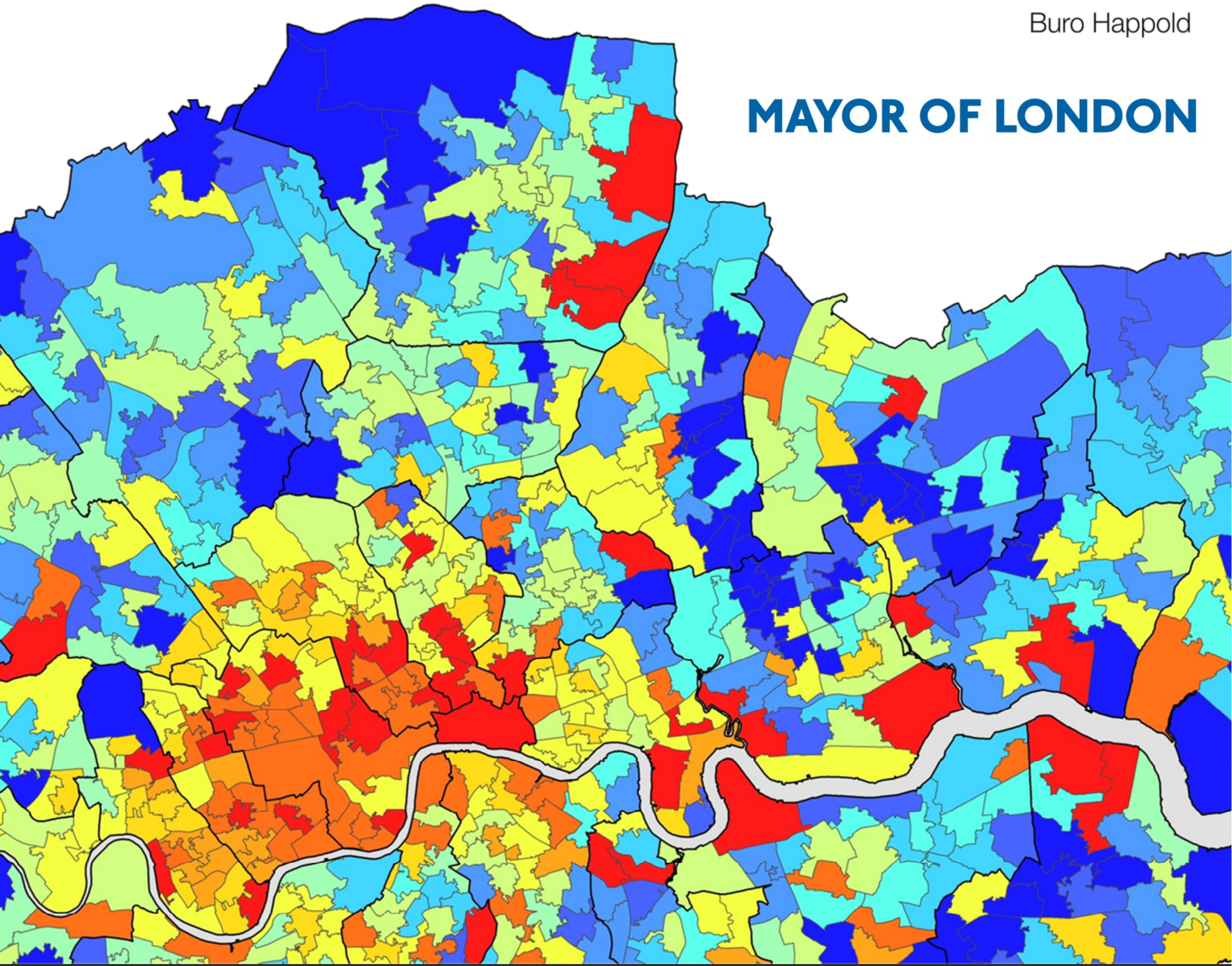
Buro Happold

MAYOR OF LONDON



LONDON'S ZERO CARBON ENERGY RESOURCE

Secondary Heat

Summary Report – July 2013

Purpose of the Study

To remain a globally competitive city, while making the transition to a low carbon economy, London will need to become increasingly resource efficient and self-sufficient in energy. This will require London's infrastructure, buildings and consumers to adapt to changing demand and supply conditions, making use of both primary and secondary sources of energy to deliver lower energy costs, resilience and environmental sustainability.

The Mayor's objectives for London's energy supply, articulated in his Climate Change Mitigation and Energy Strategy (2011), are that it should be affordable, secure and low carbon. It should make use of local sources of energy in the intelligent, integrated and efficient management of heat and power generation and distribution, and it should be delivered through a framework that provides inward investment and employment opportunities.

The Mayor's *Decentralised Energy Capacity Study* (2011)[1] suggests that by 2030, 22% of London's heat and power could be efficiently generated locally, where the heat is distributed via heat networks. Over that period, sources of heat are likely to be from the combustion of primary fuels including gas, biomass and waste. Longer-term, in the context of Government's 2050 carbon reduction pathways, resource efficiency and resource depletion, the availability and viability of these fuels is likely to reduce. Heat networks can and must then begin to make use of alternative sources to facilitate the transition towards near-zero carbon heat. This study explores what these alternatives might be and to what extent they can support these objectives.

The study looks at two particular categories of heat, both of which can be termed 'secondary sources':

- Waste heat arising as a by-product of industrial and commercial activities
- The heat that exists naturally within the environment (air, ground, water)

The study's primary objectives were:

- To provide an understanding of the availability, cost and energy considerations of secondary heat sources in London
- To provide an understanding of issues associated with the integration of secondary heat sources with existing heat networks and with the London building stock.
- To consider opportunities for operating heat networks at lower temperatures and suggest recommendations for network connections and building heating systems.
- To inform national and city policy development on the potential to utilise secondary heat via heat networks in the low carbon transition.
- To inform the market on the likely technical and economic conditions in which these sources may be viable.
- To identify emerging project opportunities in London.

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

Advisory Panel

The Greater London Authority and Buro Happold wish to thank members of the Advisory Panel and representatives from industry who oversaw and provided data for the study.

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Abbreviations

ATES	Aquifer Thermal Energy Storage
COP	Coefficient of Performance
DECC	Department of Energy & Climate Change
DESS	District Energy Sharing System
EPC	Energy Performance Certificate
HVAC	Heating, Ventilation and Air Conditioning
MSOA	Middle Layer Super Output Area
PEX	Cross-linked polyethylene
RHI	Renewable Heat Incentive

Key findings

- **The Mayor is targeting the supply of 25% of London's energy demand from decentralised sources by 2025. This study suggests that secondary sources of heat could provide the majority of this target**, although there are a large number of variables that will impact on delivery.

- **In the event that the viability of primary heating fuels in district networks is significantly reduced, the sources identified in this study could provide sufficient heat to replace them in full.**

Supply

- **Secondary sources of heat are varied in nature**. They are widely distributed across London resulting in differing availability between and within boroughs. They **vary widely in temperature** from below 10°C (some environmental sources) to 70°C (some industrial sources). They also vary in terms of **seasonal and diurnal availability**.

- **For most secondary heat sources, their temperature is too low for direct use.** It is therefore necessary to 'upgrade' them to a useful temperature using heat pumps. Heat pump efficiency is important for secondary heat source utilisation as it affects the cost and carbon intensity of the heat delivered and will impact London's electrical infrastructure.

- **Decreasing heat network temperatures increases heat pump efficiency. The minimum suggested network operating temperature is 55°C.** To maximise the amount of London's current building stock that can connect to secondary heat networks, a compromise of 70°C has been used for modelling purposes.

- Analysis shows that by using heat pumps to deliver heat at 70°C, the **total heat that could be delivered from secondary sources in London is of the order of 71 TWh/yr** which is more than the city's total estimated heat demand of 66 TWh/yr in 2010. Of this 71 TWh/yr, around 50 TWh/yr (70%) would be from the secondary heat source itself and the remaining 21 TWh/yr (30%) would be attributed to the heat pump energy requirements.

- Under the proposed conditions **some form of peak heating source would be required during very cold weather**. This could be done locally (e.g. gas boilers) or by increasing the heat network temperature.

- **Secondary heat sources that may not be significant for London as a whole may be significant locally,** such as tube ventilation shaft heat recovery. Emerging opportunities for low temperature networks in London depend on localised distribution of supply in relation to demand. A number of areas have been identified.

- **There are likely to be complex commercial issues to resolve** to balance the number of sources available and their intermittency to make a viable business case.

Demand

- Some requirements for heat, such as cooking, can never be met by low temperature sources. Space heating requirements also differ between building types, with poorly insulated ones being less able to utilise low temperature sources than well insulated ones. Applying these constraints to London's total heat demand of 66 TWh/yr it is estimated that **25 TWh/yr (38%) could be met by secondary heat delivered via heat networks operating at 70°C** without the need for significant retrofit. Of this 25 TWh/yr, around 2 TWh/yr would not currently be located sufficiently close[2] to secondary heat sources to utilise this heat via district heating networks.

- **The proportion of London's heating demand that could be met by district heating networks operating at 70°C could rise to 30 TWh/yr by 2050**, assuming ambitious retrofit programmes were implemented over that period.

Cost & Carbon

- **Generally the cheapest sources with the lowest carbon intensity are those occurring at the highest temperatures**. Some industrial sources produce waste heat at above 70°C and can be fed directly into heat networks without the need for heat pumps. Heat from data centres and electrical transformers are the next most cost and carbon efficient technologies, producing heat *throughout* the year at 40°C and 50°C respectively. Performance drops off for intermittent sources producing heat at lower temperatures.

- Based on the current carbon intensity of the electricity grid, **the carbon intensity of most secondary heat sources is lower than that of heat supplied via large centralised gas boilers**. 85% of London's 2010 heat demand (56 TWh/yr) can be considered as 'CO_2 competitive'.

- **The cost of all environmental heat sources is currently higher than that of heat supplied by large centralised gas boilers**, however **the cost of industrial and commercial sources are comparable and in some cases lower.** 18% of London's 2010 heat demand (12 TWh/yr) can be considered as 'cost competitive'.

- Due to the need to use heat pumps to utilise most secondary sources of heat, **the carbon intensity and cost of secondary heat sources are linked to those of the electricity grid.** As the carbon intensity of the grid falls, so too will that of secondary heat. As the cost of electricity rises, so too will the cost of secondary heat.

Building & Network Infrastructure

- **The fabric of buildings, their internal heating systems and the way in which they are connected to a district heating system all impact upon their ability to utilise heat supplied at different temperatures.** The more efficient the building systems and connections, the lower the temperature at which heat can be supplied and the less energy is required to upgrade low temperature secondary sources of heat to make them useful.

- **Conventional district heating networks operating at higher temperatures can be adapted to utilise lower temperature sources** but there are implications for network design such as pipe diameters and control which are likely to reduce the capacity of the networks.

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[2]A 5km limit has been placed on the distance that secondary heat can viably be transported via networks. This constraint is indicative only.

Policy and system design recommendations

Heat networks interface with a wide variety of technologies, systems and actors. These interactions are extended when considering the integration of secondary heat sources deriving from different industry and commercial sectors. To promote their effective utilisation therefore requires action in a number of different ways.

1. **A suitable operating temperature for networks providing domestic hot water across the *current* London housing stock would be 70°C**. This temperature provides a balance of controlling legionella risk as well as restricting the need to upgrade the temperature of secondary sources.

2. **Low temperature networks connecting to existing buildings should not operate below 55°C**. Below this temperature the percentage of heat demand that can be met is reduced significantly, even when considering significant retrofit measures.

3. **Financial incentives for heat pumps could support the initial uptake of secondary heat systems**. Schemes such as the RHI are important for generating uptake of secondary heat sources and could usefully be expanded to incentivise the use of heat pumps for *all* secondary heat sources.

4. **Regulations should ensure that the design of secondary heat circuits is such that low return temperatures are provided to the heat network** to improve the efficiency of the heat source, as well as reducing pumping costs and allowing smaller diameter pipework to be used. Building regulations should stipulate the use of direct connections and multi stage pumping where possible and restrict the use of low loss headers in all district heating schemes.

5. **Regulations should ensure the design of building heating systems and controls suit the uptake of lower temperature networks**. Building regulations should promote the installation of underfloor heating or large radiators as well as programmable room thermostats and weather compensation controls.

6. **Utilisation of secondary heat sources should focus on those available at higher temperatures and continuous supply**. Higher temperature sources require less heat pump electricity to ‘upgrade’ heat. Sources with less intermittency can provide a greater percentage of building heating demands and reduce the need for top up heat from conventional sources.

7. **Planning guidance should highlight opportunities for secondary heat networks** and the Mayor’s decentralised energy programme should identify opportunities for low temperature networks and facilitate the implementation of such schemes. Boroughs should be required to investigate the potential to utilise secondary sources of heat as part of their energy masterplanning work.

Summary report

The Mayor's *Decentralised Energy Capacity Study* (2011)[3] suggests that by 2030, 22% of London's heat and power could be efficiently generated locally, where the heat is distributed via heat networks. Over that period, sources of heat are likely to be from the combustion of primary fuels including gas, biomass and waste. Longer-term, in the context of Government's 2050 carbon reduction pathways and the need for greater resource efficiency, the availability and viability of these fuels is likely to reduce. Heat networks can and must then begin to make use of alternative sources to facilitate the low carbon transition. This study explores what these alternative sources might be and to what extent they can support these objectives.

Secondary heat sources

This study explores the potential to use secondary heat sources within London and the role they could play in meeting the Mayor's objectives for climate change mitigation.

Secondary heat sources are defined as those arising from commercial and industrial activities, including London's infrastructure, and from the environment. There are a wide variety of these sources within London (Table 1), **each with different characteristics in terms of temperature and availability.** There are also differing practical considerations to be taken into account related to the heat recovery infrastructure required that can be installed at a site.

Accounting for these supply side factors, total *available* heat for capture **from all sources across London equates to around 50,000 GWh/yr. This is equivalent to 76% of London's total heat demand of 66,000 GWh/yr**[4]. A spatial representation of this heat supply by census area[5] is shown in Figure 1.

[3] GLA (2011) *Decentralised Energy Capacity Study*: http://www.london.gov.uk/priorities/environment/tackling-climate-change/energy-supply
[4] Based on heat demand in 2010. *GLA Decentralised Energy Capacity Study (2011)*
[5] The census area used as the Middle Super Output Layer (MSOA)

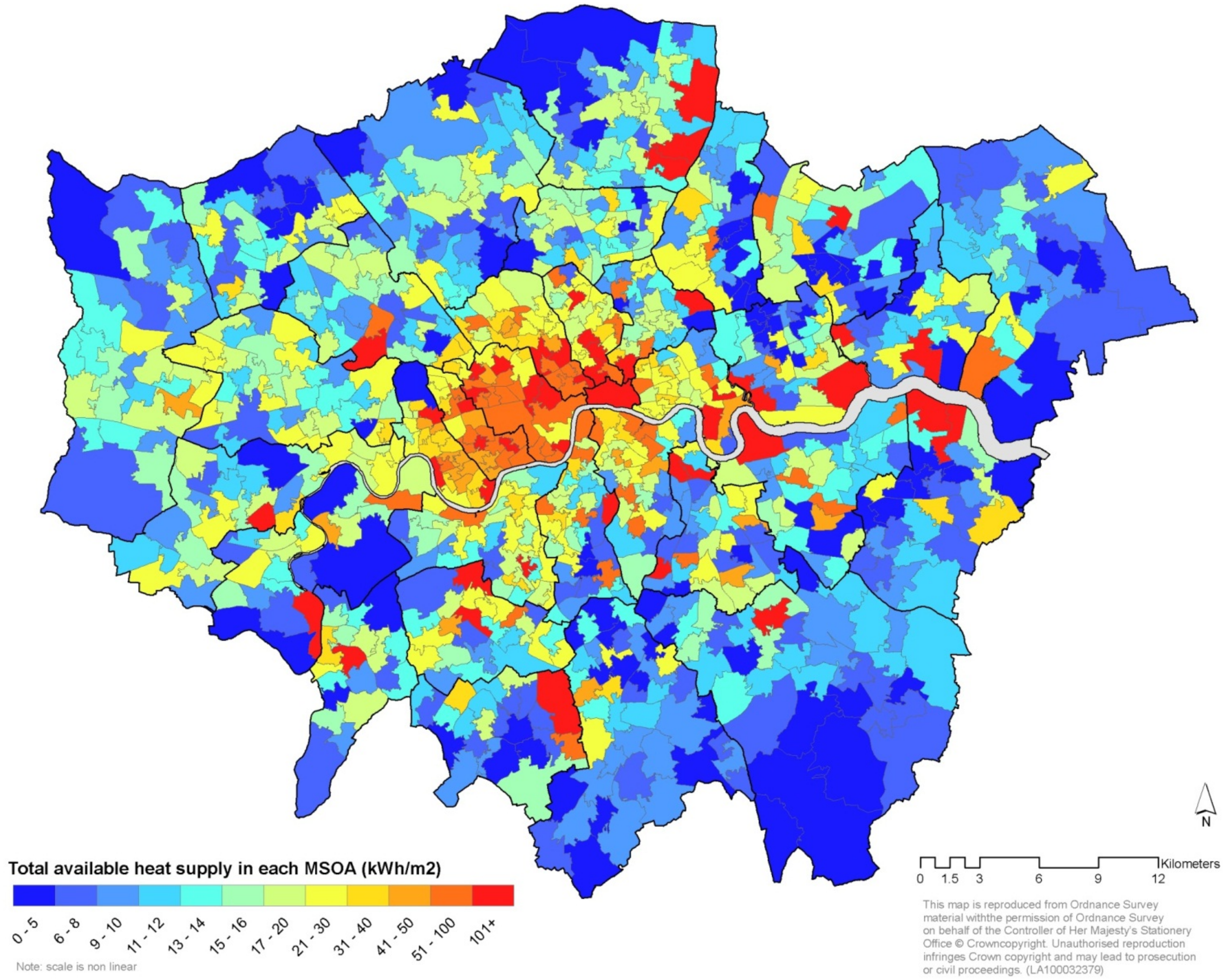

Figure 1 - Available secondary heat supply (kWh/m2) for all sources. Note that air and river sources are capped at a heat pump capacity of 20MW.

Those areas shaded in red indicate areas of high heat availability. In the centre of the city, this arises from building heat rejection, while in the periphery, significant amounts of heat could be extracted from the ground or point sources such as power station condensers, river and waste water abstraction sources and large air source heat pumps located near electricity sub-stations.

Table 1- Secondary heat sources in London

Heat Source		Description	Typical heat offtake temperature
Environmental sources	Ground source	Below ground temperatures are stable throughout the year. Heat can be extracted from 'open' or 'closed' loop systems, dependent on site conditions - the former use aquifers, the latter boreholes.	13-14°C
	Air source	Outside air at any temperature contains some heat, the quantity of which varies both seasonally and diurnally.	2-16°C can be much lower
	River source	As with air source, rivers at any temperature contain some heat. The quantity and temperature vary with flow rates and seasonal variations in ambient conditions.	5-20°C
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. Power stations types include gas fired open and combined cycle plant, energy from waste, landfill gas, biogas, sludge incineration and CHP.	35°C in some cases much higher
	Building cooling system heat rejection	Buildings use a range of different cooling systems linked to both occupation and ambient conditions. Many systems will operate more during summer months and use air or water cooled chillers to reject heat at low temperatures.	28°C
	Industrial sources	A number of industrial processes lead to the rejection of waste heat. Particular ones open to analysis are chemical industries, clinical waste incinerators and food producers.	35-70°C Highly variable
	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 are supermarkets and data centres.	32-40°C
	Water treatment works	Low grade heat is released from water treatment works due to biological activity associated with sewage treatment.	14-22°C
Infrastructure sources	Metro tunnels (eg. London Underground, Crossrail)	Heat generated underground through train braking, lighting and passengers is rejected through ventilated shafts at strategic positions along the network.	12-29°C
	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.	50°C
	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.	14-22°C

Utilisation – the importance of heat pumps

The heat *available* from secondary sources is generally of a low grade, that is, of low temperatures in the region of 5°C - 35°C with few direct uses. As such it needs to be upgraded to higher temperatures before it is *delivered* to an end user. This upgrade is achieved through the use of heat pumps.

Heat pumps use electricity to raise the temperature of low grade heat to more useful levels. **The efficiency with which they do this (referred to as their Coefficient of Performance (COP)) depends largely on the difference in temperature between the heat at source and the heat as supplied. The greater that difference, the more electricity is required and the less efficient is the heat pump**.

This is shown in Figure 2 which collates results from a review of heat pump manufacturers' data. **The electricity required to supply a network at 85°C (green line) is roughly twice that of one required to supply a network at only 55°C (yellow line).**

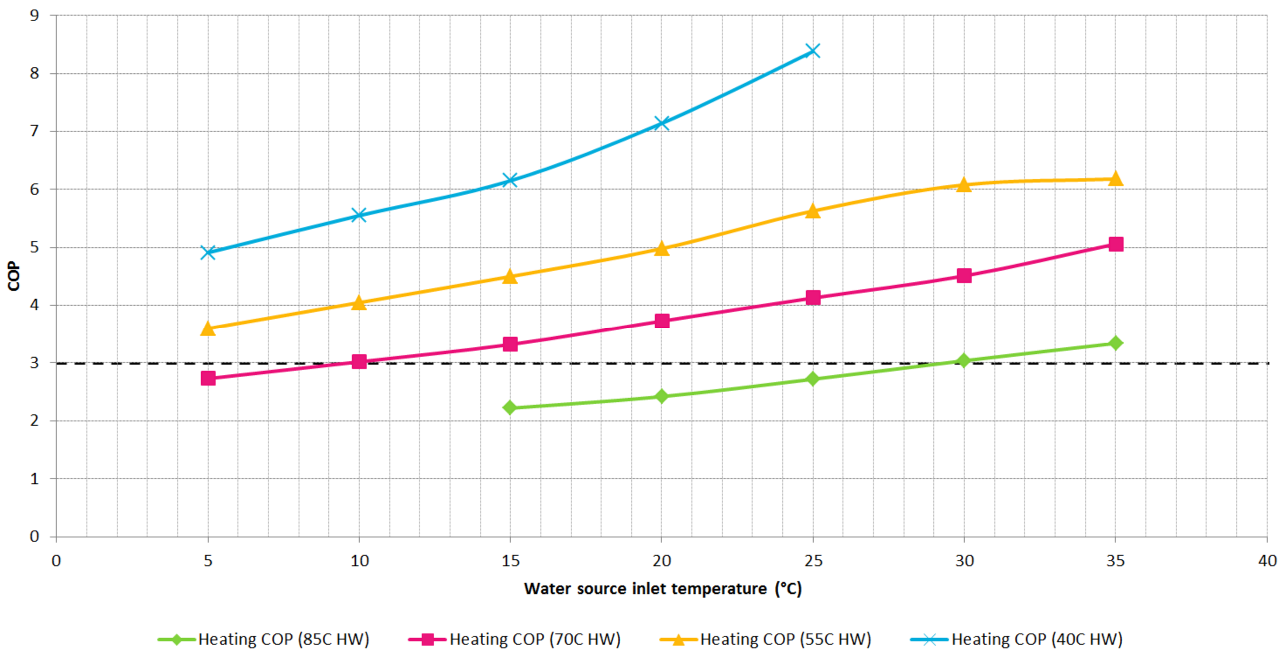

Figure 2 - Heat pump COPs for four different heat output temperatures (500-1000kW scale heat pump).

A heat pump can typically be considered to be unviable (ie. the cost of the electricity required to increase the heat supply temperature is greater than the value of the heat supplied) at a COP below ~ 3 (the dashed line in Figure 2)[6]. Where subsidies are available this figure will vary.

The COP increases when the required flow temperature decreases as the heat pump is required to do less work. Though meeting demand at a low temperature is more efficient from a supply point of view, most heating systems in the current building stock cannot utilise such temperatures. As such, a 70°C heat network provides the best compromise between upgraded supply and minimising heat pump costs. This is referred to in more detail later, in the section on building construction and internal systems.

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[6] GLA 80253 – Heat Pumps and Data Centres. A high-level review of technology and performance. GLA, May 2012.

Quantifying delivered heat

The current available heat from all secondary sources across London is of the order of 50,000 GWh/yr. If all of this were upgraded for supply via a 70°C district heating network, **21,300 GWh/yr of electrical input from heat pumps would be required resulting in a total of 71,300 GWh/yr of deliverable heat**. **This is above London's current estimated heat demand of 66,000 GWh/yr.**

Delivered heat is defined as the heat supplied to the district network as shown in Figure 3, split between that available directly from the heat source (dark blue) and that supplied via the heat pumps (light blue). **The sources at lower temperatures, such as air and ground, require more heat pump energy than those at higher temperatures, such as waste heat from power stations or electrical infrastructure.**

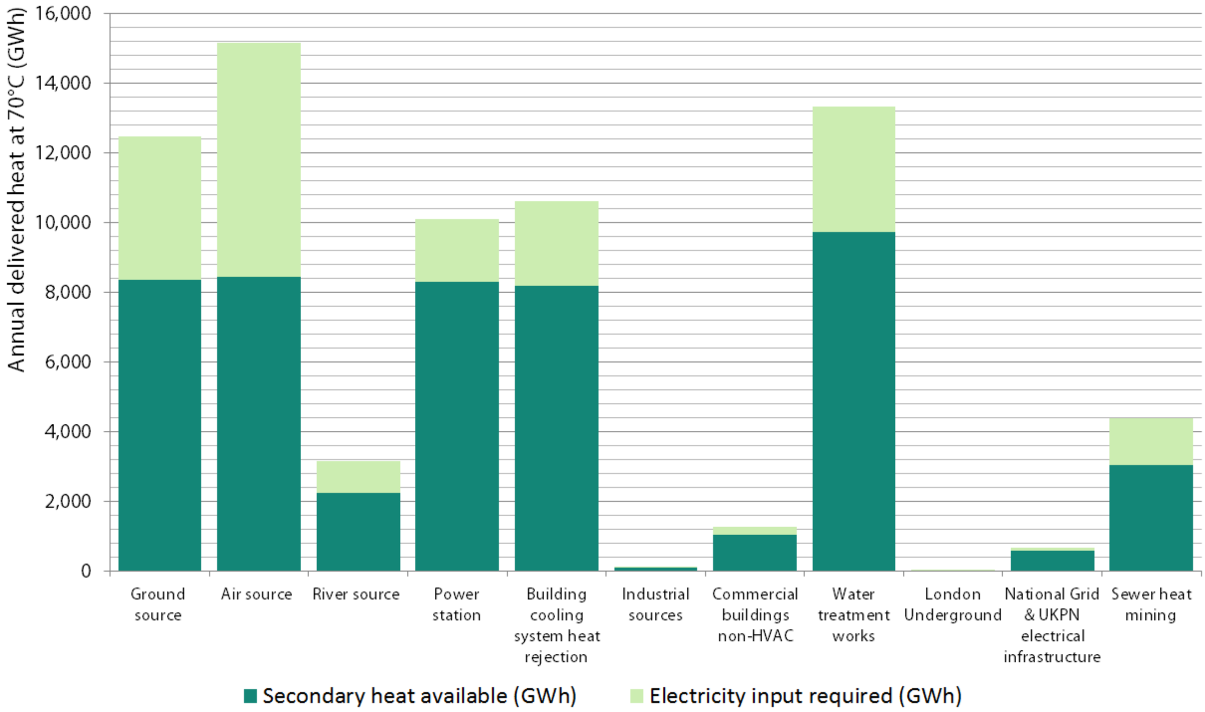

Figure 3 - delivered heat by source showing heat pump energy requirements

The three greatest sources of supply for delivered heat make up 62% of the supply from all sources. These 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 impact they could have on electricity networks and their poor performance in terms of cost and carbon.

For environmental sources practical constraints have been applied governing the frequency of heat abstraction locations as well as the maximum capacity heat pump (20MW) at any one location. In practice, implementing heat abstraction at *all* these sources is unlikely to be feasible. The figures included here for air and ground source in particular are likely to significantly overestimate the practically 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%).[7] 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 energy. Additionally recovering heat from the London Underground has the added benefit of cooling the underground. Non direct savings such as this have not been quantified as part of this study.

[7] The availability of data for industrial sources in currently relatively limited

Demand Matching

To be utilised, secondary heat supply must be matched to heat demand both in terms of temperature and location. Where there is more supply than demand in an area, there must be heat network infrastructure in place to transport the excess supply to a suitable area of demand.

The extent to which secondary sources of heat may be utilised depends both on the proximity of the source to centres of demand and on the nature of that demand. Thus, if heat were supplied at a temperature of 70°C, some end uses such as cooking could never be met. Similarly, buildings with differing fabric efficiencies (equivalent to different energy ratings in the residential sector) can make differing use of lower temperature heat with those with poor thermal efficiency being able to utilise less than those with higher thermal efficiency fabric.

In practice, it would also be necessary to have a means to transport the heat in the form of heat networks from source to centre of demand. **This study assumes that these networks would already be in place** from pre-existing district heating networks fed from gas, CHP and energy from waste plants as it is considered that secondary heat sources are unlikely in themselves to be able to support the investment in heat networks.

It is estimated that **24,900 GWh/yr of London's heating demand (as of 2010[8]) could make use of secondary heat supplied at 70°C**, without applying spatial constraints. This is equivalent to 38% of London's heat demand in 2010 and is far less than the quantity of delivered secondary heat available (71,300 GWh/yr). Applying spatial constraints limiting heat supply from sources to the surrounding boroughs with a notional 5km maximum network length reduces this heat uptake to 23,200 GWh/yr.

Looking to the future, if buildings are made more energy efficient and as demand and supply patterns change, spatial constraints are likely to have a greater impact. Thus, for a 2050 'ambitious'[9] scenario where the future building stock could support 51,300 GWh/yr of heat from 70°C heat networks, much of this new demand would be remote from supply sources. For this scenario, **30,300 GWh/yr could be met by secondary sources of heat.**

Previous research suggests that between 12,000 and 16,000 GWh/yr of heat can be provided by decentralised energy networks by 2031 *including* heat from conventional fuel sources.[10] By looking at a wider spectrum of secondary heat sources, this study demonstrates that this supply has the potential to be exceeded by secondary heat sources alone. **In the event that the viability of primary heating fuels in district networks is significantly reduced, the secondary heat sources identified could provide sufficient heat to replace them in full.**

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[8] 2010 has been taken as the scenario year for 'current' supply and demand rather than 2013 as this is the most recent year for which heating demand data for London could be obtained

[9] An ambitious scenario assumes policy is in place across all levels of government to improve energy efficiency and reduce carbon emissions. DECC high projections (DECC (2012) Updated Energy & Emissions Projections, Annex F) have been used for energy prices, heat demand growth assumes ambitious efficiency uptake and a maximum heat network penetration of 80%.

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

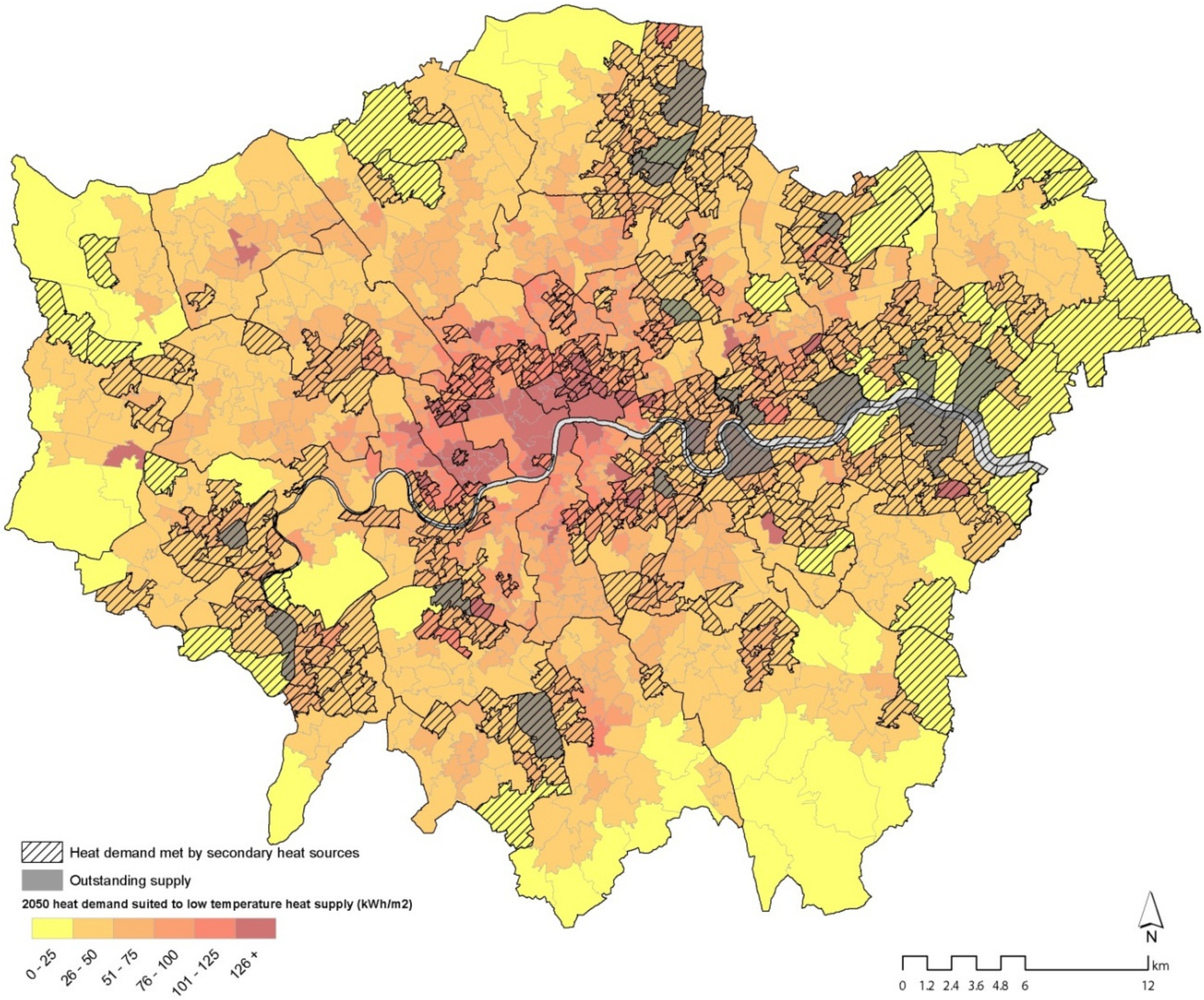

Figure 4 –supply and demand match for a 2050 scenario of ambitious building stock development

Figure 4 shows the effect of heat demand matching, highlighting areas with high supply density and the potential limits to redistribution of heat. The background image shows the demand density of heating demand suitable to connect to low temperature networks (highest in red). The hatched boxes show areas where this demand has been met by secondary heat supply in the surrounding area. After this matching exercise the shaded dark grey areas have excess supply remaining. These locations are sites such as large power stations, centralised air source heat pumps or water treatment works, where the quantum of available heat is particularly high. Matching supply to demand beyond this point would require extensive heat networks and is likely to be better served from local heat sources in the area.

The ability to effectively use secondary heat sources in the future will be influenced by both the spatial distribution of heat networks and the quantum of heat demand suited to connect to such networks. Planning policy could therefore be used to maximise opportunities for connection.

Carbon intensity and cost

The purpose of seeking to utilise secondary sources of heat is to support the decarbonisation of energy supply in a cost effective way. The carbon intensity and unit cost of heat delivered from secondary sources is strongly linked to the environmental performance and cost of electricity supplied by the grid.

Figure 5 shows the relationship of carbon intensity and levelised cost[11] for each secondary heat source for a 'business-as-usual'[12] case for 2010. The grey lines indicate the carbon intensity (205 kg CO_2/MWh) and cost (2.1 p/kWh) of a counterfactual (base case) of centralised large gas boilers. **Those sources in the bottom left hand quartile are those with a lower carbon intensity and cost than the base case.** The size of each bubble indicates the availability of each source for London as a whole.

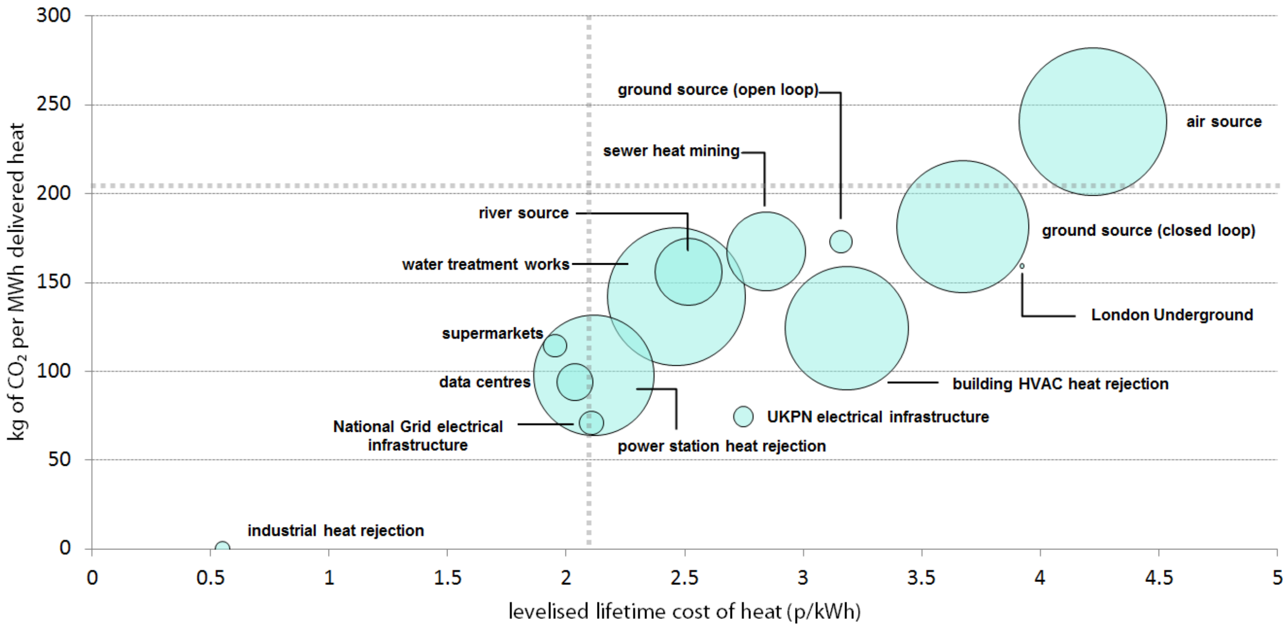

Figure 5- Current carbon intensity v levelisedcost of secondary heat sources in London. The grey dotted lines indicate the cost and carbon intensity of the counterfactual of centralised large gas boilers.

In general the higher temperature sources such as industrial sources, power station heat rejection, data centres and supermarkets are preferable, with the lower temperature sources such as air and ground being least preferable. This largely reflects the cost and carbon associated with the heat pump energy and shows that **over the life of the systems, the capital costs are typically much less significant than energy costs for heat pumps.** This split is shown for all sources across London in Figure 6 overleaf.

For the above scenario 12,000 GWh/yr (18% of London's 2010 heat demand) can be considered as 'cost competitive' and 56,000GWh/yr (85% of London's 2010 heat demand) can be considered as 'CO_2 competitive', notwithstanding demand restrictions

[11] Costs include both the capital cost of heat capture infrastructure and the operational cost of heat pump electricity. Heat networks are assumed to be pre-existing and so are not included. Levelised costs are calculated by dividing capital and operational costs by discounted heat supplied over a suitable period (20 years in most cases).

[12] A business –as-usual scenario reflects a market driven investment model leading to limited investment in long term infrastructure. DECC low projections (DECC (2012) Updated Energy & Emissions Projections, Annex F) have been used for energy prices, heat demand growth with no efficiency measures and a maximum heat network penetration of 70%. It is assumed that hot water demand cannot be supplied from secondary heat networks.

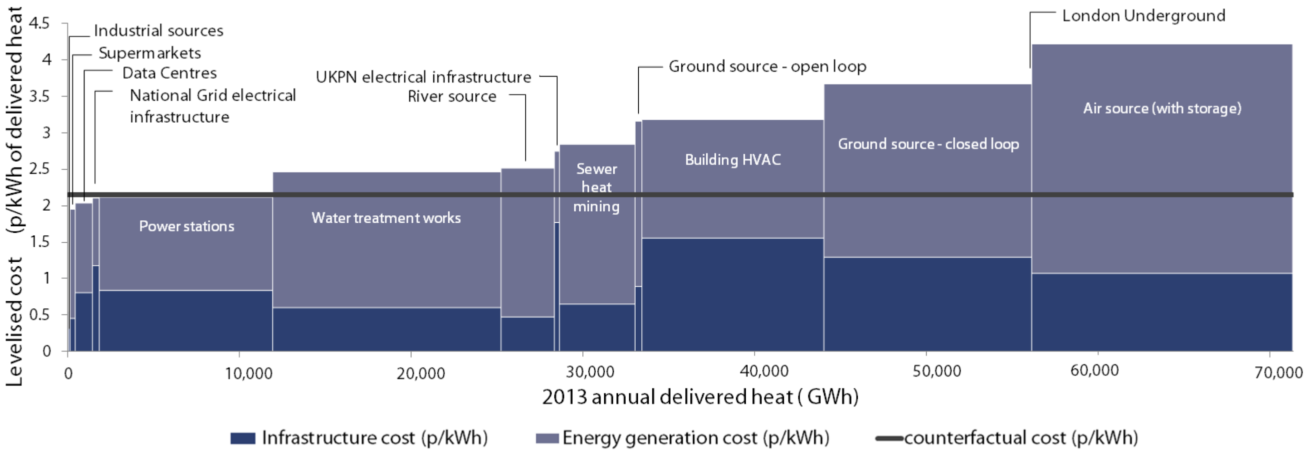

Figure 6– Heat supply marginal abatement cost curve. The counterfactual levelised cost is indicated by the grey line.

In the future, as the carbon intensity of the grid and energy prices change, the benefits of each source in relation to each other and to the base case will also change. A 'co-ordinated'[13] scenario out to 2050 in which grid carbon factors reduce but energy prices rise is shown in Figure 7.

Here all secondary sources show a significant improvement against the base case in environmental terms making even those at a higher cost (such as air source) more attractive in terms of carbon intensity. The ranking in terms of cost remains similar except for electrical transformer and building HVAC heat rejection. These have become cheaper compared to other sources because of their particularly high ratios of infrastructure to lifetime energy costs caused by their low load factors and relatively high source temperatures. This means that they are less sensitive to inflation in energy prices despite requiring a greater capital investment. **A trade-off is required between high infrastructure costs and high heat pump energy costs, based on an assessment of energy price inflation.**

13 A co-ordinated scenario assumes a combination of national and regional actions encourage infrastructure investment and development. Good levels of retrofit reduce the overall heat demand of the London building stock. DECC central projections (DECC (2012) Updated Energy & Emissions Projections, Annex F) have been used for energy prices. A maximum heat network penetration of 70% has been modelled and it is assumed that hot water demand *can* be supplied from secondary heat networks.

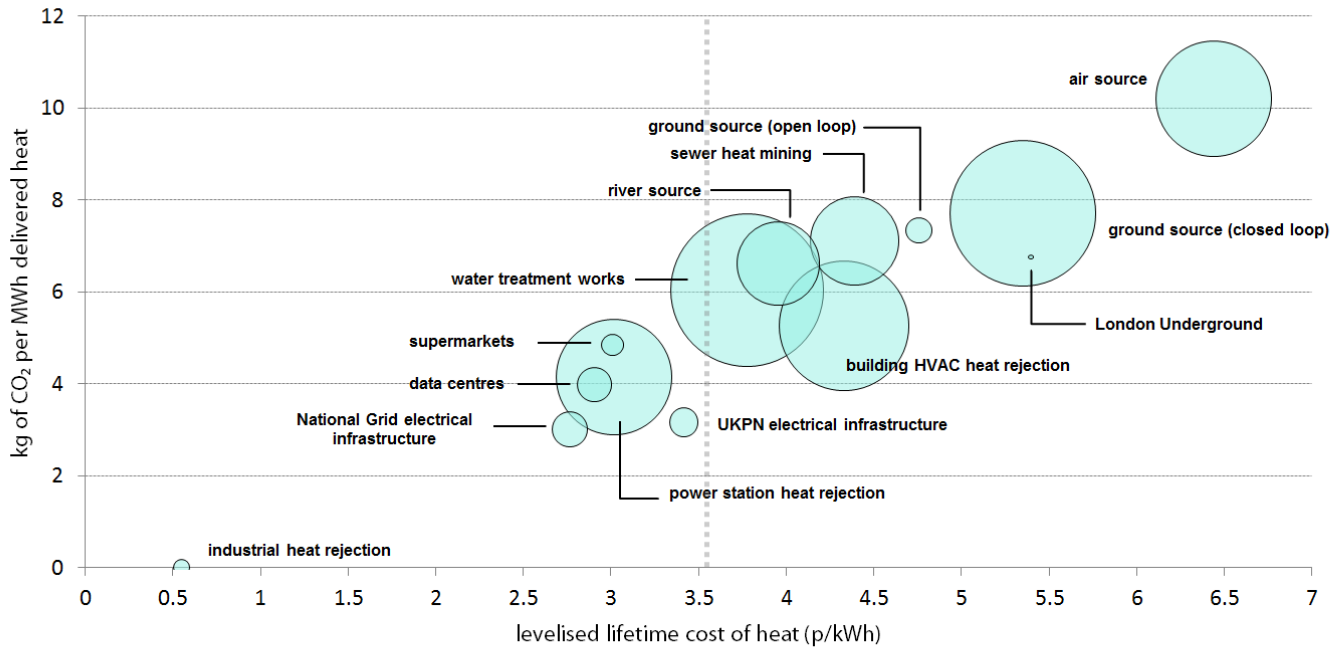

Figure 7 - Carbon intensity v levelised cost of secondary heat sources in London in 2050 under a scenario of reducing electricity grid carbon intensities but increasing energy prices. The grey dotted line indicates the cost of the counterfactual of centralised large gas boilers. Carbon intensity of the counterfactual (gas boilers) is off the scale of the graph.

Implications for connecting to low temperature sources

Conventional heating systems in existing buildings typically operate at flow / return temperatures of 82/71°C. Whilst it is possible to upgrade low temperature heat supply to this level using heat pumps, supplying heat at low temperatures can help improve the efficiency of the network.

Losses

Reducing the flow temperature has a significant effect on the network losses. The lower the flow temperature, the lower the difference in temperature between the flow pipe and the ground, and therefore the slower the heat transfer out of the pipe. Typically, a network with a **flow / return of 70/55 °C has losses of 6-7%, reducing the system conditions to 55/30 °C can reduce network heat losses to approximately 3.5-4.5%.**

Pipeline materials

Networks operating at lower temperatures can make use of plastic PEX[14] pipes which are relatively cheap, flexible and quick to fit when compared to conventional steel pipes. Their use in district heating systems is restricted as plastic pipes cannot withstand high temperatures. PEX should only be used if the operational temperatures are less than ~85°C and is therefore well suited to the conditions of low temperature networks.

Pipe dimensions

However, flow temperatures are likely to result in lower temperature differentials. For networks to operate at lower temperatures, pipe diameters may therefore need to be greater to accommodate the larger volume of water required to meet heating needs. There is an increased cost associated with this however savings in pipe material and losses can be used to offset this.

Multiple temperature networks

A low temperature source can in theory be integrated into a high temperature network without upgrade via a heat pump, though this will be difficult to control for smaller networks. This could make integrating secondary heat sources cheaper.

A more straightforward solution is the use of networks split into a number of areas at different temperatures. This arrangement is used successfully in Denmark where there are high temperature transmission mains and lower temperature networks to distribute heat to end users.

Connection of lower temperature sources to the return leg of DH pipe work

It may be possible to connect low temperature sources to the return leg of the district heating mains, depending on the primary heat production plant. **This design would not suit a CHP unit, where return temperatures are required to be as low as possible.** However, it may be suitable if the primary plant is boiler plant and is capable of receiving return water at a high temperature without losing efficiency.

Domestic hot water and legionella

Legionella regulations require any domestic hot water storage to be disinfected on a regular basis by raising temperatures to a minimum of 65°C[15]. This limits the practical district heating network temperature to around 70°C.

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[14] PEX is the common abbreviation of cross-linked polyethylene, a material often used for pipe manufacture.

[15] Building Regulations Approved Document G says that control of legionella should be done in accordance with the HSE Approved Code of Practice L8. These requirements are echoed in the CIBSE guidance document TM13 2002.

Systems in new flats in Denmark are operated at 50°C and deliver hot water at 45°C, minimising health risk by having negligible storage of hot water in their systems. Volumes are 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.

In the UK, domestic hot water is required to reach 50°C after 1 minute, suggesting that a similar approach might be viable here, increasing eth amount of heat demand secondary heat sources can serve.

An alternative solution is to use chemical dosing with chlorine dioxide to disinfect the lower temperature water. This is an appropriate method of legionella control under UK health and safety policy[16], with levels of 0.5 mg/l recommended. This dosing could take place in a cold water storage tank, however it would require on-going management input.

[16] Approved Code of Practice on Legionnaires' disease (ACoP L8)

Buildings – their construction and internal systems

The fabric of buildings, their heating systems and the way in which they are connected to a district heating system all impact upon their ability to utilise heat supplied at different temperatures. The more efficient the building systems and connections, the lower the temperature at which heat can be supplied and the less energy is required to upgrade low temperature secondary sources of heat to make them useful.

At the connection end of the network there are a number of different factors at play which influence the degree to which low temperature heat may be utilised. There is the building itself, in particular its thermal efficiency. There are the heating systems within the building such as radiators, underfloor heating, programmable thermostats etc. And there is the internal heating ('secondary side') circuit design.

Building fabric

Building energy modelling of different generic building types – high and low grade residential and non-residential – suggests that, without retrofitting or replacing existing heat emitters, **the majority (96% minimum) of the heating loads for these buildings can be met by supply/return temperatures of 70/50°C** and a significant majority (>70%) can be met by supply/return temperatures of 55/35°C. The proportion which can be met falls away significantly beyond this such that **at 40/20°C only around 30% of the heating load can be met** (dependent on building type).

Figure 8 illustrates the annual load profile of one building type (residential low build quality). A similar shape is demonstrated by the other three types modelled.

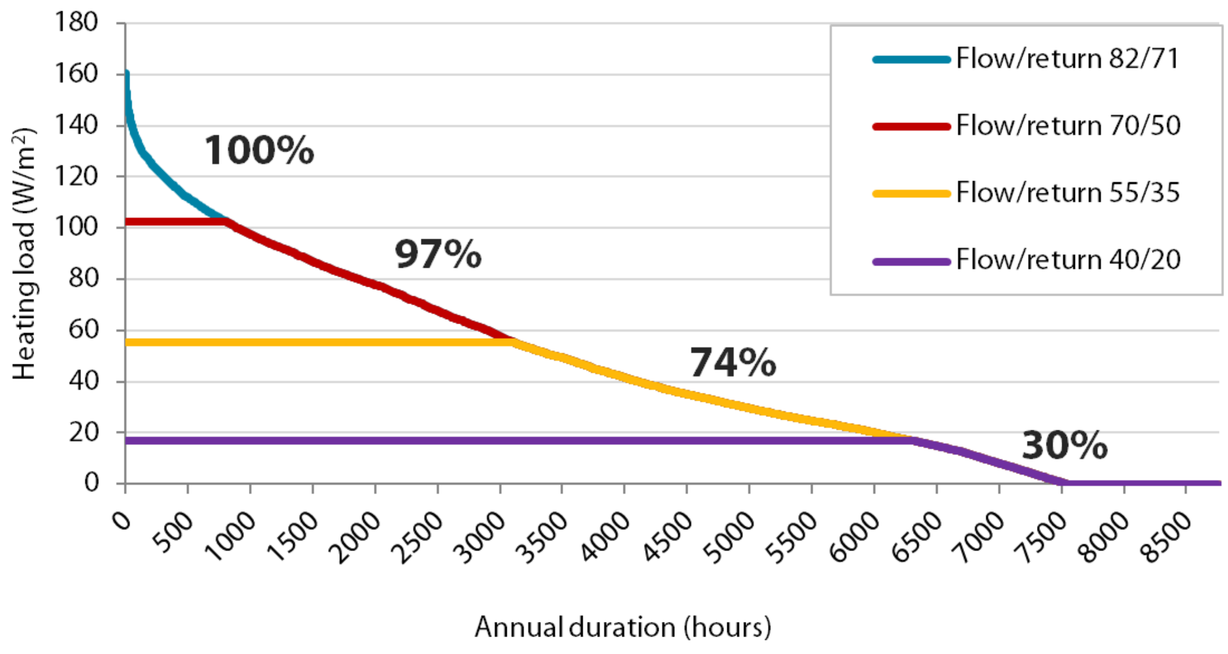

Figure 8 - Annual heat demand met by different supply temperatures (residential low build quality)

Retrofit measures may improve the ability of a building to utilise low grade heat. Modelling these measures **suggests that even upgrading a building by a single energy rating (eg. from EPC grade E to EPC grade D) provides a significant benefit.** Figure 9 demonstrates this effect for upgrading an E-rated building. Without retrofit measures, a low temperature supply with a flow/return of 55/35°C is estimated to meet only meet 74% of the annual demand. Upgrading the energy performance of the building to a D rating would allow this low temperature supply to meet 96% of the annual heating demand – higher temperature gas boilers could then be used to meet the remaining peak heating demand. Further upgrade to a C rating could allow 100% of demand to be met by a 55/35°C network , however although clearly providing an additional benefit, the cost associated with high levels of retrofit is likely to be prohibitive .

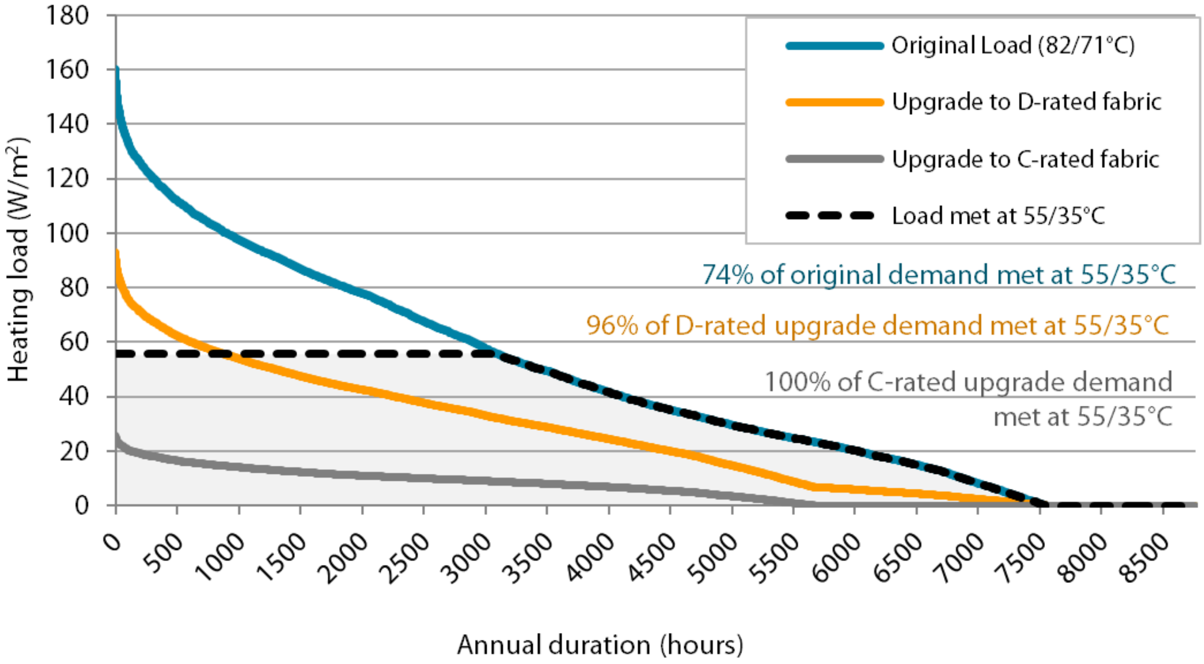

Figure 9 - Impact on load duration curve of upgrading the fabric of a poor quality building (ie. residential E-rated)

Secondary system design and control

The design of the final heating systems and the control of that system are important for effective utilisation of lower temperature heat sources, and particularly for ensuring low return temperatures to the heat network. Low return temperatures are essential as they enable the use of low temperature heat sources. They also maintain the capacity of the networks. **Many buildings connected to heat networks in the UK do not provide adequate cooling of the return water.** The following recommendations set out a best practice approach and draw from research by the International Energy Agency as well as case studies of recent practice.

Recommendations for terminal design and controls

Principle	Benefits
2-port control	Regulates flow and ensures heating water passes through heat emitters at only the rate required to heat the space. This means that heating water is cooled as much as possible, reducing the return temperature.
Underfloor heating	Central heating system operating temperatures are typically around 30 – 45°C and so well suited to low temperature supply without the need for extensive modifications.
Thermostatic radiator valves (TRVs)	Valves automatically control the temperature of the room by changing the flow to the radiator.
Programmable room thermostats	Allows heating to be restricted to certain periods and temperatures to reduce heat wastage and to avoid overheating.
Weather compensation controls	A more predictive control mechanism to measure outdoor temperatures and adjust heating supply temperatures accordingly. The network and systems can be operated at lower temperatures allowing lower temperature sources to be used. Only on cold days are flow temperatures increased.
Large Radiators	Sized to meet a pre-existing high heat demand with a lower flow temperature.

Principle	Benefits
Use of hot water storage tank	Reduces peak load on the heat network, allowing pipe sizes to be minimised
Use of plate heat exchangers for hot water provision	Instantaneous hot water performance, which does not run out. Excellent cooling of return water. Can be effectively combined with hot water storage tanks.

Recommendations for circuit design

Principle	Benefits
Variable speed pumping	Ensures that return temperatures are kept to a minimum even when low loads are present at the district heating connection.
Use of direct connections	Minimise costs and enables the lowest possible supply temperatures to be used.
One circuit (no use of low loss headers)	Heating water passes through the full heating system, maximising the opportunities to cool the water, reducing return temperature.
Multi-stage pumping	Gives good variation of flow over the whole range of load conditions allowing good turndown performance, maximising cooling of return water.
Plate heat exchanger sizing	Correct sizing means that close approach temperatures can occur (e.g. return temperatures on the primary side can approach the return temperature on the secondary side), maximising the cooling of the district heating return water.
Strainers	Protect heat exchangers from being blocked by debris. A flushing loop should also be installed on the secondary side to bypass the heat exchanger.
Pumps on return leg of heating circuit	Installed prior to the heat exchanger / connection point to reduces cavitation on the pump.
Connect circuits in series	When connected in series with lower temperature requirements such as underfloor heating, the return from the higher temperature system becomes the flow to the lower temperature system, maximising the cooling of the heating water.

Figure 10 shows the recommended configuration of a secondary heating system for connection to a district network. This includes the use of true variable flow pumping whereby flow can be reduced to very low (almost zero) levels during low load conditions. Low loss headers and primary circuits with separate pumping are avoided due to the large bypass flows which pass to the return of the primary heat network side without being cooled, leading to high return temperatures limiting use of secondary sources.

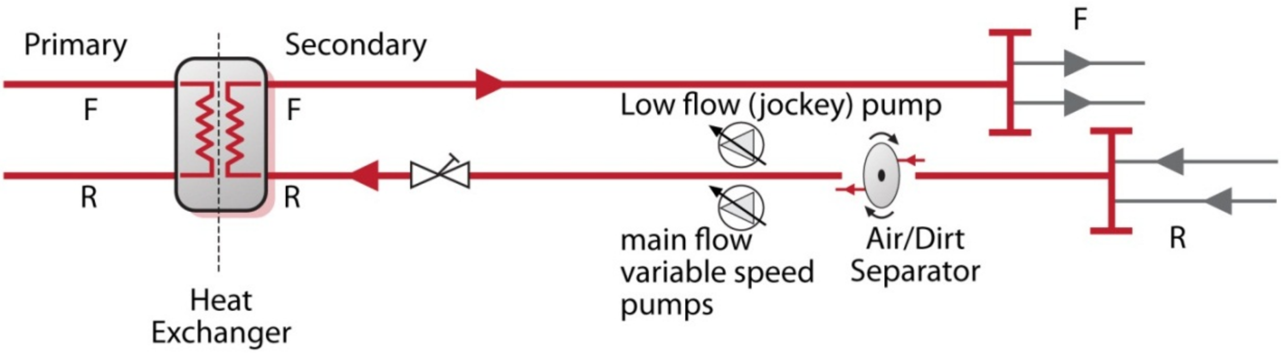

Figure 10 - Principle of recommended approach for secondary side heating systems

Emerging opportunities

A city wide geographical balance of secondary heat supply and demand highlights several areas particularly suited to low temperature networks.

In order to short list emerging opportunities across London, factors to consider are:

- Availability of multiple secondary heat sources
- Availability of quantum of heat sources
- Location with high density heat demand area making district heat networks more viable
- Location close of existing or planned district heat networks
- Ability of available secondary heat sources to meet majority of heat demand within a given area
- Knowledge of stakeholders supportive of secondary heat sources and district heating.

Based on this, the following opportunities are highlighted:

Opportunity	Reasons for shortlisting	Key stakeholders
Brent Park	Data centres and transformer stations supply	National Grid, UKPN, Options Technologies Ltd, Telecity Group, Vital Group
Paddington, Farringdon	Demand well suited to low temperature sources, mixed range of sources available. This area includes Bunhill Energy Centre and district network in Islington. This scheme has previously been targeted for piloting the integration of secondary heat sources.	Westminster City Council, Islington Council, private commercial stakeholders
Edmonton	Low carbon power station supply, minimal commercial risk	North London Waste Authority, E-ON (Enfield Power Station)
Barking and Royal Docks	Multiple heat sources, existing network forecast, extensive new build	Various
Hounslow	High supply (water treatment works, river abstraction) and reduced network costs.	Thames Water, Environment Agency

Pilot area study

To explore the opportunities and constraints of secondary heat systems in a real life scenario, a good example for more in-depth study is Barking and the Royal Docks area. This area presents the largest mix of supply sources including Barking Power Station, the Tate & Lyle sugar refinery and Becton Sewage Treatment Works. These large producers of waste heat are coupled with a high emerging demand in the Royal Docks where continued new development could suit low temperature networks as well as a high existing demand in Canary Wharf.

Based on a more detailed analysis of supply and demand, the analysis suggests that **delivered heat from secondary sources (2,800 GWh/yr) far exceeds the current demand in the area** which can connect to low temperature networks (446 GWh/yr).

Due to the intermittency of sources however, to guarantee that this demand can always be met, it is necessary to either connect more sources to a network for resilience, or to use top up gas boilers for peak demands. Top up gas boilers could also be used to meet peak demands by increasing network flow temperatures above the notional 70°C supply.

Figure 11 shows the spread of carbon intensity and cost of each heat source within the Barking and Royal Docks area. This suggests that **sources with both high load factors and low costs should be prioritised. These include energy from waste plants, industrial sources, supermarkets and data centres.** Barking Power Station highlights the negative effect of high intermittency of supply. The available supply here is large; however the cost of large heat pump infrastructure is slow to pay back due to the low (10%) load factor assumed for the power station.

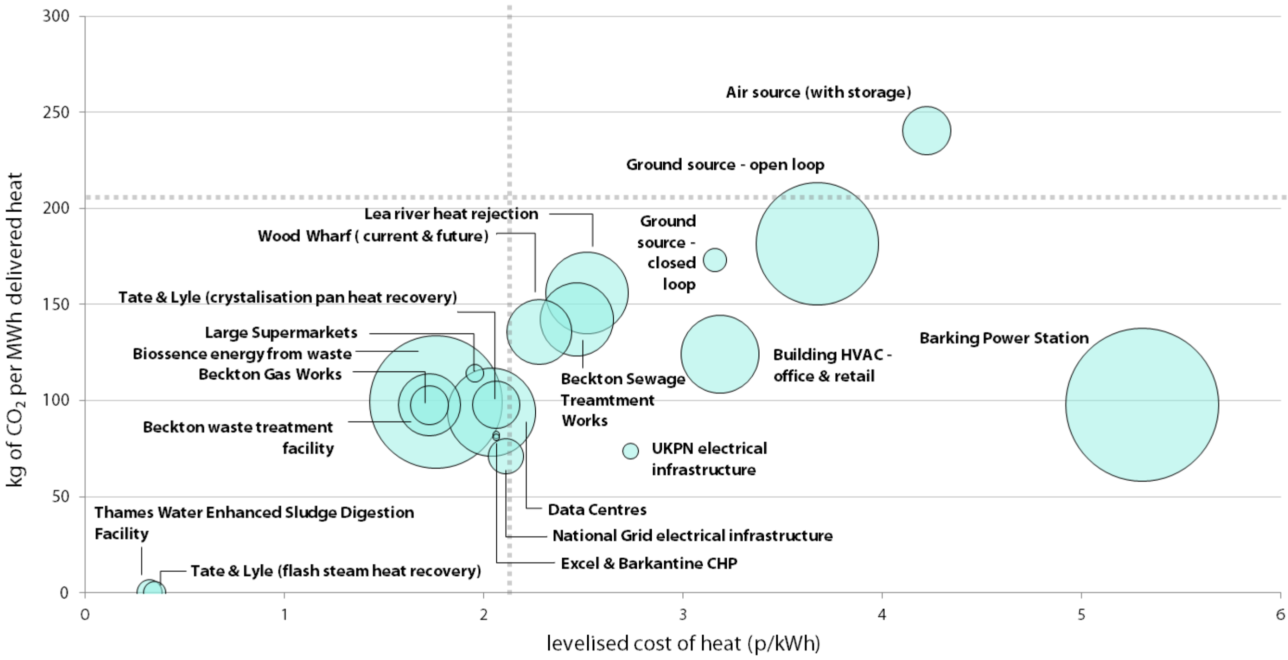

Figure 11 - Carbon intensity vs levelised cost of secondary heat sources in Barking and the Royal Docks. The grey dotted lines indicate the cost and carbon intensity of the counterfactual of centralised large gas boilers.

An energy balance has been carried out to determine the proportion of the 446 GWh/yr heat demand which can reliably *and* cost effectively (under a 2010 scenario energy price comparison) be provided by secondary heat sources. It was found that 399 GWh/yr could be delivered by these sources at 70°C, of which 332 GWh/yr would be available from the secondary heat sources themselves and the remaining 67 GWh/yr would be required as heat pump energy. The shortfall in meeting the annual demand would be met with heat provided from centralised gas boilers (the counterfactual case).

When comparing this scenario to one where *all* heating is provided by gas boilers, secondary heat sources demonstrate a 73% saving in the energy required for heating across the pilot area. Using the 2010 assumptions for carbon intensities this also represents a CO_2 saving of 48%.

The role of storage

Thermal stores can be used as 'dumps' for heat produced during off-peak periods or when excess electricity from wind generation is available at low or negative cost. Where sources do not require heat pumps to reach required temperatures, this energy would be available at no additional energy cost and could be used to effectively maximise the load factor of the lowest cost sources.

Diurnal (daily variation) storage can take the form of large water tanks used to balance peaks and troughs in daily supply variations. Where sources vary seasonally it is possible to store low temperature heat for several months using aquifer thermal energy storage (ATES).

Alternative network system designs

As noted, the cost and carbon involved in upgrading low temperature sources of heat to match demand needs can be significant. Alternative network system designs are being developed, particularly in Canada, that seek to utilise and balance heating and cooling demands between buildings using very low temperature networks. These are known as District Energy Sharing Systems (DESS).

A DESS utilises a warm and cool pipe to share low grade thermal energy between buildings. Each building has a heat pump (which can be reversible) to provide heating (or cooling) at the required temperature.

The system is based on a low temperature un-insulated distribution system that draws energy from diversified sources. Two pipes connect various loads and sources through distributed heat pumps. These provide heating to connected buildings by drawing heat from the DESS 'warm pipe'. The same heat pump can be used to cool the buildings in this case rejecting heat back into the 'warm pipe'. Buildings in heating mode pull their heat from a 'warm pipe' (10°C to 20°C) and dump their cool water into a 'cool pipe' (5°C to 15°C).

This type of system works particularly well in areas with a mix of heating and cooling loads such as residential and offices or retail. It is suited to low temperate heat sources and could be introduced into schemes where buildings and building layouts are suitable. A schematic showing an overview of this concept is given in Figure 12.

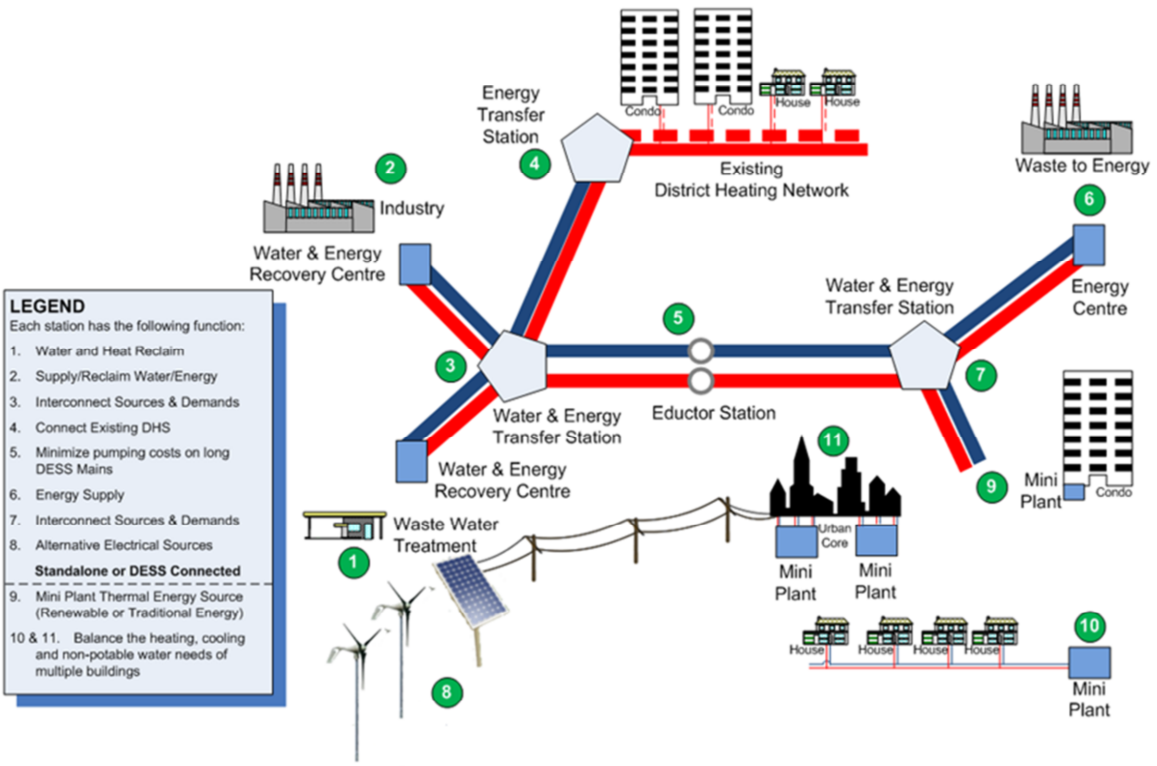

Figure 12 – Overview of the concept for a District Energy Sharing System (DESS) *© DEC Engineering*

Conclusions

The utilisation of secondary heat sources via district heating networks has the potential to be viable at scale. The estimated maximum quantity of secondary heat that could be effectively used (24,900 GWh/year) represents approximately 24% of London's current heat and power demand.[17] This would exceed the Mayor's target of supplying 25% of the heat and power used in London from localised decentralised energy systems, given that some district energy schemes are already in place.

There are many factors that will influence the achievement of this goal. Viability is dependent on the cost of electricity as most heat sources require an upgrade in temperature via electric heat pumps prior to being delivered to the end user. Industrial sources require the least energy to upgrade heat and so should be prioritised above other sources.

Building design will also affect the ability to fully utilise secondary sources of heat. Where building fabric is improved, internal heat demand can be met by heat supplied at lower temperatures. These lower temperatures make the integration of secondary sources of heat more viable.

In terms of environmental impact, as the carbon intensity of the electricity grid falls, the carbon intensity of heat from secondary sources that require upgrade to higher temperatures will also fall.

The potential for secondary heat sources to support the transition to a low carbon economy and to meet the Mayor's targets is clear, however, integrating these sources into district heating networks in practice will be challenging and require concerted action between a number of parties. Local and national government will have a role to play in supporting the development of low carbon heat projects, the prize being greater resource efficiency and effective carbon reduction over the long term.

[17] Total London energy consumption figures based on the GLA Decentralised energy capacity study. GLA, 2011.