Building Automation Control Network (BACnet) controls. This has proven to be a very efficient and cost effective way to manage the DESS and the buildings connected to the DESS.

Other Innovative Features

The materials used in the distribution system are unique. Due to the use of low temperature water in the distribution piping, it was possible to use low temperature HDPE piping for all of the distribution mains at significant savings in cost and Greenhouse Gas reduction.

The system is also designed to transport reclaimed water from a future tertiary treatment plant. The reclaimed water will be pumped into the cool pipe to distribute it to the homes that are plumbed with purple pipe for toilet flushing. In this manner, the DESS can supply heating, cooling, and reclaimed water with a two-pipe system.

Economic issues

As noted at the beginning, the sole motivation for this DESS project was to create a profitable green utility.

As a private utility, the capital and operating costs cannot be disclosed.

Success factors

Key Success Factors

One of the biggest on-going challenges associated with developing the Westhills DESS network, has been the need to grow the DESS at the same rate as the development and match the capital and operating costs to the revenues. This has meant that not all the Energy Transfer Stations or monitoring stations have been put in to complete the local service area ahead of occupancy. The challenge is the warm and cool DESS pipes are interdependent. If the appropriate Energy Transfer Stations are not built, than bypasses are required to ensure flows are maintained in some segments of the distribution network. This is further complicated when monitoring stations are not installed or operational.

One of key success factors that enabled the successful construction and occupancy of the residential community alongside the construction of the DESS was the significant thermal storage in the DESS distribution system that has helped to:

- Create a long duration response cycle between changes made to the control of the DESS and its noticeable impact on the DESS line temperatures, improving overall resiliency;
- Provide enough time to manually go and change the position of bypass valves within the network to adjust to the changing needs of the community;
- Improve the DESS's ability to balance its need for heating and cooling in the shoulder season and summer months by itself;
- Reduce the thermal peaks which reduces the thermal capacity requirements of the plant and its operating costs;
- Operate in a partially completed stage without the need for fully automated controls;
- Monitor and test control strategies without adversely affecting the connected community.

Barriers to Success

The biggest barrier to the success of Westhills has been the politics related to permitting and ownership of water reclamation plants, and the use of the reclaimed water for such applications as irrigation and toilet flushing. These barriers are starting to come down as other integrated energy and water DESS systems are being designed and built in other jurisdictions.

Replication

TITUS Infrastructure Services Limited (TITUS) has been setup to acquire and commercialize the DESS patents globally. TITUS provides turn-key design-build-finance-operate DESS utilities in partnership with local municipalities and/or developers (the development partner). TITUS is currently finalizing the capitalization of $30million (CAD) in one DESS contract, with over $100 million (CAD) in proposals to be finalized in the new year.

APPENDIX C – HEAT SUPPLY SCENARIOS

Table C 0-1: potential changes in available supply of low grade secondary heat in 2030

Source	Specific type	BaU	BaU scenario			Co-ordinated scenario			Ambitious scenario		
		Total available supply in, 2013	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply
		GWh	*Y/N*	*%*	*GWh*	*Y/N*	*%*	*GWh*	*Y/N*	*%*	*GWh*
Ground source	Open loop	296	Y	0%	296	Y	0%	296	Y	0%	296
	Closed loop	8,048	Y	0%	8,048	Y	0%	8,048	Y	0%	8,048
Air source		8,435	Y	-10%	7,591	Y	-25%	6,326	Y	-50%	4,217
River source		2,251	Y	0%	2,251	Y	10%	2,476	Y	25%	2,814
Power station heat rejection		8,283	Y	0%	8,316	Y	-25%	6,237	Y	-25%	6,237
Building cooling system heat rejection	Offices	2,700	Y	25%	3,375	Y	10%	2,970	Y	-10%	2,430
	Retail	5,400	Y	25%	6,751	Y	10%	5,941	Y	-10%	4,860
	Gyms	79	Y	25%	98	Y	10%	87	Y	-10%	71
Industrial sources	Part A processes	77	Y	0%	77	Y	0%	77	Y	0%	77
	Part B processes	22	Y	0%	22	Y	0%	22	Y	0%	22

Source	Specific type	BaU	BaU scenario			Co-ordinated scenario			Ambitious scenario		
		Total available supply in, 2013	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply
		GWh	*Y/N*	*%*	*GWh*	*Y/N*	*%*	*GWh*	*Y/N*	*%*	*GWh*
Commercial buildings non-HVAC	Supermarkets	278	Y	0%	278	Y	-10%	250	Y	-25%	208
	Data centres	755	Y	0%	755	Y	-10%	680	Y	-25%	566
Water treatment works		9,723	Y	0%	9,723	Y	0%	9,723	Y	0%	9,723
London Underground		9	Y	0%	9	Y	0%	9	Y	0%	9
UKPN / National Grid electrical infrastructure		583	Y	10%	641	Y	25%	729	Y	50%	874
Sewer heat mining		3,034	Y	0%	3,034	Y	0%	3,034	Y	0%	3,034
TOTAL		**49,974**			**51,267**			**46,905**			**43,489**

Table Co-2: potential changes in available supply of low grade secondary heat in 2050

Source	Specific type	BaU	BaU scenario			Co-ordinated scenario			Ambitious scenario		
		Total demand which can be met by available low temperature supply, 2013	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply
		GWh	*Y/N*	*%*	*GWh*	*Y/N*	*%*	*GWh*	*Y/N*	*%*	*GWh*
Ground source	Open loop	296	Y	0%	296	Y	0%	296	Y	0%	296
	Closed loop	8,048	Y	0%	8,048	Y	0%	8,048	Y	0%	8,048
Air source		7,591	Y	-10%	6,326	Y	-25%	12,938	Y	-50%	4,217
River source		2,251	Y	0%	2,476	Y	10%	2,481	Y	25%	2,814
Power station heat rejection		8,316	Y	0%	6,237	Y	-25%	6,237	Y	-25%	6,237
Building cooling system heat rejection	Offices	3,375	Y	25%	2,970	Y	10%	2,970	Y	-10%	2,430
	Retail	6,751	Y	25%	5,941	Y	10%	5,941	Y	-10%	4,860
	Gyms	98	Y	25%	87	Y	10%	87	Y	-10%	71
Industrial sources	Part A processes	77	Y	0%	77	Y	0%	77	Y	0%	77
	Part B processes	22	Y	0%	22	Y	0%	22	Y	0%	22

Source	Specific type	BaU	BaU scenario			Co-ordinated scenario			Ambitious scenario		
		Total demand which can be met by available low temperature supply, 2013	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply	Available at this time, in this scenario?	% increase from 2013	Total demand which can be met by available low temperature supply
		GWh	*Y/N*	*%*	*GWh*	*Y/N*	*%*	*GWh*	*Y/N*	*%*	*GWh*
Commercial buildings non-HVAC	Supermarkets	278	Y	0%	250	Y	-10%	250	Y	-25%	208
	Data centres	755	Y	0%	680	Y	-10%	680	Y	-25%	566
Water treatment works		9,723	Y	0%	9,723	Y	0%	9,723	Y	0%	9,723
London Underground		9	Y	0%	9	Y	0%	7	Y	0%	9
UKPN / National Grid electrical infrastructure		729	Y	25%	874	Y	50%	875	Y	75%	1,020
Sewer heat mining		3,034	Y	0%	3,034	Y	0%	3,034	Y	0%	3,034
TOTAL		**51,354**			**47,051**			**53,665**			**43,635**

APPENDIX D – CENTRALISED V DECENTRALISED HEAT PUMPS

The issue of whether ASHP are best utilised centrally, linked to large scale substations, and supplying heat into heat networks, or located within buildings supplying energy directly is a complex one, dependent on a number of factors.

A centralised approach to using ASHP entails ASHP supplying heat to a heat network, and onwards to consumers. The ASHP would be of the large multi-megawatt scale and connected to the medium voltage (11kV) distribution network. Heat pump motors would be low or medium voltage (400V or 6.6kV).

A decentralised approach entails installing ASHP within buildings with the energy supplied via building electrical connections and the electricity distribution network. This connects to the buildings via low voltage feeders (400V) and subsequently back to the grid supply point via medium voltage (typically 400V/11kV) transformers and feeders, and primary substations (typically 11/33kV or 132kV) and their feeders. Often installing a heat pump requires reinforcing electrical connections to cope with the additional demand. For a residential property this might entail an upgrade from a 100A consumer unit to a 150A consumer unit. The cost of this is relatively small. More significantly the low voltage distribution network must be capable of supplying the required coincidental heat demand.

These factors affecting whether centralised or decentralised heat pumps are the most economically viable include the following:

- Presence of an existing heat network and its ability to operate at low temperatures (e.g. less than 85^{0}C)
- Capacity of the electricity distribution network to deal with additional loads
- Where neither heat network nor electrical network capacity exist the relative capital cost difference between building a new network of each type
- The operating cost difference between a heat network and electrical network capable of providing the heat demand
- Capital cost difference between large and small scale heat pumps, and the impact of diversity
- Efficiency difference between large scale heat pumps together with heat network losses, and building scale heat pumps together with electrical network losses (I2R losses)
- The extent to which storage can be incorporated into either approach
- The extent to which limiting peak load on the electrical transmission and generation system is considered important.

Presence of an existing heat network

Where a heat network exists, connecting into it with a centralised HP is likely to represent the most cost effective approach in terms of capital cost. The impact of the ASHP on operating cost and carbon intensity is largely driven by seasonal efficiency; network temperature (e.g. condenser temperature) is the greatest driver of this for a given heat pump.

Heat pump performance (measured in terms of COP or seasonal efficiency factor) reduces by around 1.0 for every 10⁰C increase in supply temperature (see Figure 2-1). For example for a heat pump supplying heat at 80⁰C the COP is 2.2, whereas for supply at 60⁰C the COP is 4.4 (for a heat input temperature at the evaporator of 15⁰C). This difference is critical as a COP of around 2.46 represents the level at which a heat pump delivers lower carbon intensity heat than a condensing gas boiler. Based on 2010 values for carbon intensity used above, and assuming ASHP only operate above 5⁰C ambient temperature, centralised heat pumps only reduce carbon emissions when network temperatures are around 70⁰C or less. Where networks operate at higher temperatures than detailed study of the associated carbon intensities of the fuel inputs should be considered, as well as the feasibility of operating the network at lower temperatures.

Capacity of the electricity distribution network to deal with additional loads

Using decentralised heat pumps implies upgrading the electrical distribution network. Research by Imperial College suggests that even at relatively low levels of heat pump penetration (50%) 70% of distribution transformers become overloaded. At higher heat pump penetration levels (75%) 90% of transformers are overloaded, reducing to 50% if 'smart grid' demand management is used. Low voltage feeders are also overloaded at high (75%) heat pump penetrations. Around 60% of feeders are overloaded in this case, falling to around 22% if smart grid approaches are deployed. The impact on primary substations (33kV) is suggested to be even more pronounced, with almost 70% overloaded at this heat pump penetration, even allowing for smart grid systems.

This suggests that even with the use of smart grid approaches there are many areas where electrical networks will require upgrading to deal with decentralised heat pumps.

Capital cost difference between building a new network of each type

Where limited capacity exists to deal with high penetration levels of heat pumps a decision is required whether to invest in a heat network or invest in reinforcing the electrical network. The choice between these approaches is partly driven by their relative capital costs. In each case significant investment could be required, though this is highly dependent on the area in question. More research is required into the relative cost difference between heat networks and electricity network reinforcement as providing a like for like analysis is more involved than comparing the unit cost per linear metre of each type.

The operating cost difference

The relative operating cost difference between a heat network and electrical network capable of providing the heat demand is a key decision making factor as this influences the whole life cost of the network asset, and hence the unit cost of distributing energy.

Capital cost difference between large and small scale heat pumps

Whilst the unit costs (e.g. per kW) of large scale heat pumps are likely to be less than for small scale individual building heat pumps the latter may benefit from economies of scale. For example the relative difference between domestic boiler costs on a per unit basis and industrial boilers is less pronounced than expected due to the mass production of the latter. Further research is required into this difference.

Centralised heat pump schemes benefit from diversity, as the total load on the heat network is always much less than the total peak heat demand of all the buildings connected. Conversely individual heat pumps must be sized to meet the design day requirements of the buildings which they serve. The installed capacity for a centralised heat pump scheme will therefore be reduced compared to a decentralised scheme.

Efficiency difference

Efficiency improvements are expected between large and small scale heat pumps. The increase in efficiency (as COP) from a 20kW domestic scale unit to a 10,000kW scale industrial heat pump is around 1.0 (a 42% increase). However, heat losses from a heat network need to be factored in to this. Typically they are much less than 10% for a well-insulated heat network operating with a reasonable load factor, and so offset by improvements in heat pump efficiency. Similarly pumping energy is typically less than 1%, again offset by the greater efficiency of the larger scale heat pump.

Decentralised heat pumps in buildings also incur losses in the electrical network directly proportional to the load served (I2R losses). On average, losses in the distribution network account for around 7% of electricity demand[35]. These losses increase at peak load, and so the energy utilised by heat pumps may incur greater losses.

A detailed study comparing the performance of electricity networks and heat networks in decentralised and centralised scenarios is required to resolve which option is most cost and carbon effective.

Storage and peak loads

Storage provides several benefits, including:

- Peak lopping and reducing the scale and hence cost of plant required to meet peak loads
- Optimising base load plant output, reducing emissions and cost
- Separating heat generation from electricity use, enabling heat pumps (or electrode boilers) to play a part in balancing the electricity market.

Incorporating storage into centralised systems with heat network systems is likely to require significant land area for large thermal stores, though there is some storage inherent in the distribution network pipework. These would be analogous to gas holders, many of which are now being decommissioned.

For a scenario with heat pumps in individual buildings incorporating storage within buildings of a significant scale (say 7 hrs of heat generation during off peak periods) is likely to be difficult due to

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[35] OFGEM (2003) Electricity distribution losses: A consultation document: http://www.ofgem.gov.uk/Networks/ElecDist/Policy/DistChrgs/Documents1/1362-03distlosses.pdf

space constraints and the significant structural loads associated. Research into new more compact heat storage technologies could mitigate this.

The extent to which storage is important depends on the specific economics of the scheme in question and the value of reducing peak loads on the electricity network.