MAYOR OF LONDON

London Heat Network Manual II

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Greater London Authority
May 2021

Published by
Greater London Authority
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London SE1 2AA

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Preface to the Second Edition

In the seven years since the Greater London Authority (GLA) first published the London Heat Network Manual (LHNM, the Manual), decentralised energy (DE) infrastructure and heat networks in London have developed significantly, through Mayoral strategies, programmes and policies as well as the efforts and commitment of utilities, institutions, government programmes, local authorities, commercial entities and other stakeholders. The national picture also looks different with the introduction of the Government's Heat Network Delivery Unit (HNDU), Heat Network Investment Project (HNIP) and Green Heat Network Fund (GHNF), the Heat Networks Efficiency Scheme (HNES) as well as the recommendation of heat network regulation by the Competition and Market Authority (CMA) and emerging government work around what the associated market framework should look like. The Manual has been revised, updated and relaunched to reflect these developments and the latest thinking and best practice in the industry; the objective of moving to a low-carbon economy is now at the centre of London's vision.

The Mayor's London Environment Strategy (LES) was published in 2018, which set out the ambition for London to be a zero carbon city by 2050, to improve the city's poor air quality, and to catalyse the transition towards a low-carbon circular economy[1]. Since the LES was published the Mayor's has declared a climate emergency and set a new and more ambitious target in response to the heightened need for action and that is for London to be net zero carbon by 2030. The Mayor's actions to decarbonise the heating of London's buildings, the city's largest source of carbon dioxide (CO_2) emissions, are directed towards developing clean, smart and integrated energy systems using local and renewable energy resources. The London Plan 2021 incorporates new policies promoting sustainable infrastructure in new developments aimed at reducing greenhouse gas emissions and increasing the uptake of heat networks[2].

In this Second Edition, the Manual has been updated to reflect the London Plan 2021 and the LES including the identified Heat Network Priority Areas[2] and the latest energy planning guidance[3]. It contains guidance on low temperature networks, the use of heat pumps (HPs) and the role of smart controls. The concept of exergy is introduced offering the potential for a more resource-efficient and circular approach to heat supply.

Glossary

Acronym	Term
3G	Third Generation Network
4G	Fourth Generation Network
5G	Fifth Generation Network
ACC	Air Cooled Chiller
AHU	Air Handling Unit
AMR	Automatic Meter Reading
API	Application Programming Interface
ASHP	Air Source Heat Pump
AQMA	Air Quality Management Area
BHE	Borehole Heat Exchanger
CAPEX	Capital Expenditure
CCME Strategy	Climate Change Mitigation and Energy Strategy
CHP	Combined Heat and Power
CHW	Chilled Water
CIL	Community Infrastructure Levy
CIU	Cooling Interface Unit
CMA	Competition and Market Authority
CO_2	Carbon Dioxide
COP	Coefficient of Performance
CPI	Consumer Price Index
CV	Calorific Value
D&B	Design and Build
DBO Contract	Design, Build, Operate Contract
DE	Decentralised Energy
DEEP	Decentralised Energy Enabling Project
DEPDU	Decentralised Energy Project Delivery Unit
DHW	Domestic Hot Water
DNO	Distribution Network Operator
DUKES	Digest of United Kingdom Energy Statistics
EA	Environmental Agency
EfW	Energy from Waste
EMP	Energy Master Plan
EPR	Environmental Permitting Regulations
ESCo	Energy Services Company
FCU	Fan Coil Unit
FiT	Feed-in Tariff

Acronym	Term
GIS	Geographic Information System
GLA	Greater London Authority
GSHP	Ground Source Heat Pump
HIU	Heat Interface Unit
HNDU	Heat Networks Delivery Unit
HNIP	Heat Networks Investment Project
HP	Heat Pump
IGT	Independent Gas Transporter
IoT	Internet of Things
IP	Internet Protocol
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
kW	Kilowatt (unit of power)
kWh	Kilowatt hour (unit of energy)
LDF	Local Development Framework
LDO	Local Development Order
LEA	Local Energy Accelerator
LES	London Environment Strategy
LTHW	Low Temperature Hot Water
MEEF	The Mayor's Energy Efficiency Fund
MPC	Model Predictive Control
MW	Megawatt (unit of power)
MWh	Megawatt hour (unit of energy)
NBP	National Balancing Point
NJUG	National Joint Utilities Group
NO_x	Nitrogen Oxide
NPPF	National Planning Policy Framework
NPV	Net Present Value
NRSWA 1991	New Roads and Street Works Act 1991
O&M	Operation and Maintenance
Pa	Pascal (equivalent to one newton per square metre)
PFI	Private Finance Initiative
PHE	Plate Heat Exchanger
PI Diagram	Process and Instrumentation diagram
PVC	Polyvinyl Chloride
REPEX	Replacement Expenditure
RHI	Renewable Heat Incentive
ROC	Renewables Obligation Certificate
RRR	Required Rate of Return
RPI	Retail Price Index
SAP	Standard Assessment Procedure
SD&C	Sustainable Design and Construction

Acronym	Term
SLA	Service Level Agreement
SCOP	Seasonal Coefficient of Performance
SoLR	Supplier of Last Resort
SPD	Supplementary Planning Document
SPV	Special Purpose Vehicle
UFH	Underfloor Heating
UIP	Utility Infrastructure Provider
ULTHW	Ultra-Low Temperature Hot Water
VSD	Variable Speed Drive
WSHP	Water Source Heat Pump

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Introduction

Heating remains the single largest source of energy demand in the UK, exceeding both transportation and electricity generation. The vast majority of our heat is still produced by burning fossil fuels, with around 80% coming from natural gas, and consequently heat is responsible for close to a third of the UK's CO_2 emissions.

This ongoing dependence on fossil fuels not only represents a significant and immediate challenge, but is also in direct conflict with the requirements for urgent climate change action presented by the Intergovernmental Panel on Climate Change (IPCC)[4], the Paris Agreement and the UK's recent legislative commitment to bring greenhouse gas emissions to net zero by 20505. The Mayor has declared a climate emergency and through his London Plan requires all major new developments to be net zero carbon. This is echoed nationwide by the UK Green Building Council's framework definition for the construction industry to also transition new and existing buildings to net zero within the same timeframe[6].

Heat networks are recognised as one of the key opportunities for transformational change, and have the potential to address all three components of the energy trilemma facing the UK: CO_2 emissions, energy security and energy cost. This can be realised through their ability to use low-to-zero carbon energy in dense urban areas; provide long-term flexibility to accommodate new and emerging heat production technologies and energy sources; and increase the diversity of the energy supply mix, which contributes to energy security.

Currently, heat networks supply about 2% of the UK's heat demand in the domestic, public, industrial and commercial sectors[7], but this is set to increase close to tenfold in the coming years. Since 2011, the Mayor has initiated this growth across London with three projects supporting the development and implementation of heat networks. From August 2011 until March 2016, Decentralised Energy Project Delivery Unit (DEPDU), helped London boroughs and other private and public sector partners to develop DE projects, offering specialist technical, financial and commercial advice. The project was set up with €3.3m funding, 90% of which was from the European Investment Bank's ELENA fund.

The second project, following on from DEPDU, was Decentralised Energy Enabling Project (DEEP). From June 2017 until September 2020, DEEP was established to bring London heat network projects to market by providing public sector intervention and support to larger-scale DE projects which the market has failed to develop and realise. The £3.5m project is 50% funded by the European Regional Development Fund (ERDF).
In October 2020 the GLA launched the Local Energy Accelerator (LEA), a new £6m programme providing expertise and support to organisations to develop clean and locally generated energy projects such as heat networks which use renewable heat sources.
On a National Level, the Department for Business, Energy & Industrial Strategy (BEIS) published the Clean Growth Strategy in 2017, which sets the target for the development and expansion of heat networks across the country to deliver 18% of the heat demand by

2050. This is supported by nearly £20m in technical assistance through HNDU[8] and £320m in capital support under HNIP[9].

The Green Heat Network Fund (GHNF), due to be launched in April 2022, is a capital grant fund which aims to support the development of low and zero carbon heat networks. The £270m fund will be open to both the public and private sector in England and will further build on the progress and developments made by HNIP.
With energy at the heart of our major cities' transformation to sustainable, resilient, low-carbon communities, the delivery of new district heating energy infrastructure will be critical to securing our energy future. This district heating infrastructure will need to be smarter and more integrated with the existing national energy systems to ensure long-term effectiveness.

The evolution of heat networks in London

Over the course of the past 17 years, the publication and creation of a series of strategic planning documents and tools, advisory and funding projects by the Mayor have enabled the evolution and delivery of many heat networks in London. Published in 2004, the first Energy Strategy[10] highlighted the growing issues of energy security and fuel poverty in London, within the global context of climate change and resource constraints. The strategy committed to supporting the growth of DE generation as a core component of sustainable energy supply. This has been instrumental in the promotion and development of heat networks in London.

The London Plan (2008) established the requirement for London boroughs to embed policies and proposals within their local plans in support of establishing DE network opportunities, with particular focus on heat networks[12]. Proposed alterations to the London Plan, published in 2014, retained the principles for energy and climate change, but placed more emphasis on the transition from gas CHP and configuring networks for lower temperature, secondary heat sources.

The London Plan (2016)[13] reconfirmed the zero-carbon standard (Policy 5.2) and support for heat networks and CHP systems (Policy 5.6), but, underpinned by the LES [1], placed greater emphasis on improving air quality, required major developments to have communal low temperature heating systems, and set a heating hierarchy which puts zero-emission or local secondary sources above gas-fired CHP and ultra-low NOx boilers. This was complemented by the 2018 publication of Zero Carbon London: A 1.5°C compatible plan[14].

This focus on strategic DE planning across London led to the realisation of the London Heat Map[11] in 2019, which revealed that opportunities for the creation of heat networks across the capital.
As a result of the London Plan and the Mayor's DE support initiatives many heat network projects have already been delivered across London, including low temperature networks running from various low-carbon sources. For example, Bunhill Phase II, Islington (abstracted from ventilation shaft heat from the Underground)[15], London South Bank University, Southwark (ambient loop)[16] and Kingston Heights, Kingston upon Thames (water source heat pump - WSHP)[17].

The London Plan 2021 continues to support the development and expansion of heat networks, establishing Heat Network Priority Areas (HNPAs) and a heating hierarchy for major development proposals. Further guidance relating to energy, carbon and heat network requirements for planning proposals is available on the London Plan Guidance webpage.

Scope of the London Heat Network Manual

The primary objective of the Manual is to support the development of heat networks utilising large-scale renewable and waste heat sources. Individual district heat networks are expected to develop initially as islands in Heat Network Priority Areas within London, where the heat density and availability of renewable and local heat sources is sufficient for their formation and subsequent expansion as they connect an increasing number of buildings within the area over time. These district-level island networks will form the major building blocks of what will eventually become larger area-wide heat networks as adjacent island networks expand and interconnect. These larger heat networks will enable the exploitation of multiple low-carbon waste heat and environmental energy sources, as well as economies of scale that will allow them to provide secure, clean, low-carbon and affordable heat to their customers.

The Manual is intended to provide practical, accessible and consistent guidance for planners, designers and developers of heat networks. It is intended to complement not supersede other published technical standards and good practice guides.

The Manual covers the following aspects of heat network development:

- The technical design principles and concepts for the physical infrastructure of a heat network focusing on interfaces between heat sources and the network, distribution and consumer installations;
- Guidance on contract structures and management to help inform developers and project sponsors of appropriate options and the key issues to be considered when establishing delivery models and determining procurement strategies;
- Guidance on tariff structures and associated charges that can reasonably be incorporated as part of a project’s revenue streams; and

The updated Manual includes sections covering exergy, smart controls and ambient networks, along with specific content on HPs and hybrid networks. The concept of exergy is introduced with its ability to give a complete insight to resource efficiency that traditional policy strategies and energy efficiency does not. Smart controls will be essential to optimise the use of intermittent renewable energy sources in combination with thermal storage. Smart systems will have the capability to deliver flexibility to the national electricity system to ensure affordable heat for Londoners. Environmental and local waste heat will play a major role in delivering low-carbon heat enabled by heat networks and HPs.

The Manual also reflects the Heat Network (Metering and Billing) Regulations (2014), which establish an obligation for landlords to provide heat metering for all tenanted properties[18] supplied from a heat network.

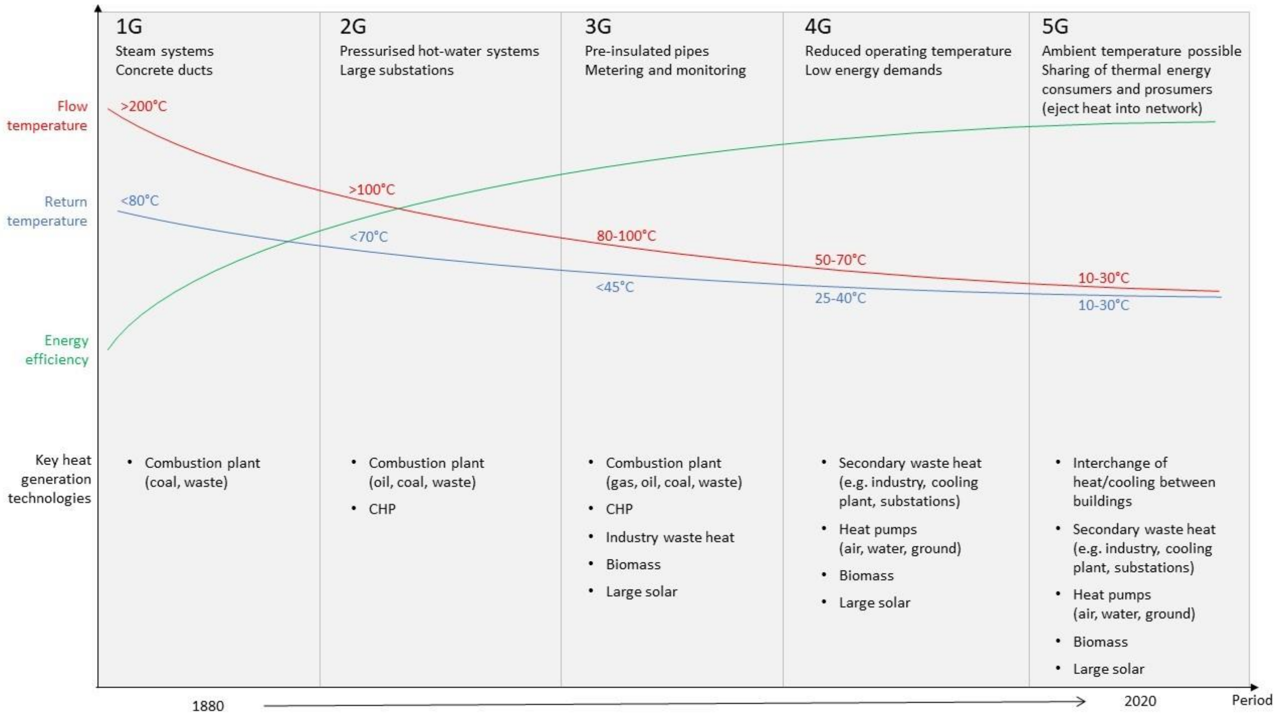
Introduction to heat networks

Heat networks act as an energy carrier to supply heat produced by various means to multiple domestic, commercial and industrial buildings in densely populated areas, such as London. In some cases, associated networks may also deliver cooling through rejection of waste heat from buildings back into the heat network.

Heat networks transition

Figure 1 illustrates the trending direction of heat networks. Most of the existing heat networks in the UK are ‘third generation’ (3G) networks, with flow temperatures around 80-100°C. The need for greater carbon reduction is driving the transition of heat networks to ‘fourth generation’ (4G), which operate at lower temperatures and enable secondary heat sources to be used more extensively. Emerging ‘fifth generation’ (5G) networks operate at ambient temperature and could deliver both heating and cooling.

Figure 1: Trend towards lower temperature, lower carbon heat network (future generations)[19]



3G and 4G heat networks are based on a flow and return distribution system, while 5G networks can be designed based on different primary side hydraulic arrangements (see Primary side network design section).

Drivers and benefits of heat networks

There are many drivers and potential benefits for implementing heat networks which, as can be seen from the summary in Table 1, vary according to the project and contextual circumstances. Both the London Plan, more broadly, and its Policy SI3 Energy infrastructure specifically have been primary motivators in the increase of heat networks and have provided key justification for their deployment as a central tenet of London's energy transition. Not least in their requirement for large-scale development proposals to have energy masterplans (EMPs) to establish the most effective energy supply options.

Table 1: Drivers and benefits of heat networks

	Drivers	Potential additional benefits
Environmental	• reduced CO_2 emissions. • reduced air quality impact.	
Economic and financial	• reduced cost of compliance with Building Regulations (e.g. reduced carbon offset payments) for the developer.	• job creation and stimulation of the local economy. • reduced operation and maintenance costs as compared to individual systems. • reduced space in the building to provide the same low-carbon heat source. • heat networks can be set up as an attractive Energy Services Company (ESCo) offering, reducing the developer's up-front capital costs and removing the developer's need for long-term engagement in the project.
Legal	• compliance with regulations and planning policy.	
Social	• reduced energy costs for the customer. • alleviated fuel poverty.	• no maintenance responsibility for the consumer; the heat network operator required to maintain the heat supply 24 hours per day.
Technical	• flexibility of heat source depending on location (these can either operate alone or in combination).	• flexibility for fuel diversity, with reduced exposure to fluctuations in commodity prices (increased energy security and resilience).

	Drivers	Potential additional benefits
	• increased fuel efficiency through use of CHP and use of recovered heat which would otherwise be lost. • allows a broad range of energy generation technologies to work together to meet demand for heat. • provides wider benefits to the National Grid by managing electricity demand/generation.	• longevity of pipework and potential to transport heat regardless of the type of heat source/generation technology. • efficient operation of the heat generation plant (such as CHPs and HPs) can be achieved through the use of thermal stores.
Health and Safety	• elimination of a potential source of carbon monoxide where gas would otherwise be used (poisoning and ignition risks)	

Introduction to heat sources

District heat networks supply heat in the form of hot water either through extraction from a nearby heat source or production in an energy centre (for example, a gas boiler which converts gas to heat). In this context ‘supply’ refers to the transfer of heat post-production or generation. While the term, heat networks, encompasses not only the physical infrastructure, but also all the contracts, regulatory structures and organisations required for the generation, distribution and consumption of heat within a city.

This section introduces some of the potential heat sources that are commonly considered for the supply of heat in the development of networks. The Manual does not assess or recommend specific renewable or waste heat generation technologies, but discusses the alternatives available and provides guidance on the merits of any particular scheme design and how it might be assessed. The heat source for a network may change over time as the market and technologies change to favour new, lower carbon, generation technologies, or other more economic heat sources.

Gas-fired CHP has played a large role in heating in the UK for the last few decades. CHPs provide a reliable and efficient use of fuel for small scale heat networks and deliver primary energy savings of 30-45% compared with the conventional separate generation of heat from boilers and electricity from central power stations.

However, because CHPs burn gas to generate heat and electricity, they produce CO_2 emissions associated with the combustion of gas. While the grid electricity carbon factor in the UK continues to drop (through grid decarbonisation), the benefit of generating electricity by CHP will also reduce and this will result in higher net carbon emissions associated with their operation. That said, when CHP displaces gas-fired power stations at times of peak usage, savings will still be made due to their associated efficiency improvement. With this in mind, a transition to new, zero-emission solutions, including the use of secondary heat sources, will be required to meet London's carbon and air quality targets.

Over the past few years there has been an increase in the diversity of both energy sources and generation technologies selected for heat networks, particularly as the scale of networks increases. Technology selection depends on a range of technical, environmental and economic considerations; in some cases, multiple technologies may be used within a single energy centre to ensure efficient and reliable operation across the range of heat demands. With London's increasing focus on carbon emission reduction and air quality improvement, a range of secondary heat sources are becoming key in the transition towards low- or zero carbon heat[20]. These include but are not confined to:

- Environmental sources:
    - Air
    - Ground
    - Surface water (e.g. rivers)

- Heat as a by-product of processes and infrastructure operations (waste heat):
    - Cooling systems (e.g. chillers in buildings and cooling plant for data centres)
    - Electrical substations
    - Industrial processes
    - Power stations (including energy from waste plants)
    - Sewers
    - Ventilation extracts from underground railways (e.g. London Underground)
    - Water treatment works

Further information on these sources can be found in Appendix 2: Heat Sinks.

The report *London's Zero Carbon Energy Source: Secondary Heat* also includes guidance around the availability, cost and energy considerations of secondary heat sources, as well as opportunities and issues for the integration of these sources into heat networks and with the London building stock[20]. In addition, London Heat Map aids identification of locations of these sources[21].

Heat sources can be split broadly between 'direct' and 'indirect'. Direct heat sources refer to those with an available temperature higher than that required for distribution through the network, i.e. the heat can be directly imported into the network through a heat exchanger.

Indirect heat sources refer to those with an available temperature lower than that of the network, i.e. an HP is required to raise the temperature of the heat to that of the network. Most secondary heat sources are indirect.

The coefficient of performance (COP) of an HP measures its efficiency, and it is the ratio of useful heat (or coolth) supplied to the electricity consumed. The ratio depends on the temperature differential between source and supply temperature. When the system parameters allow for higher COPs to be achieved, HPs are more likely to be viable as they require lower electricity input, with associated benefits in terms of operational costs and carbon emissions.

It is important that district heating networks are able to maintain the supply of heat in the event of unexpected plant failure. In heat generation, backup supply is typically met using additional low-cost technologies such as boilers to provide stand-by and peaking capacity.

Introduction to heat distribution

The distribution of heat from the source of production to the end consumer requires a pipework system with a network of flow and return pipes, which supply hot water to the consumer and return cooler water back to the heat source. This is known as a ‘closed system’, in which continuously recirculating water transfers energy to the consumer to meet their heating requirements. The heat distribution network comprises:

- Heat network flow and return distribution pipework, including insulation, valves, branches, blanked-off ends for future connections, sensors (if necessary) and leak detection equipment; and
- Ancillary equipment in the energy centre including distribution pump sets, water treatment plant and pressurisation equipment.

When correctly designed, installed, commissioned, and operated, heat networks are reliable long-life assets that can deliver heat produced by a variety of sources to the consumer. The heat temperature depends on the type of source and can affect the efficiency of heat distribution. As previously mentioned, many sources are at a temperature which is too low for direct use and therefore the heat must be upgraded through the use of an HP to meet the building’s required temperature. Conversely, lower temperature heat supply is possible but requires larger emitters inside buildings – for example, larger radiators or underfloor heating (UFH) – in order to achieve the same comfort levels, which should be considered during the design stage.

A study by Buro Happold[22] found that lower temperature heat sources can be suited to act as a base supply for a building, meeting 99.8% and 59.7% of the annual heat demand of a low efficiency house at a supply temperature of 70°C and 40°C respectively. Therefore, a lower supply temperature results in greater reliance on a backup high temperature energy source to meet peak demand, particularly in cold weather, as explained further in the Hybrid network section.

The pipework for a heat network is typically installed under a public highway in much the same way as water and gas infrastructure, with the main differences being that the pipes are insulated and run in pairs, and so tend to require more space within the utility corridor. Branch connection pipes to supply each building or estate served by the network are also laid under pavements or estate roads and typically emerge directly into a development plant room or energy centre.

Introduction to heat consumption

The residential sector accounts for the greatest share of London's heat demand, using energy for space heating and domestic hot water (DHW). Other heat consumers include commercial buildings, offices, community centres, schools and hospitals. In total, London consumes around 66TWh/year in heat energy. Buro Happold's research indicates that as much as 50TWh/year of currently unused heat sources may be available in London and the surrounding area, which could be captured and used in heat networks to supply the majority of London's heat demand[23].

Consumers of a well designed and installed heat network should not perceive any difference in the delivery of space heating and DHW when compared with a conventional building heating system. For most consumers, the key difference is the replacement of a gas boiler with a heat interface unit (HIU), which transfers heat from the network to the building's heating and hot water systems.

The HIU controls the delivery of heat to the consumer and normally incorporates billing meters which measure, record and communicate heat consumption. For consumers with large heating requirements, a heat exchange substation may also be included, which hydraulically separates the building's heat distribution from the heat network. Heat exchange substations represent a convenient commercial boundary between the heat network operator and its consumers.

The operating temperatures of a heat network and its consumers' heating systems must correspond to ensure the efficient and effective delivery of heat. If the operating temperatures can be reduced at the consumer end, this can allow the operating temperature of the heat network to also be reduced. In turn, this may create opportunities for more efficient use of lower temperature and low carbon sources of heat (for example, heat recovered from electrical substations or underground railway ventilation shafts), while still meeting the heat demands of consumers.

Heat network development

The development of heat networks relies on the identification of the right mix of heat demands, connecting buildings and a motivated project sponsor. The Energy Master Planning process has been developed to identify opportunities for new networks in an area, and to set out a long-term vision for heat network development.

An Energy Master Plan (EMP) sets out initial proposals for pipe routes and plant locations, as well as a high-level technical and economic assessment. EMPs should outline existing, planned and proposed developments that may be of interest for future interconnection and should therefore play a key role in the considerations of a development's network design, such as placement of energy centres and the capacity of pipes to interconnect with other heat loads.

The key steps in an EMP involve:

- Mapping existing energy demands in the area and identifying ownership and control of these demands;
- Highlighting the demand points which are more likely to connect to a district heating network for prioritisation (major heat loads including anchor loads, such as social housing, universities, hospitals, etc.);
- Mapping planned new development in the area, considering development phasing and how this could connect to future phases of the heat network;
- Mapping energy supplies/plants in the area, including local heat and fuel sources, opportunities from energy from waste plants and secondary heat sources, including both environmental and waste heat;
- Mapping existing and planned heat networks;
- Identifying opportunities for low and ambient temperature heat networks;
- Identifying suitable locations for energy centre(s) and/or energy storage;
- Identifying opportunities to maximise renewable electricity generation and incorporate demand-side response measures;
- Identifying barriers and constraints (physical, land ownership etc.), including infrastructure and land requirements for electricity and gas supplies;
- Identifying routes for potential heat and/or cooling networks;
- Identifying opportunities for future-proofing utility infrastructure networks to minimise the impact from road works; and
- Identifying implementation options for delivering feasible projects, considering issues of procurement, funding and risk, and the role of the public sector.

Once the above information is assembled into the map, different combinations of demand connected to potential energy centres can be evaluated using techno-economic modelling techniques, which provide indicative sizing and financial viability of the network. There are various tools which may be helpful in the EMP stage, such as the London Heat Map[11] and THERMOS[24]. The London Heat Map is a tool provided by the GLA to help to identify areas of high heat demand in London and to construct heat network models and assess their feasibility, and also includes data on existing and proposed heat networks. THERMOS is a project to develop a modelling methodology and software to support planners in identifying opportunities for thermal energy networks in any given area in Europe. The application is designed for use by local authorities and developers.

A number of London boroughs are contributing towards EMPs across London, using and building on data in the London Heat Map[11]. They identify opportunities for heat networks within the masterplan area, both within the boroughs themselves and across borough boundaries. The latest information on which boroughs are carrying out EMPs is available on the GLA website[25].

EMPs have resulted in the development of planning policies to promote heat networks, and the connection of new developments to those networks. EMPs that have resulted in either an existing or proposed heat network can be found listed online on the London Heat Map[11].

Following the production of an EMP, a feasibility study of an individual opportunity should be undertaken for more detailed assessment. The study may consider the specific requirements of individual buildings to be connected, the phasing of the network, and the route of the network. It will provide a more robust indication of the economics of the proposed network, and the technical information required to enable decisions on commercial structures for network delivery and operation needed to proceed with the procurement process.

Principles of design for heat networks

This section covers the main technical features of heat network design, control and operation and includes guidance on the design requirements and options for secondary (building) side systems. Further details on heat networks as well as the latest best practice guidance can also be found in *CP1: Heat Networks Code of Practice for the UK*[34].

Components of heat networks

The components of the physical network infrastructure as covered by the Manual include:

- **Energy sources**: the diverse sources which can be used to supply heat to a network include environmental (for example, ground or water sources), waste of low-grade heat (for example, from underground railway ventilation shafts) or fuel-based production (for example, gas boilers or gas-CHP). With decarbonisation as increasingly important driver for heat network deployment, they are transitioning from fuel-based production towards environmental and waste sources;
- **Heat production plant**: plant and equipment that takes one or more energy vector (for example, electricity, gas, low-grade heat) and converts it to heat at the temperature required by the network. This is typically located in a central energy centre, but in some cases heat generation plant may also be located at a building level;
- **Heat transmission and distribution network**: the network of pipes necessary to distribute the heat to each connection/building/consumer; and
- **Heat exchange and consumption equipment**: the interface(s) between the network and the consumer, located within buildings either in a plant room or in each flat.

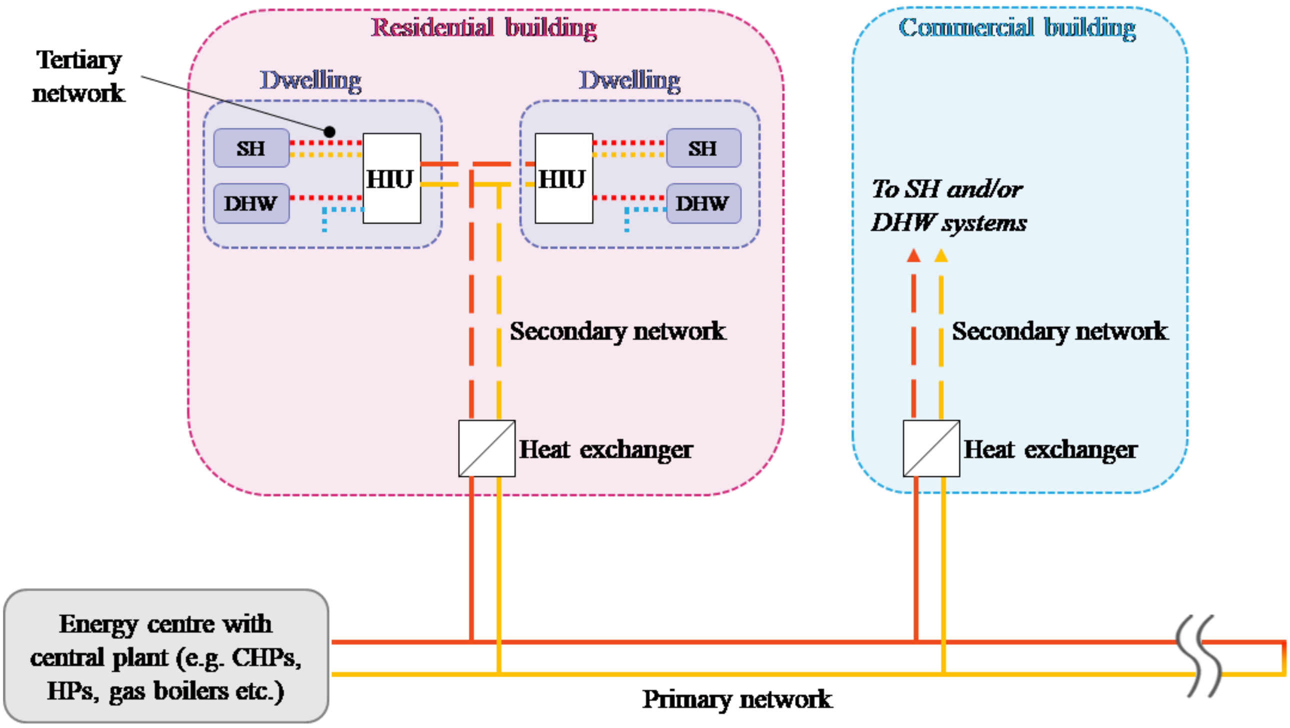
Design considerations

There are a number of key design considerations for the generation, distribution and consumption equipment that should be addressed when designing heat networks, including the energy source.

A good design should consider the consumer heat needs for space heating and DHW, as well as available local heat sources. Networks connecting to existing developments should be designed with a consumer-led approach to ensure that heat can be supplied under all conditions, whilst also considering the available heat sources.

The network, distribution pumping equipment, heat transfer equipment and standby and top-up heating arrangements (forming the energy centre) can be designed according to the principles outlined in this section. Figure 2 shows an example heat network; it is indicative only and not representative of all potential configurations.

Figure 2: An example heat network



Design life

Heat networks form a substantial element of London's energy infrastructure, and require significant planning, design, resource effort and investment in order to be delivered. This is particularly the case in the capital's dense urban environments where hard surfaces and busy routes require excavation at significant cost.

Properly designed and installed heat networks can be reasonably expected to have lifespans of 50 years or more. To ensure a long lifespan strict quality control during installation and water treatment throughout operation are key; once pipe trenches are backfilled, any shortcomings in the installation process may be hidden and are subsequently difficult and costly to locate and repair.

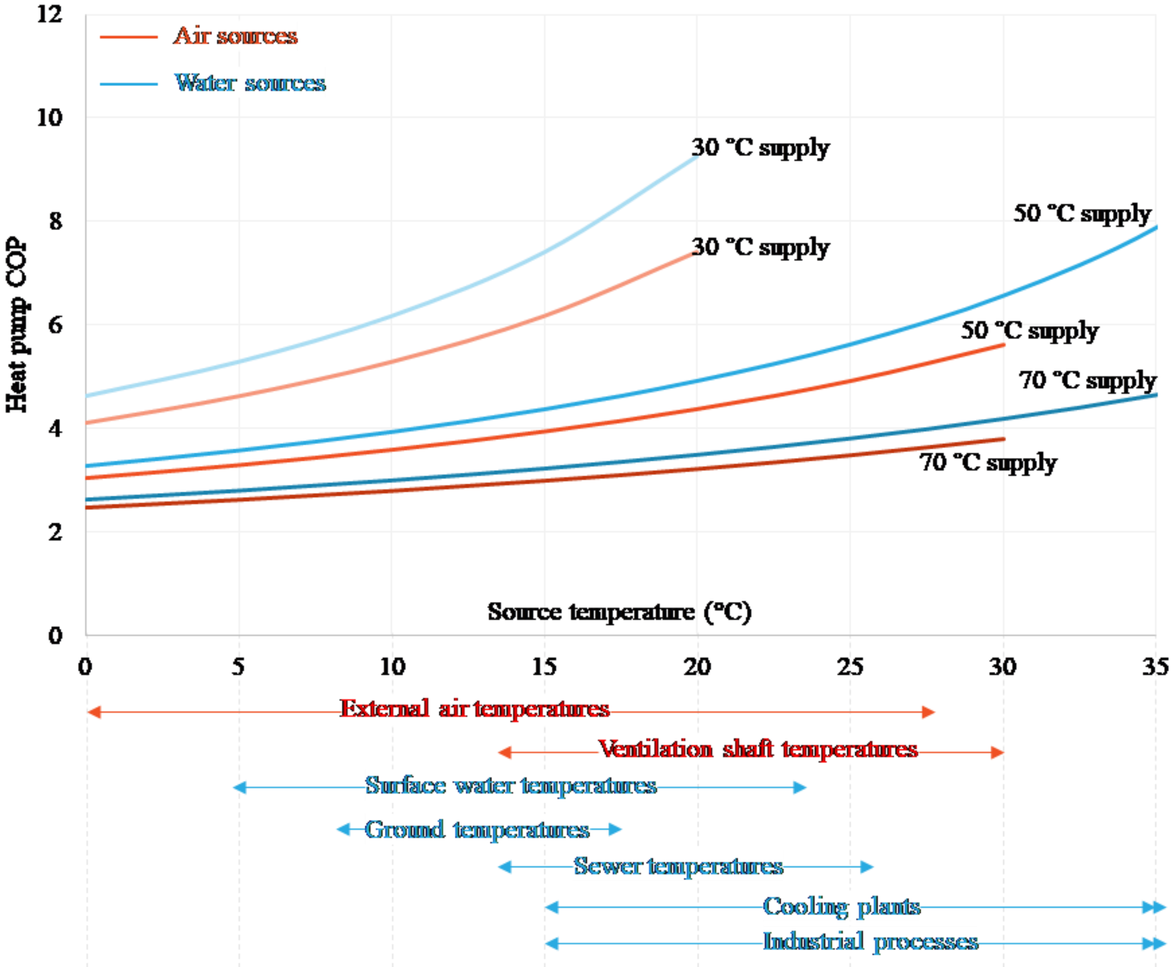
Although this lifespan is a reasonable aspiration for both pre-insulated, welded steel and plastic pipework and fittings (in lower temperature applications), for ancillary equipment, including the heat generating plant, distribution and pressurisation equipment, and HIUs, is dependent on the type of technologies used. These technologies generally have a design lifespan shorter than 50 years, but are easier to replace than pipework. There are numerous sources of information recommending the lifespan of individual components; CIBSE Guide M[26] is a useful place to start.

Heat pumps

A HP is an electric device that captures the heat available from a thermal reservoir (such as air, water or ground), compresses it and then transfers it to meet the heating demand of a building. A reversible HP can perform the opposite process to meet the cooling demands of a building.

Figure 3 shows typical COPs for HPs operating at different source and supply temperatures. Actual COPs will differ depending on several factors such as type of refrigerant, system controls, ancillary equipment and HP size. The temperature differential between source and supply temperatures has a direct impact on the COP. When possible, this differential should be minimised to achieve more efficient HP operation, with associate benefits of electricity and carbon savings. This means that higher source temperatures (for example, extracting air from a ventilation shaft rather than ambient air) and networks with low supply temperatures (for example, a network supplying 50°C water rather than 70°C) should be prioritised.

Figure 3: COP of HPs for different source and supply temperatures (based on Carnot efficiency approximation)



Principles of operation

This section outlines the design and control principles for the operation of modern heat networks (excluding 5G systems).

Variable flow, variable temperature

One of the main principles for efficient and cost-effective network operation is for the supply flow rate and temperature to be controlled by variable flow and variable temperature functionality to accurately match the consumer heat demands on the system. This principle has been proven to give good economic performance over the lifetime of a heat network through a combination of lowering heat losses and improving distribution pump energy efficiency, by utilising variable speed drive (VSD) pumps, whilst minimising the pipe size installed across the network.

Under the variable flow, variable temperature principle the system is designed to satisfy fluctuating demand. During peak times, the maximum temperature and flow rate are provided, then as demand reduces off the temperature and flow are also reduced, thereby achieving energy savings.

Peak demand only represents a small percentage of the normal daily and seasonal consumer demand profile. The reduction in temperature significantly reduces thermal losses, whilst the reduction in flow provides consequential savings in pumping costs. Therefore, in combining the two to match the amount of heat being demanded from the system at any time ensures reliable and cost-effective heating for consumers.

This accurate control not only achieves high energy efficiency in operation (through the reductions in heat losses, pumping energy consumption and improved HP's COP, where applicable) but also minimises the size of pipe required across the network. It is a proven model for providing good economic performance throughout the lifespan of a network.

Variable supply temperature is normally controlled at the heat source interface; however, where a number of heat sources are connected on the same network at different prices, lowest cost delivery can be maintained through heat source sequencing controls. In this case, the control system allows a lower cost, low temperature heat source to be selected over a more expensive, high temperature one. Additionally, the higher cost source can be enabled to operate when there is increased demand on the system.

The supply temperature is controlled at the energy centre, typically based on a 'weather compensation curve'; when outdoor temperatures are lower, supply temperature is raised, and vice versa.

The use of variable flow control systems will result in lower flow rates and lower return temperatures when the network is operating at part load. Variable speed pumps should be used and controlled such that the pump pressure differential reduces at part load to a level which is sufficient in maintaining the minimum design pressure differentials at the extremities of the network. This control principle enables the reduction of heat losses and pumping energy.

The curves in Figure 4 and Figure 5, below, show the variation in supply temperature and flow rate concurrent with seasonal temperature changes outside. It should be noted that return temperature is only an estimate and is dependent on the secondary (consumer) system temperatures and on the design and operation of consumer substations.

Figure 4: Heat network flow and return temperature variation with outside temperature

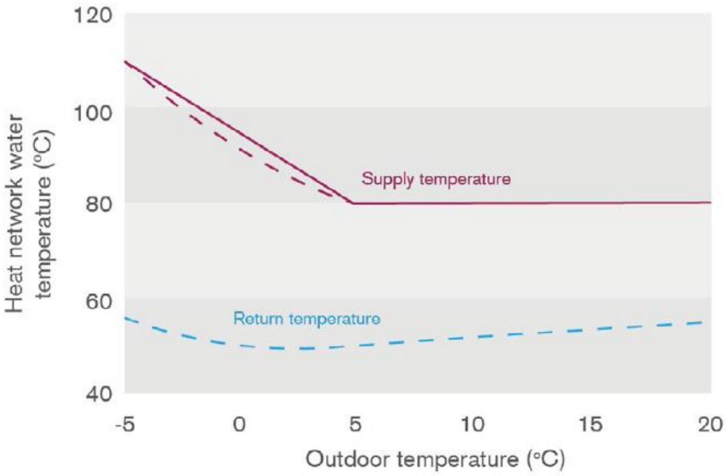
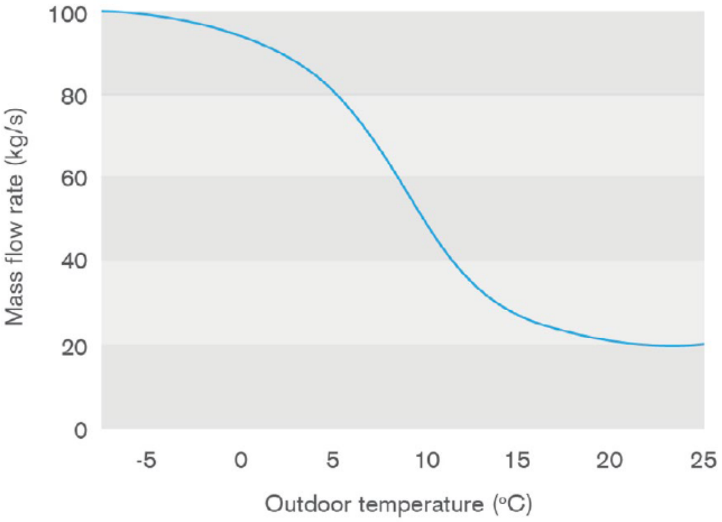


Figure 5: Heat network mass flow rate variations in relation to outdoor temperature



The key characteristics of heat network variable flow rate design are:

- Main VSD pump motor inverter control;
- Use of multiple pumps to match the variation in flow rates; and
- Consumer connection, primary heat network two-port motorised control valve for new installations, or as a replacement of a three-port control valve, or to bypass existing arrangements. Two-port control valves are actuated on building temperature and DHW demand.

The heat network flow rate is a function of consumer demand, through the control of distribution pumps to maintain system pressure reflecting the aggregate position of the two-port valve controls in heat substations which are constantly adjusting to match the primary flow to meet the consumer demand. As outdoor temperature falls, consumer demand for heating increases, two-port valves open to draw heat from the network, resistance to network flow decreases resulting in a fall in system pressure which is monitored at the energy centre and the distribution pumps are modulated to deliver higher flow rate to satisfy the demand. This adjustment process is continuously occurring throughout seasonal and daily demand variations.

The variable volume flow is kept above a predetermined minimum value to ensure the full heat supply service is maintained across the network. This makes certain that a minimum pressure difference is sustained for a reference consumer (usually the one furthest away or the one having the greatest resistance from the circulation pumps) to provide adequate heat supply.

There are variations to the control mechanism by which variable flow, variable temperature control is achieved; however, in all cases the control system is designed such that the functions of variable flow, variable temperature do not interfere with each other; a scenario termed ‘hunting’.

Low return temperature

The capacity of a specified network pipe size to distribute heat at a defined flow rate is primarily determined by the difference in the supply and return temperatures (also referred to as ΔT). Wider temperature differences allow more energy to be transported through the pipe. This means that networks with a greater temperature difference may be able to utilise smaller heating mains, leading to a reduction in capital costs.

For most but not all heat sources, the cost of heat supplied to a system increases with supply temperature. It is therefore preferable for systems involving the transmission of heat over long distances to achieve wider temperature differences by lowering return temperature rather than increasing supply temperature. This requires that control systems, and more importantly the heating and hot water systems of consumers on the network, are able to deliver services at low return temperature operation.

Heat transfer between the water flow in the emitter and the room is related to the surface area of the emitter and the temperature difference between the room and that surface. Conventional radiators in the UK are designed with supply and return temperatures of 82°C and 71°C respectively. This gives a temperature difference between the radiator and the ambient room temperature (19°C) of approximately 55°C. The transition towards lower temperature systems and increased use of HPs relying on waste and low-grade heat will impact on these supply and return temperatures. Reduced temperatures might require resizing of radiators (in existing buildings) and might be more suitable for UFH.

Increasing the surface area of the emitter, such as by replacing radiator heating with UFH or fan coil units (FCUs), enables a lower supply and return temperature to be used, which in turn reduces the cost of heat. UFH efficiently distributes heat evenly, as the larger surface area compensates for the lower supply temperature, while providing the same space heating comfort level. The low supply temperature also supports more sustainable but low-grade heat sources such as GSHPs.

For an existing radiator with a fixed supply temperature, the return temperature could be reduced by decreasing the water flow rate. This will reduce the temperature difference between the room and the surface of the emitter, and hence will reduce the heat delivered to the room. This might only be viable when radiators have been oversized, or the space being heated has been thermally insulated after the radiators were selected and installed.

Figure 6 provides an indication of the relationship between the cost of pipework infrastructure with its capacity to deliver energy. The different curves show the impact of increasing the differential temperature. As it increases, the same heat content can be transmitted through the system using smaller pipe sizes, thereby offering a reduction in the cost of installation of the heat network.

Figure 7 presents the same concept in an alternative format. It shows the energy flow capacity that can be delivered in relation to pipe sizes, where the different curves indicate the impact of increasing the differential temperature. For example, for a network pipe size of DN250 lowering the return temperature to increase the supply-return temperature difference from 20°C to 40°C means that, without changing the installed pipework infrastructure, the capacity for energy flow in the system may be doubled from 8MW to 16MW.

Figure 6: Relationship between cost of pipework installation and differential temperature on a system

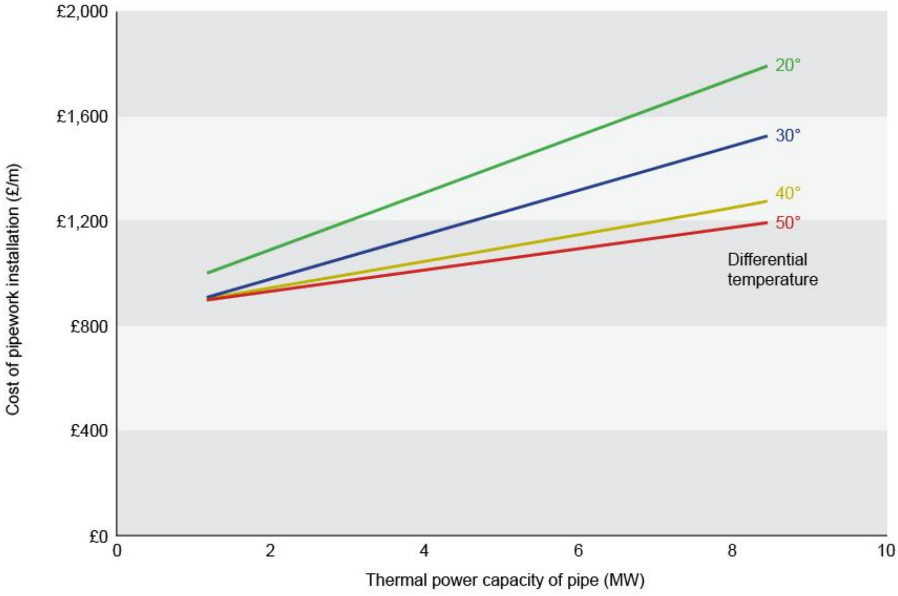
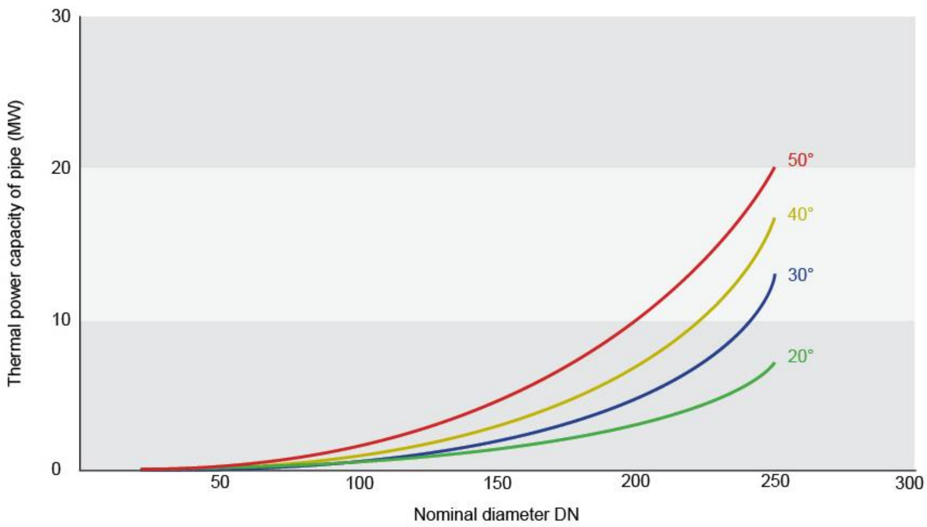


Figure 7: Heat network system capacity variation in relation to pipe diameter and temperature difference



In addition to the potential for decreasing network capital costs through selection of smaller pipe sizes, there are further gains to be realised through lowering the return temperature on heat networks. In many cases the efficiency of energy recovery from the heat source can be improved as the return temperature is decreased leading to lower costs. The heat loss from the return pipe will be reduced, as well as the pumping energy, as a result of decreased volumetric flow.

Reduced operating temperature
London's secondary sources, such as heat from underground railway ventilation shafts, electrical substation transformers, sewers and water treatment works all represent potential low-carbon heat source opportunities.

Low-grade heat can be used in a heat network in three key ways:

- Through direct heat exchangers, when the heat source is at a higher temperature than the network; and
- Through the use of HPs to raise the temperature of the low-grade heat to the temperature required by the network.
- Through distribution of the secondary low-grade heat source in an 'ambient temperature network' with HPs located in plant rooms in each building.

The former is more efficient as it requires no additional energy for operation of a HP. Reducing the network temperature as far as possible will maximise the amount of heat that can be directly imported, and maximise the efficiency of the HP (if applicable). HPs delivering water at 60°C would have a higher COP than HPs delivering water to a network at 70°C. This means that heat networks operating at a lower temperature can use HPs more efficiently, requiring less electricity and operating at reduced operational costs and CO_2 emissions.

As network operating temperatures are reduced, the proportion of heat lost to the environment from the network is also reduced, reducing CO_2 emissions and fuel consumption.

Lower temperatures can also result in a wider selection of potential pipework materials, such as plastic pipes, which have the associated benefits in terms of ease of installation and overall cost savings.

In determining network temperatures, it is important to understand the requirements for the end users' heat emitters and the levels of hydraulic separation between consumers' systems and the energy centre (see Secondary side heat network design section for further information on hydraulic separation).

Conventional UK wet heating systems in buildings and dwellings have typically been designed with flow/return temperatures of 82/71°C respectively. This necessitates flow temperatures in the distribution network pipes of 90°C or higher.

Changes to Part L of the Building Regulations have set more stringent carbon reduction targets, driving the adoption of more energy efficient measures, including the use of condensing boilers and designs for new buildings incorporating lower temperature emitters (for example, UFH and FCUs), which in turn lower network temperatures. In order to achieve the latter it is also now common for network operators to influence the design of building heating systems.

Domestic hot water

Compared to traditional networks, DHW production requirements become particularly important in the design of networks with reduced operating temperatures.
Networks supplying water to each building at a temperature below the minimum DHW temperature, would require additional local systems for DHW temperature top-up to minimise Legionella risks (see Legionella section). For example, a heat network delivering water at 45°C to new residential developments could serve space heating directly, but would require either immersion heaters in each dwelling or water-to-water HPs in each building's plant room to raise the temperature of the DHW[27].

Retrofitting existing buildings

There may be an opportunity to change the operating characteristics of older buildings connected to a network in order to reduce their required supply temperature. Retrofitting insulation reduces overall heating demand; upgrading building energy performance by a single energy rating can significantly increase the proportion of the heating load that can be supplied by low flow and/or return temperatures, as shown in the report, *Connecting existing buildings to district heating networks*[22].

Retrofitting insulation includes building fabric improvements, such as increasing insulation of walls and roofs and increased glazing of windows. The impacts of different building fabric improvements have been studied in the same report[22], and the report *London's zero* *carbon energy resource: Secondary Heat*[20], including the percentage heat demand saving and the impact on the percentage of the total heat load that can be supplied from a network, at a lower supply temperature.

Many existing buildings currently operate on a fixed volume regime. A change to variable volume flow would allow the internal system to be controlled via modulating pumps to maintain a fixed index differential pressure, resulting in a reduced and more reliable return temperature on the heat network side of the heat exchange substation. In addition, existing hot water storage systems could also be switched to instantaneous systems to help reduce the return temperature of the system.

In order to avoid these changes in the future, new developments should be specified to have low temperature heating systems at the master planning stage.

Hybrid networks
Hybrid networks comprise HPs to supply the network base load heat demand, and ultra-low NO_x gas boilers supplying the network's peak demand and as stand-by generation. Since September 2018, the mandatory maximum NO_x emissions level has been 56mg/kWh for gas boilers. Ultra-low NO_x gas boilers meet this requirement as they have a maximum emission level of 30mg/kWh of NO_x.

Hybrid networks could be key in the transition to lower carbon, lower temperature networks by supporting the use of HPs, whilst using the reliability and flexibility of ultra-low NO_x gas boilers to manage peak loads. As technology improves sufficiently for low-carbon solutions to be able to cope with peak loads, the complete transition away from gas boilers will be necessary. Various HP technologies could be integrated into hybrid networks, and while GSHP and WSHP would bring operational benefits in terms of cost savings and lower carbon emissions compared with AHSP, they tend to be less flexible solutions as they rely on location-dependent heat sources.

The use of HPs for base load heat will provide significant carbon savings over traditional networks with gas boilers and CHPs in the future, as shown in the GLA report *Low-carbon heat: heat pumps in London*[28]. Carbon emissions savings are key for planning and future-proofing, as well as potential economic benefits in terms of avoided carbon offset payments[29]. As the grid decarbonises, the carbon savings from HPs compared with gas boilers will become even more significant.

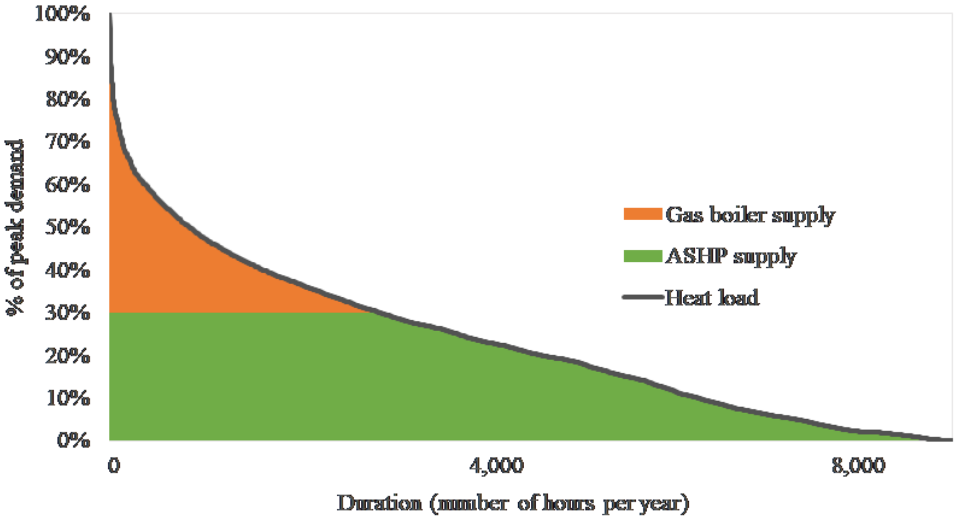
In a similar way to traditional heat networks, the heat generation plant and the pumping equipment would be located in centralised energy centre(s), with benefits in terms of maintenance costs, space requirements and ease of access.

To enable the integration of HPs, the network should be designed at a reduced operating temperature (e.g. flow of 70°C or below).

Figure 8 is an example of the heat demand duration curve for a large-scale mixed-use development. The demand duration curve (or load duration curve) is derived by re-ordering the hourly heat demands for one year into descending order, illustrating the duration of different heat loads. The heat demand split is shown between multiple technologies for the peak demand and the base load simultaneously. The black curve in Figure 9 is an example of the relation between HP sizing and annual heat supply for a large-scale mixed-use development. The orange line represents the HP sizing approach used for Figure 8. As the heat demand curve is largely dependent on the heat demand profile, the relation between percentage peak demand and percentage annual load will vary for different developments. In this case, when the HP peak output is sized to meet around 30% of the peak load, 80% of the actual energy (area under the curve) is delivered by the HPs. Gas boilers are used to meet peak conditions for a limited amount of time.

The integration of peaking gas boilers into the design can offer significant space and cost savings compared to an HP only solution.

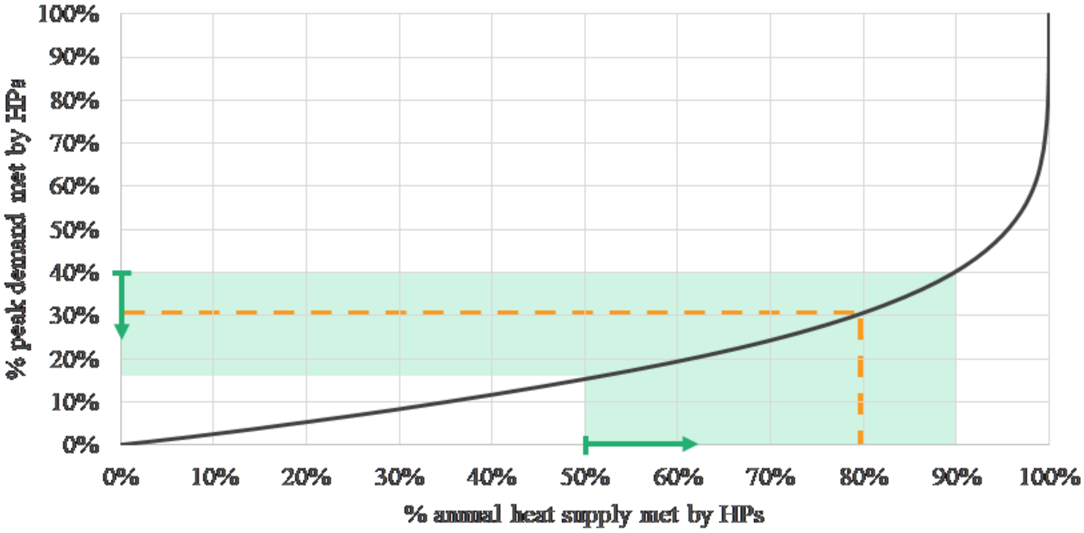
Figure 8: Example heat demand curve with supply from HPs and gas boilers



From a carbon emission perspective and for HNIP funding eligibility[9], generated zero carbon heat and/or recovered heat should represent at least 50% of the development's annual heat supply[30]. HPs have higher capital costs (£/MW) and space requirements (m^2/MW) than gas boilers and are typically sized below 40% of the peak demand. However, the additional capital costs compared to traditional gas boiler systems tend to be relatively small, between 0 and 3% of total project costs[28]. For the example development used for Figure 8 and Figure 9, if the HP size is doubled from 40% to 80% of the peak, the annual heat generation is only increased by around 10%. This also ensures that HPs are not operating at very low COPs during peak winter conditions.

These criteria for sizing HPs for a hybrid network are shown by the green arrows and green zones in Figure 9.

Figure 9: Example sizing of HPs for hybrid networks



By relying on different heat generation technologies and diverse fuel supplies, hybrid networks can also provide additional heat supply resilience and mitigation against fuel price fluctuations.

As the efficiency of HPs varies throughout the year (depending on source and supply temperatures), the operation of hybrid networks can be optimised for carbon and/or operational costs. This can be achieved through smart controls that rely on inputs such as electricity carbon emission factors and fuel and electricity prices to optimise system operation.

Temperature compensation curves can help to reduce carbon emissions and fuel costs; network supply temperatures are reduced with increased ambient temperatures, and vice versa.

Hybrid networks can be suitable for both new developments and also to retrofit some gas CHP networks. For example, CHPs in some heat networks could be replaced with air source heat pumps (ASHPs), provided there is enough external space or air intake and discharge for the HPs and that the network temperature is suitable for the integration of HPs (e.g. flow of 70°C). If the temperature of a network is reduced significantly through the retrofit (e.g. flow temperature reduced from 80°C to 60°C), internal systems might need some upgrades including radiators being resized or replaced with UFH.

With a hybrid system, the highest temperature requirement on the network dictates the temperature of the supply. For this reason, hybrid networks might not be particularly suitable for a mix of existing and new buildings. If existing buildings are designed to receive hot water at 90°C, while new buildings are designed to receive hot water at 70°C, the network temperature would be required to be at least 90°C, unless localised plant can be used to provide top-up heat to the existing buildings (unlikely to be suitable for integration of HPs).

The choice of suitable HP technologies depends on a range of factors; including locally available heat sources as well as space and noise constraints. The GLA reports *Low-carbon heat: heat pumps in London*[28] and *Heat pumps in district heating*[27] contain further information on HPs, including space and cost implications, potential carbon savings, refrigerant considerations and common efficiency standards.

Table 2 includes capital expenditure (CAPEX) rules of thumb for some of the key components required for hybrid networks. This does not include costs for energy centre(s), utility connections and any on-costs (e.g. design, preliminaries, testing and commissioning). Installation and labour costs are included, except for items installed in each dwelling (HIUs and heat meters).

Table 2: Key components for hybrid networks, with associated CAPEX rules of thumb (from: manufacturer quotes, SPON's Price Book[31] and the report *Research on district heating and local approached to heat decarbonisation*[32]]

Component	CAPEX rules of thumb	Notes
Potential plant for base load: ASHP WSHP/GSHP/HPs using waste heat	Based on plant over 300kW: • ASHP £350-750/kW • WSHP/GSHP/HPs using waste heat £500-2,000/kW	WSHP, GSHP and waste heat HPs can vary significantly depending on configuration, type of system (i.e. closed or open loop) and additional components required (e.g. water filtration).
Peaking gas boilers	£35-45/kW (based on plant over 300kW)	Excludes flues and ancillary plant such as pumps, pipework etc.
Primary network pipes (including trenching, installation and fitting, for flow and return)	£1,000-2,000/kW (for urban/suburban pre-insulated steel pipework of 150-300DN)	This can vary significantly depending on the pipework route, size and material.
Ancillary equipment (e.g. pumps, thermal storage, heat exchangers) and controls	Varies	Varies depending on the system design and the buildings.
Secondary network pipes	Varies	Depends on the system design and the buildings.
Domestic HIU and heat meter	£1,700-2,300 per dwelling	Excludes installation costs (typically free-issued to developer by network operator and installed by developer/contractor).

Høje-Taastrup, Denmark[33]

Høje Taastrup Fjernvarme is Denmark's largest consumer-owned district heating cooperative, which for more than 50 years has supplied district heating to customers and co-owners in Høje-Taastrup.

In 2015, the company established the first plant for Copenhagen Markets comprising a large HP simultaneously serving connected district cooling and heating networks.

Heat is recovered from cooling plant with a capacity of 2MW and used to feed two HPs which upgrade the heat, providing 3.2MW of heat at 75°C directly into the local network. This operation achieves an overall HP plant COP of 5.3.

Primary side heat network design

This section sets out the requirements for the design of the primary heat network. The convention applied in the Manual regarding primary and secondary heat networks is that ‘primary side’ refers to the main pipework that joins the consumer connections. ‘Secondary side’ refers to equipment on the consumer side of the building connection Figure 10 details an overview of the component parts of a heat network.

3G and 4G heat networks comprise a flow and return pipe, whereby the temperature in the return leg is lower than that of the flow leg. 5G networks may employ this same principle or use an alternative primary side arrangement, as described in Primary side network design section. This section is relevant to 3G and 4G heat networks only.

Primary network design

Good design for a primary heat network enables the operator to ensure that service is maintained, and consumer demand is met at all times. The distribution equipment should be installed as near to the source of heat as practical, normally in a combined energy centre. Here, the control system will match the demand for heat by monitoring and controlling the network pressure, flow rate and temperature. This control system is commonly based on maintaining a target pressure differential in the network at critical consumer points, such that the required flow rates can be maintained throughout the system.

Where there are multiple energy centres, there is often a designated ‘control’ energy centre that varies its output to follow demand (load follow), while the other energy centres operate at constant output, providing the base load.

Figure 11 indicates the plant and main components and controls required for a variable flow and variable temperature heat network.

Figure 10: Component parts of a heat network

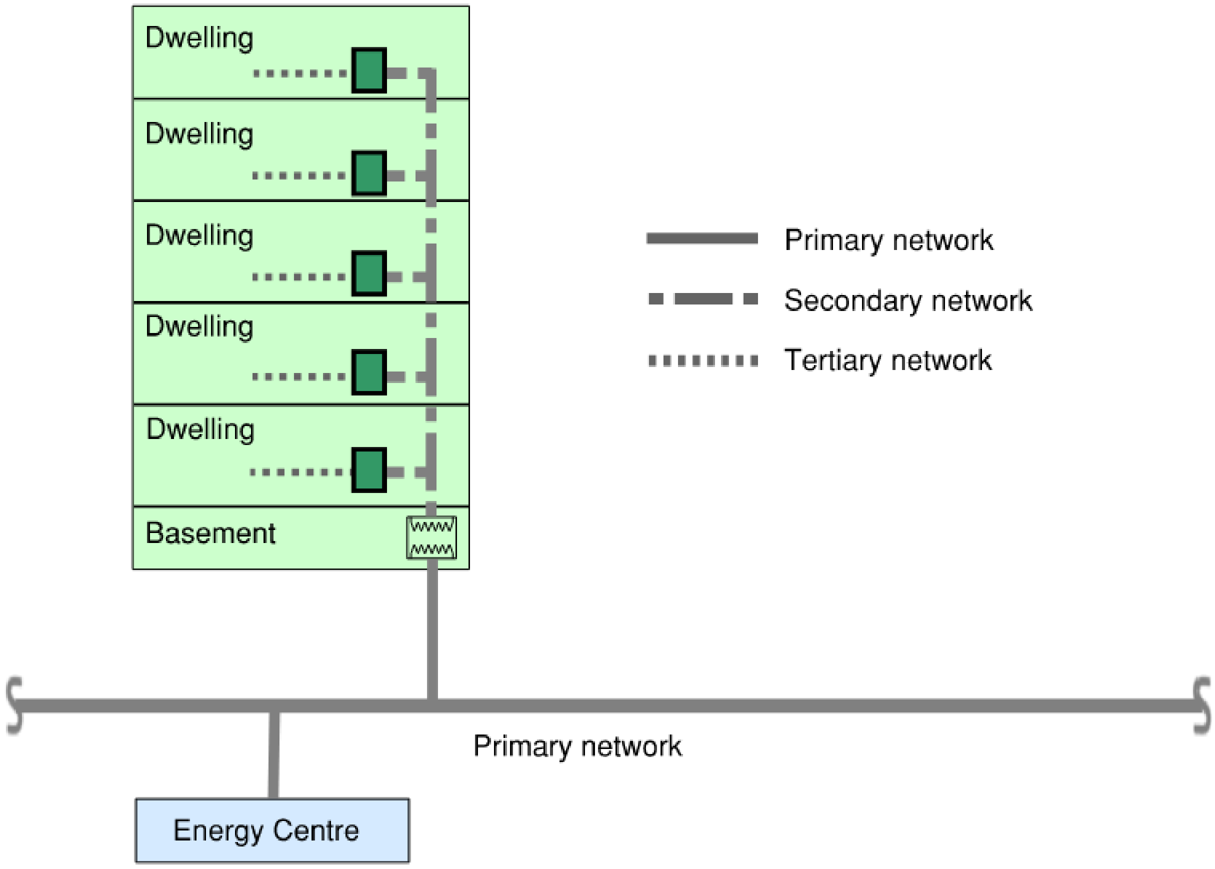
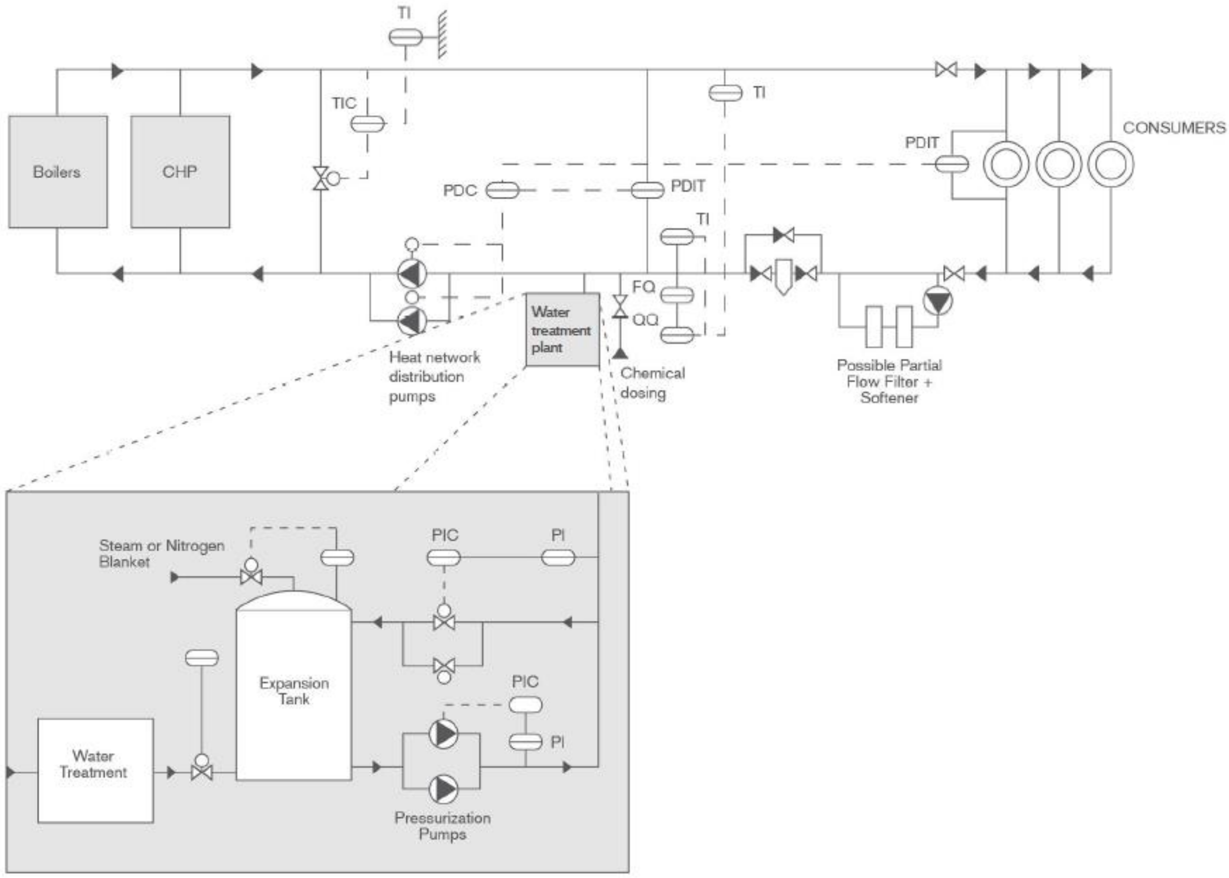


Figure 11: Typical plant arrangement for a variable flow, variable temperature heat network



Network design, routing and thermal expansion
The requirements for the design of networks are explored below, considering in particular their routing and thermal expansion. The key design criteria include:

- The network must be capable of supplying hot water to consumers with sufficient temperature and temperature difference to meet the heat demand;
- The network must be designed to minimise heat losses;
- The pressure across the entire network must not allow hot water to boil at any time;
- Pressure differences between flow and return pipes must always be sufficient to meet the required flow rate for all consumers;
- The network route should be designed to ensure long pipe lifespan, through minimising pipe stresses and accommodating expansion;
- The network route should be practical and distances should be minimised; and
- The pipes in the network should have sufficient capacity for all heat loads that may reasonably be expected to connect in the future.

In practice, heat network routes must be established by ensuring a route corridor can be found to all consumer points. Hydraulic modelling software is used to size pipes against the peak heat demand loads, with load profiling, heat load diversity and network phasing considered. Reference consumers/connections are identified for control of pressure, pressure difference, temperature and temperature difference. Typically, these are located at the furthermost point on the system from the heat source and distribution energy centre and would be the first consumer to experience loss of minimum required flow rate across their heat interface if the system pumps were throttled back.

Normally a pressure differential of 1 bar (100kPa) is selected as the set point for the reference consumer, to provide a small margin for error given substation units are normally designed for 0.6 bar maximum pressure loss. If the 1 bar pressure differential is maintained at the reference consumer then at least 1 bar pressure differential is assumed to be achieved at all other consumer connection points on the system.

When preparing the mechanical design of a network pipe route, pipework stress including thermal expansion stress must be considered, especially for larger diameter pipes. This design should be carried out by experienced engineers to avoid reducing pipe lifespan. Due to the nature of network installations at the area-wide scale, involving typically long straight runs of pre-insulated steel pipework, these pipes are subject to significant expansion forces when heated under normal operating conditions.

Techniques to compensate for thermal expansion are calculated and specified during design and applied in installation. Expansion joints and loops are sometimes used, however the ultimate design principle is to accommodate expansion of network pipework within stress tolerances, while reducing, as far as reasonably practicable, the need to access and maintain equipment, such as expansion joints. A thermal expansion design specialist will attempt to achieve this through the arrangement of pipework bends that can accommodate expansion with no additional mechanical equipment.

Expansion design also needs to consider how and where the pipe is anchored, ensuring that allowance for expansion is provided between anchor points, and that pipework guide supports are used to direct the lateral movement of pipework under expansion/contraction.

In lower temperature applications, where plastic pipework may be used, consideration of thermal expansion should account for the higher thermal expansion coefficient of polyvinyl chloride (PVC) than steel, but also the reduced change in temperature. Whilst thermal expansion of plastic pipes is higher than for steel applications, plastic has a lower Young’s modulus than steel and so is able to accommodate the expansion without generating high compressive stress.

Pipe line pressure loss

Heat networks are designed, and pipe dimensions selected based on a maximum pressure loss per metre. This is normally achieved through software simulation of the entire network, based on the designed connected heat demand profiles and expected supply and return temperatures, considering the topography and distances of the proposed pipe routes.

The design trade-off associated with pressure loss per metre is the balance between pipe costs, pumping costs and heat losses. Designing systems at higher flow velocities allows smaller diameter pipes for a given temperature differential, resulting in lower heat losses and pipe cost. However, this will also result in greater frictional losses and therefore higher pumping costs.

CP1: Heat Networks Code of Practice for the UK[34] includes typical velocities for different pipe sizes. These velocities represent a good economic balance between heat loss and pumping energy.

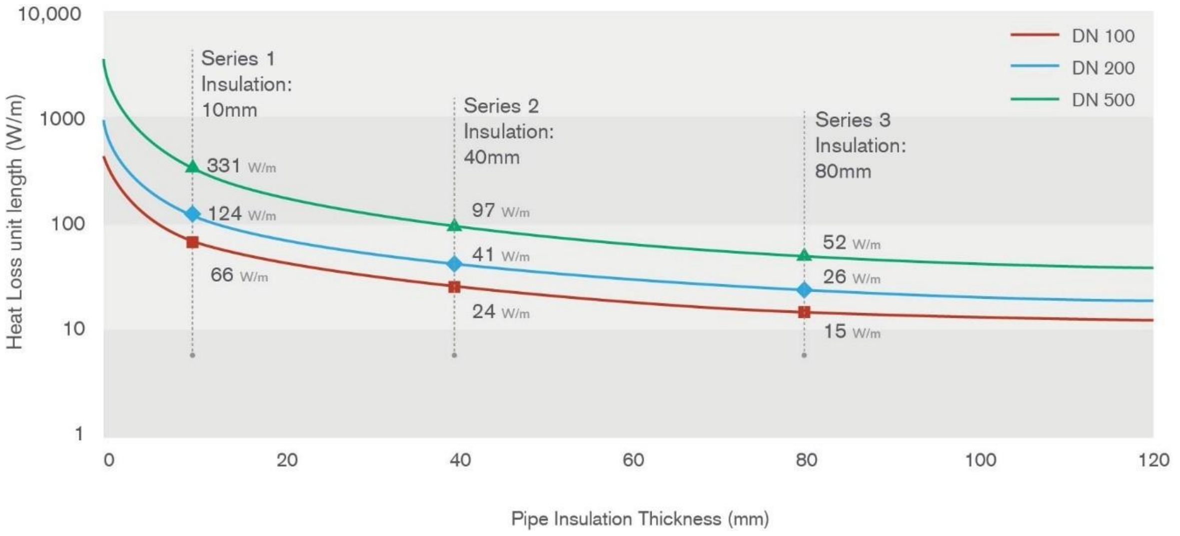
Thermal insulation
Reducing thermal losses in heat networks is one of the most important design considerations in the development process. A life cycle cost analysis should be carried out to select the most economic insulation option[34]. In most circumstances the optimal solution is achieved with pipe insulation specifications beyond the minimum requirement under the British Standard[35]. The life cycle cost assessment should consider:

- Actual pipework temperatures rather than assumed averages; often different levels of insulation may offer the best economic performance (i.e. more insulation on flow pipework than return pipework), but this will need to be balanced against practicalities of multiple pipe specifications;
- Accurate estimates of average annual ground temperature;
- Degradation of the insulation over time;
- The price of heat, adjusting for future fuel inflation over a 50-year (typical) lifespan; and
- Pipework above ground and on secondary systems, with the external temperature adjusted to a suitable still internal air condition, or exposed external air condition.

The risk of overheating in building corridors should be carefully considered when selecting pipe insulation specifications/thickness, ensuring that the design allows for a comfortable environment year round[34]. Overheating is further discussed in the Overheating in communal areas section.

Figure 12 indicates the relationship between insulation thickness and the heat loss from insulated pipes. The rate of heat loss depends upon a range of factors and in the production of Figure 12, ambient temperature and fluid temperature have been set at constant. The three curves show the influence of pipe sizing and the shape of the curves show the reduction of heat loss per metre of pipe as the thickness of insulation is increased. Note that the heat loss per unit length is on a log scale.

Figure 12: Indicative heat losses from insulated pipes and relative performance of series 1-3



Heat network pipe insulation is categorised as Series 1, 2 or 3. Series 3 has the lowest heat loss coefficient and so offers the most effective heat insulation. Modern heat networks in the UK are commonly installed with Series 2 insulation.

Twin-pipe installations, whereby the flow and return pipes are housed in a single insulated casing, require a different calculation method in assessing the thermal losses. While some heat is lost from the flow into the return line, this modest proportion of leaked heat is returned to the heat source and overall heat losses from twin pipes are significantly lower than for a pair of separate pipes.

The cost of heat supply to the network is used to establish the monetary value of the heat loss per metre of pipe. This can then be used to compare heat loss, in addition to the affiliated running costs and emissions, against the CAPEX and embodied carbon associated with the higher specifications/thicknesses of pipework insulation that would be required.

Primary side network system components

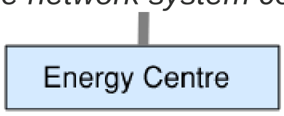


Figure 11, in the Primary network design section, indicates the typical arrangements of these components within the heat network system.

Distribution pumps

Distribution pumps transmit water through the primary network from the heat source to the consumers. The pumps are commonly controlled for variable flow rate using a VSD which adjusts the frequency of electricity supply to the pump to enable the motor to slow down and speed up as necessary. As service-critical plant items, duty and stand-by pumps are typically installed for resilience. Multiple pumps should also be installed to ensure that they can operate efficiently at partial load (e.g. during summer)[34]. Various ancillary items, including isolation valves, differential pressure gauges and strainers are also necessary to assist in monitoring, isolation and safety.

System pressurisation/expansion

Pressure must be maintained to ensure water is distributed to all points on the network and to prevent boiling at operation temperatures above 100°C. For this reason, pressurisation pumps are essential and commonly linked to an expansion tank or spill back system to regulate system pressure and volume under changes in temperature. In some cases, directly connected thermal stores may act as expansion vessels.

Water treatment

Maintaining good water quality standards is essential to realising maximum system lifespan; poor water quality can damage pipework and equipment through erosion, corrosion and the depositing of scale. Scale can also significantly reduce the rate of heat transfer, for example, in plate heat exchangers (PHEs). Network installers should build in a water treatment plant, such as chemical dosing pots and strainers, and develop a comprehensive water treatment regime, including regular monitoring of pH value and water hardness, to avoid this risk.

Flushing and Filling

When a system is installed, the network should be flushed in order to remove any debris from within the pipework and other hydraulic systems. For larger diameter pipes, pigging using conventional or ice methods may be more appropriate[34]. After the system is flushed or pigged, the system should be filled along with a suitable chemical treatment. The water is then circulated regularly until conditions stabilise within the agreed water treatment parameters[34].

Leakage and breakage monitoring

Monitoring for leaks and breakages along pre-insulated steel pipe networks is essential to guarantee supply and prevent heat losses. Make-up water volumes should be recorded systematically and anomalies should be investigated[34]. Left unidentified, a leak in a network could lead to damage of other utilities, buildings, or the public realm.

Leak detection systems, as shown in Figure 13, allow the operator to quickly establish the location of a leak by installing two wires along the length of the network and monitoring the circuit resistance at a detection control box in the energy centre. It is common for detection points to be located on cells or sub-sections of the network, including any spurs off trunk pipelines. Upon commissioning of the network, datum points must be recorded. Under normal operating conditions, the resistance is constant. In the event of a leak, the water penetration into the insulation layer short circuits the detection wires, changing the resistance and giving an approximate indication of the location.

It is common that the identified leak is in fact caused by external groundwater entering through damaged outer casing, rather than due to the failure of the inner pipework. Regardless of the cause, repair is required to maintain the thermal efficiency and longevity of the network.

Polymer pipes are increasingly being used on small scale schemes, where systems may operate at lower temperature and pressures. As these pipes do not suffer from corrosion damage, leak detection systems on polymer pipes are not included as standard.

Figure 13: Heat network pre-insulated steel pipe indicating leak detection wires (courtesy of Logstor)

Valves

Isolation valves should be installed at regular intervals on the system, particularly at pipework branches located in valve pits external to the consumer buildings, to enable control of supply without entrance to the building.

Isolation valves improve the resilience of the network by enabling legs to be shut off or bypassed. This allows damaged sections to be investigated and repaired without affecting the rest of the system, thereby minimising service disruption.

Isolation valves should be delivered as pre-insulated units, supplied and manufactured by the same supplier/manufacturer as the pre-insulated pipes. Insulation and outer casing material should meet the same quality requirements which apply to the pipe and all other components of the system. Main isolation valves sets should have flushing valves that enable control of water quality and add resilience.

Thermal storage

Thermal stores (or accumulators) are frequently used in heat networks to temporarily decouple heat generation from consumer demand. They are commonly located near the CHPs/HPs to ensure that they are only charged by these (rather than by gas boilers), but can also be installed at other locations on the network when deemed appropriate for the system.

Thermal stores act in the same way as DHW buffer vessels or cylinders; containers of hot water at a controlled temperature that can be ‘charged’ during periods of low demand and ‘discharged’ when the demand rises again.

The heat stored can then be used be at a later, more commercially advantageous time. As it is not economic, except at very large-scale, to store heat for long periods, thermal stores are normally designed on the basis of charging and discharging daily, or multiple times per day. Heat storage utilisation varies according to seasonal demand changes.

The amount of heat stored varies over time and has a continuous heat loss to the environment. When correctly designed and operated, the advantages of having a stored source of heat outweigh the heat lost during storage.

One of the major benefits of thermal stores is that they may be used to replicate the peak instantaneous capacity of the heat generating asset. For this reason, the generating asset may be selected at a more economical size, which brings the benefits of reduced capital cost and increasing its total running hours, thereby improving the operational economics. Thermal stores also allow generating assets to operate more of the time at their maximum continuous rated output, reducing part load operation and number of starts. Generally, only the low-carbon or low-cost thermal generation assets should be used to charge the thermal store; conventional peaking plants such as gas boilers, which operate well at part load, are not normally used.

In addition, thermal stores can be used to optimise the plant use either for operational costs or for carbon content. For example, they could be charged by HPs when electricity prices are low and/or when their performance is high (thus with lower carbon content), and discharged when the electricity prices are high and/or when the HP’s COP is low.

Localised thermal storage in individual buildings or buffer tanks on the primary side of the heat exchanger could also be used to flatten the demand profile and reduce pipe diameters.

Figure 14: Typical mode of operation of conventional thermal stores

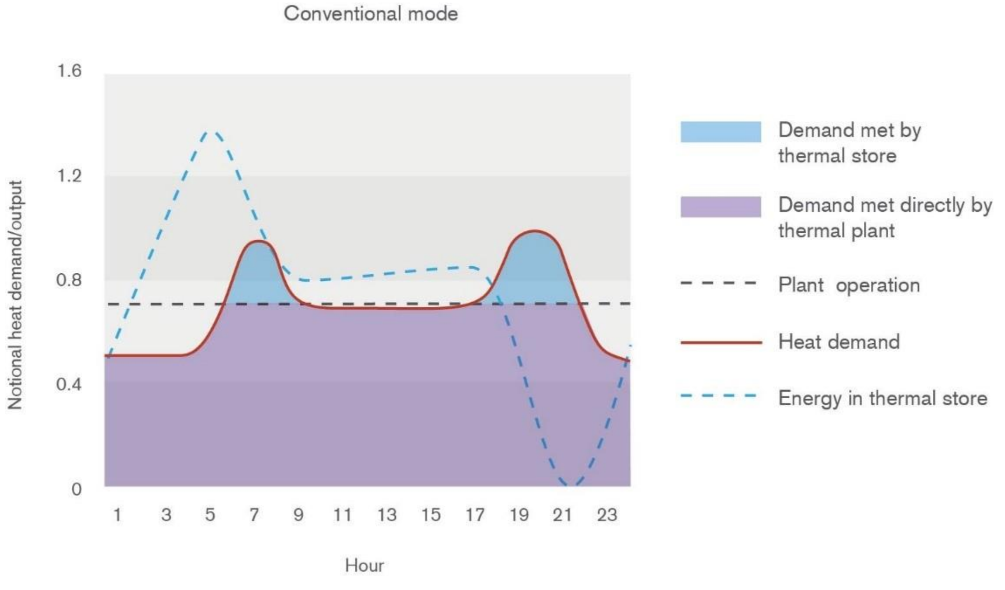
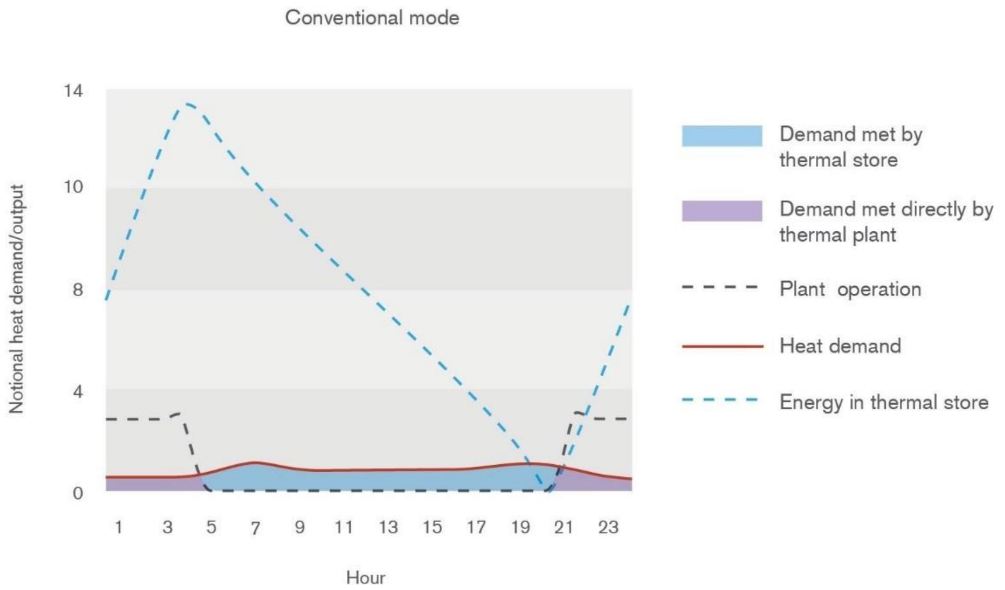


Figure 14 and Figure 15 indicate the function of a thermal store in two different modes. The curves show indicative plant operation, consumer heat demand and the energy level in the thermal store over one day.

Figure 14 represents a thermal store with partial storage capacity, able to charge an amount of cheap heat for discharge later. It works in parallel with heat generating plant also operating during the period of heat demand. The benefits of such a system may be the ability to operate a CHP asset continuously throughout the day and night. The size of the thermal store is determined by modelling to establish the desired degree of flexibility in heat source selection, limited by the practicalities of physical space for the thermal store itself.

Figure 15 shows a system with a large thermal store of sufficient size to decouple the time of heat generation to heat use. An example of such a system may be one involving heat generation that is only cheaply available at specified times of the night. In this instance the cheap heat is used to charge the thermal store, and then the thermal store is used to supply the heat network throughout the day when the low-cost heat is not available.

Figure 15: Mode of operation for large thermal store



In designing a thermal store, dimensioning is very important. The sizing should be carried out using an hourly model. An effective store can hold any amount of hot water between the minimum and maximum capacities by taking advantage of internal thermal stratification. For this reason, thermal stores are generally tall and thin in shape, with a minimum height to diameter ratio of 2 (and preferred ratio of 3 or higher). Additional design recommendations for thermal stores can be found in *CP1: Heat Networks Code of Practice for the UK*[34].

Figure 16 and Figure 17 show an example thermal store installed at the Bunhill Energy Centre, with a capacity of over 100m^3, measuring approximately 15m in height and 3m in diameter.

Figure 16: Thermal storage vessel during early phase of installation at the Bunhill Energy Centre, with thanks to Islington Council

Thermal stores can be connected to the heat network either directly or indirectly. For indirect connections, the store is hydraulically separated by a heat exchanger. Additionally, they can be installed to operate at atmospheric pressure or be pressurised.

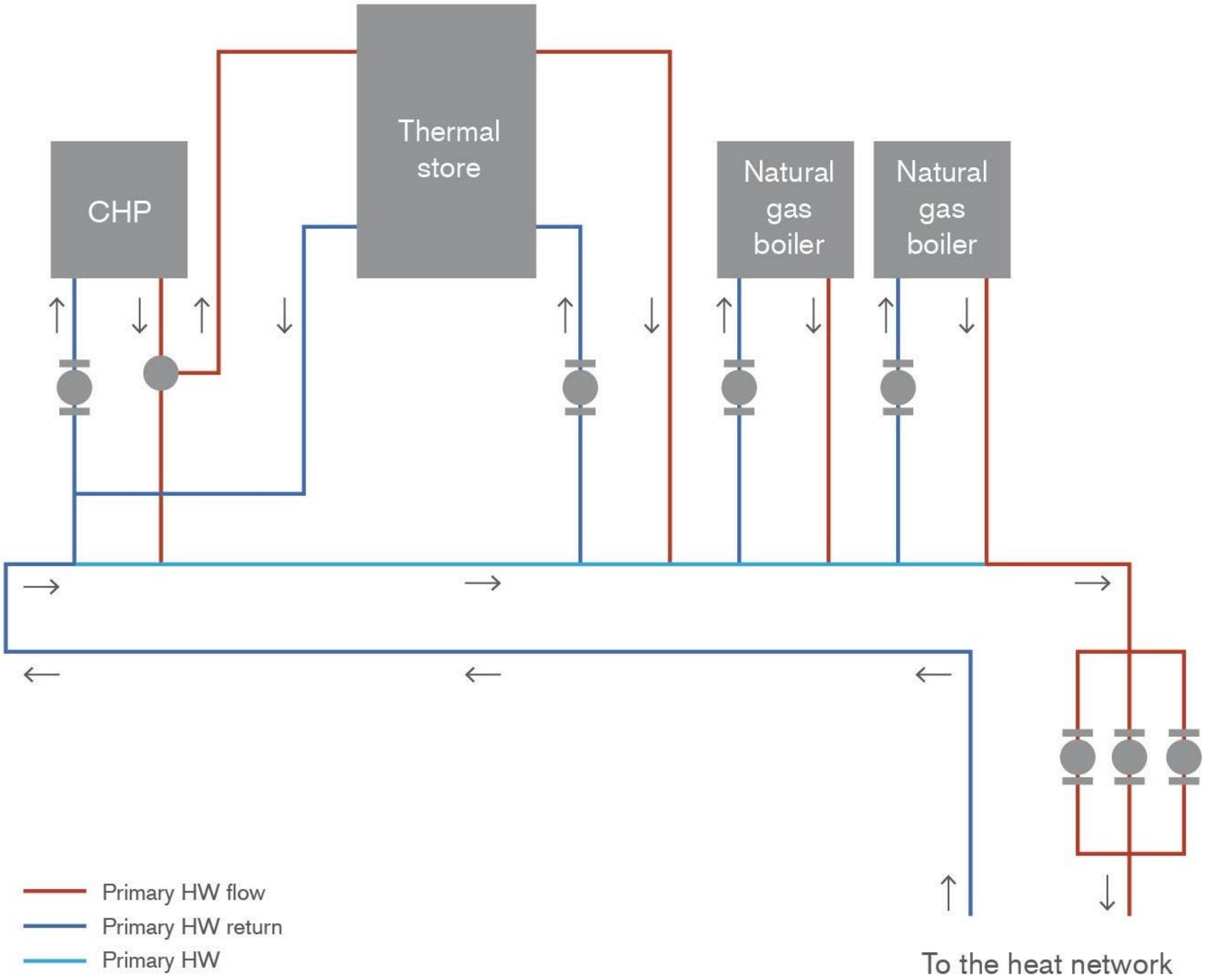
Figure 17: Thermal storage completed installation at Bunhill Energy Centre, with thanks to Islington Council

The system pressure within the heat network is a key consideration in the design and location of thermal stores.

If the thermal stores are directly connected, installation must be at a point in the network where their pressure is lower than that of the local system. In the case of a store operating at atmospheric pressure, this means that the hydrostatic pressure of the store must be higher than the network pressure at the point of connection. Similarly, for a pressurised thermal store, the pressure must be higher than the network pressure at the point of connection.

If the stores are hydraulically separated via a heat exchanger, the store pressure does not require the same consideration. This often comes at a cost to system efficiency due to the temperature drops across the heat exchangers. Pressurised thermal stores are more expensive than stores operating at atmospheric pressure.

Figure 18: Indicative thermal store arrangement



Given these design considerations, the advantages and disadvantages of a set of thermal store configurations are set out in Table 3.

Due to their typical size and dimensions, stores are frequently installed outside the energy centre, making installation, maintenance and replacement easier. Alternative solutions such as sinking the vessels underground, or partially underground, can reduce the visual impact and can offer additional benefits as the underground pit area may be structured to form a bund. However, in this case multiple routes for egress from the pit are essential as the contents of a store can be dangerous in the case of rapid leakage.

Table 3: Advantages and disadvantages of thermal store configurations

Thermal Store Configuration	Advantages	Disadvantages
Atmospheric, direct connection	Least cost and most energy efficient configuration	Limited by the operating pressure at the point of connection

Thermal Store Configuration	Advantages	Disadvantages
Pressurised, direct connection	More flexibility in connection point	More expensive than atmospheric pressure stores
Atmospheric, indirect connection	More flexibility in connection point	Indirect connection reduces thermal effectiveness for charging and discharging
Pressurised, indirect connection	More flexibility in connection point	More expensive than atmospheric pressure store, heat exchange reduces thermal effectiveness for charging and discharging

Top-up and backup plant
Conventionally, low-carbon heat generation equipment (e.g. HP, gas CHP) is sized to meet the baseload demand (kW, MW) of the system, but supplies the majority of the consumption (kWh, MWh) on the network. Meeting peak demand is then achieved through ‘top-up’ plant; low cost generation plant that is able to modulate easily to meet varying demand.

In some cases, low-carbon plant will be able to meet the full peak demand of the network, however, in such cases this generation plant may not be operational throughout the year (e.g. due to planned maintenance, fuel security). In order to guarantee supply to customers it is therefore necessary to install backup plant that can meet the full network demand in the event of the primary heat supply being unavailable.

It is possible to implement further resilience into the design of top-up or backup plant through, for example, ‘N+1’ plant installation. This ensures there is a spare generation unit to meet peak demand in the event that one unit is not functioning.

To date, these functions have typically been fulfilled by gas boilers as they are low cost, low space, require no fuel storage requirements in the UK and are a well understood technology that can modulate easily. Although, as we move to a lower carbon future, gas boilers may be replaced by alternative backup heat generation sources.

Normally, top-up and backup equipment will be located in the main energy centre alongside the main heat generating plant. However, an alternative location is within consumer buildings, should utilise the network as its primary heat supply and make-up any shortfall with its own plant. Schemes designed in this way may be able to reduce CAPEX on the pipework infrastructure, since the system would not need to be able to deliver the entire peak load demand from the network, particularly as peak demand periods exist for relatively short periods in the year. This may also apply to schemes where existing buildings connecting to a heat network can retain and obtain value from existing plant which is not life expired.

Local and temporary boilers might also be purchased and utilised in early phases of a new development before connection to a heat network is complete. These boilers can then be retained and integrated in the main energy centre as a backup for the network.

Carbon intensity of heat
The carbon intensity of heat is used as a measure of the carbon footprint of an energy source. In particular for establishing the relative environmental benefit of selecting one specific source over another. The primary goal of DE market development, and the Mayor's Decentralised Energy for London programme, is in establishing infrastructure for the supply of low cost, low-carbon heat, at scale. Therefore, the carbon intensity of a heat supply is a critical factor for the design of any new heat network in London.

Networks are able to take heat from a range of technologies and generation plant can change over the lifetime of a network. Carbon calculations for heat supply to new developments should be undertaken in Standard Assessment Procedure (SAP) or Simplified Building Energy Model (SBEM), based on the latest information in the GLA's Energy Assessment Guidance[3], to comply with Part L of the Building Regulations.

Carbon calculations for heat networks should be calculated based on the carbon intensity of the technology's primary energy consumption (i.e. grid electricity for HPs) for a given amount of heat delivered to the network. Heat networks which are made up of a number of technologies should be calculated based on their percentage contribution of the total heat delivered. All calculations should consider the seasonal performance of the heating systems, as well as the performance of the distribution networks.

Further guidance relating to specific technologies and the calculation of their seasonal efficiencies can be found in the Non-domestic Building Services Compliance Guide 2013[36] and the BESA TR/30 Guide to Good Practice on Heat Pumps[37]. The carbon calculations for schemes considering gas-fired CHP should follow CIBSE AM12:2013 or the calculations set out in the CHPQA.

As the grid has decarbonised, the comparative carbon saving from using gas-fired CHP has reduced compared to gas boilers only. On days where grid carbon content is particularly low, gas CHP can increase emissions. However, this is not to say gas CHP does not have a role to play as a transition technology, facilitating area-wide heat networks where the supply technology can be swapped to a lower carbon source in the future, in line with London Plan. Some alternatives that should be considered are:

- Secondary heat sources and HPs;
- Biogas sources
- Solar thermal

- Hydrogen

Example case studies and academic studies into the listed alternative sources can be found: Biogas/biomass[38]; solar thermal[39]; hydrogen[40].

It is important that networks are implemented with a clear decarbonisation plan in mind and designed accordingly. Where the decarbonisation strategy is uncertain, some no regrets design choices can be made, such as reserving space in the plant room, reducing network temperatures and enabling later installation of plant on the roofs of energy centres.

Heat supply from heat networks should be demonstrated to be lower carbon than the business as usual (BaU) alternative. In residential applications to date, the BaU case is typically defined by the carbon intensity of heat supplied by a gas boiler with an efficiency of 85%.

For new developments in London, the counterfactual, for planning purposes, is normally considered to be the emissions associated with heating a dwelling with a gas boiler.

For existing buildings, using the DEFRA emissions factor and a boiler efficiency of 85%, the counterfactual carbon emissions of a unit (kWh) of heat would equal:

$$\frac{0.184\ \mathrm{kgCO_2e/kWh}}{85\%} = 0.216\mathrm{kgCO_2e/kWh}$$

For a dwelling with its own ASHP, the calculation would use the manufacturer’s seasonal coefficient of performance (SCOP) and the prevailing electricity carbon factor under Part L of the building regulations. Using the SAP 10 electricity factor, and an assumed SCOP of 2.9 (including fan power), the calculation would be as follows:

$$\frac{0.233\ \mathrm{kgCO_2e/kWh}}{2.9} = 0.080\mathrm{kgCO_2e/kWh}$$

It should be noted that SAP emission factors are updated periodically and that GLA guidance should be referred to for the approach to their use[3].

At a dwelling level there is unlikely to be storage that could help to decouple demand from supply, thereby stressing the national grid infrastructure and the operational cost is put on to the consumer at domestic retail electricity cost. The carbon content of electricity is currently calculated as an average, yet peaks in electrical demand (i.e. corresponding to peaks in heat demand) tend to result in the use of more flexible, higher carbon generation technologies like gas CCGT to operate.

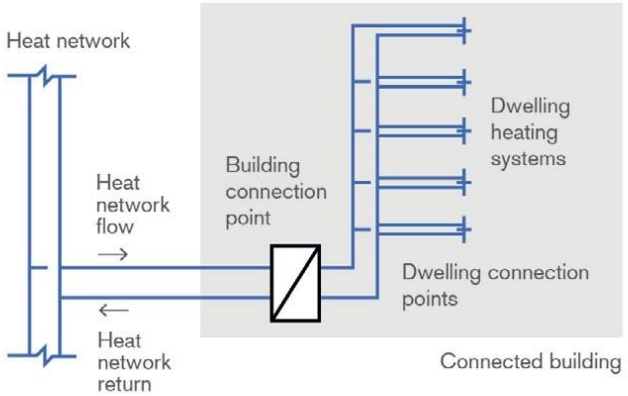
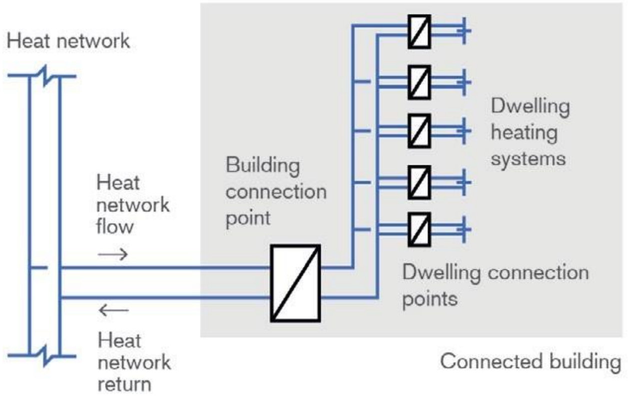
The carbon intensity of a network should be calculated inclusive of system losses (energy centre, connection and transmission losses). The system losses will vary among individual systems and buildings and can be factored in during the design process. Heat losses on the secondary side should not be included in the heat supply carbon intensity calculation if they are included in the counterfactual, but will need to be reflected in the emissions calculation as part of a new development planning application energy assessment report.

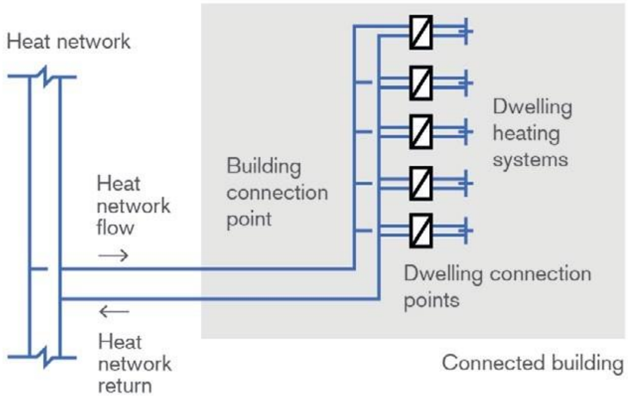
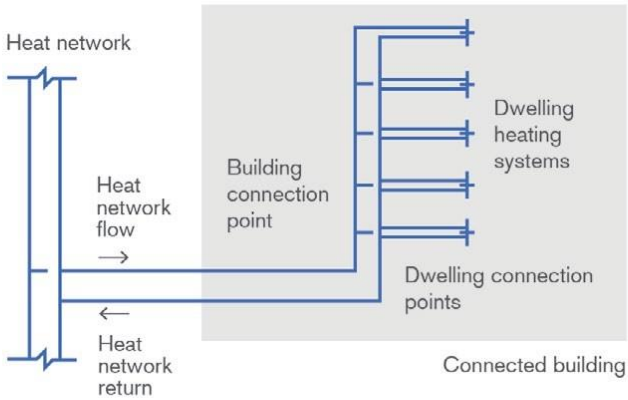
Secondary side heat network design

This section explores the connection of existing and new consumers to the heat network. In each case, these connections can be either direct or indirect, as previously mentioned.

Table 4 discusses the advantages and disadvantages of each option. Note that a heat network may include a number of these; in fact, all types may exist on the same system depending on the requirements of different consumers. For a newly designed system connecting to new developments it is preferable to adopt a common solution as there will be economies of scale in installation and reduced spares inventory savings for operation.

Table 4: Advantages and disadvantages of heat network connection configurations

Connection Configuration	Advantages/Disadvantages
	Primary to Secondary - INDIRECT Secondary to Consumer - DIRECT + Building heating system is hydraulically separated from the primary heat network + Heat exchange substation is a convenient commercial separation between the building and the heat network for metering and billing + Heat network is protected from higher building heating system pressures - Individual consumers are not hydraulically separated in the building
	Primary to Secondary - INDIRECT Secondary to Consumer - INDIRECT + Building heating system is hydraulically separated from the primary heat network + Heat exchange substation is a convenient commercial separation between the building and the heat network for metering and billing + Heat network is protected from higher building heating system pressures

Connection Configuration	Advantages/Disadvantages
	- Heat exchange losses will occur at the building and consumer level
	Primary to Secondary - DIRECT Secondary to Consumer - INDIRECT + No heat exchange losses at the building level + Individual consumers are hydraulically separated from the primary heat network, allowing a convenient metering point for billing - Primary heat network water circulates in the building heating system, introducing new potential points of failure
	Primary to Secondary - DIRECT Secondary to Consumer - DIRECT + No heat exchange losses - Primary heat network water circulates in the consumer heating systems, introducing new potential points of failure - Consumer heating systems must be rated to the same temperature and pressure as the primary heat network

The advantages and disadvantages presented in Table 4 are discussed in more detail over the following two sections.

See Secondary side network design section for a description of secondary side design in 5G networks.

Building connection

This section examines the potential options for the connection between the primary heat network and the secondary heat network within a consumer building, applicable for both new and existing buildings. There are two key options available with respect to the connection between the networks: direct or indirect connection.

Indirect connection

Indirect connection is currently the most common method in modern heat network systems. This maintains the primary heat network hydraulically separated from the secondary consumer building system, with limited potential damage from leaks in buildings or dwellings. The arrangement of heat exchangers, valves, shunt pumps and controls is known as the heat substation. This is typically installed in the basement plant room of each building.

Typically, substations comprise two or more heat exchangers for resilience. It is not normally necessary to size the heat exchangers based on 100% redundancy, however a design risk assessment should be undertaken, which considers the implication on the consumers for a loss or reduction of service. The risk for a hospital or care home may be considerably different to that of a commercial property or residential building. Where two heat exchangers are used, it is common to size each at 60% of the building's peak load, such that when one is isolated for maintenance, the bulk of the heat may continue.

Figure 19: Typical example of a heat substation (courtesy of Danfoss)

Figure 19 shows a typical example of a packaged heat substation incorporating PHEs, pumps, valves and necessary controls monitoring system installed on steel frame. With much of the installation work being completed by the manufacturer, site installation time and cost for mechanical and electrical connection can be minimised.

If the operator of the heat network is contracted to operate and maintain this equipment, the building owner would need to provide access to fulfil this obligation. Access rights are normally agreed at the time of contracting the service and are commonplace.

Due to the direction of heat flow necessary from the primary network into the secondary networks of each building, heat substations impose a higher temperature output requirement from the energy centre. In HPs and other lower temperature applications, this may not be desirable and heat exchangers should be selected to minimise the drop in temperature across them (also known as the approach temperature difference or, for PHEs, the logarithmic mean temperature difference).

Direct connection

Direct connection does not hydraulically separate the primary network water from the building's heating circulation system. In residential applications this would mean the primary network water would directly feed HIUs in each flat (where there is hydraulic separation between the network and the consumer heating circuit; see Consumer connections section). In commercial applications, the primary network water would feed the heat emitters of that building, e.g. AHUs and FCUs.

The strategy of direct connection is gaining traction as network temperatures are reducing: it removes a stage(s) of heat transfer and the associated temperature drop this brings, allowing lower energy centre output temperatures and lower network losses. This approach also has lower costs, lower plant room space requirements and fewer points of failure compared to indirect connection.

Under this strategy it is common for the network operator to design, install, operate and maintain the building's distribution circuits. This ensures that these systems are designed and installed in line with the network specification.

In the following section, Process and Instrumentation Diagrams (PI Diagrams) are shown for the main consumer connection options, indicating the control principle and energy metering points.

For either direct or indirect systems, control valves shall be two-port so that a variable volume control principle is established.

Consumer connections

The connection to individual consumers may be achieved through the installation of an HIU. HIUs are of a similar size to a domestic gas boiler and are installed in individual dwellings, providing heat to meet the demands of the consumer, with the added safety benefit of not requiring gas connections.

There are several types of HIU; some provide space heating only, while others provide both space heating and DHW. As supply temperatures in heat networks may go below the minimum temperature required to generate DHW in the future, it is likely that HIUs could play a role in pre-heating.

Figure 20: Typical HIU

Figure 20 shows a typical example of an HIU for in a consumer dwelling. It incorporates many of the same components as the heat exchange substation, but on a smaller scale. As with heat exchange substations, the connection may be indirect (typical) or direct (uncommon, especially if the building connection is direct). Figure 21 shows how HIUs could be installed in a building, interfacing between the building heat distribution system and the heating systems of the individual consumers.

HIUs present the most suitable solution to supply, control and meter hot water for space heating and domestic needs to each individual consumer. HIU suppliers can supply a range of solutions to connect consumers to heat networks, with the main differences being whether connection is made with (indirect) or without (direct) a PHE between the two heating circuits. The most common arrangements for residential units include, but are not limited to:

- Direct connection for space heating and indirect connection (PHE) for DHW;
- Indirect connection for space heating and DHW (two separate PHEs); or
- Indirect connection for space heating with DHW cylinder.

Additional guidance on types of building connections can be found in Annex H [1]of the *CP1: Heat Networks Code of Practice for the UK*[34]. These also include options with centralised hot water with two separate services for DHW and SH. The appropriate HIU configuration is dependent on the space heating and DHW systems in the connecting buildings. This is particularly important where a heat network is being connected to existing consumer buildings requiring retrofit of their heating and DHW systems.

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[1] Annex H, Guidance on types of building connections and internal heating systems for dwellings CP1 2020

Figure 21: Image of HIUs installed in an example consumer building (courtesy of Danfoss)

Direct connection for space heating with instantaneous production of DHW

This solution is recommended only where a central heat network substation has been installed to hydraulically separate the primary heat network mains from the secondary heating system within the building via a PHE.

In the absence of such a substation, having a direct consumer connection means the heat network water would flow into the consumer's heating system up to each individual radiator, introducing water quality and leak risks to the primary system in the event of faults within a building. Most crucially, health and safety standards would not allow operating temperatures and nominal pressures to exceed 90°C and 10 bar (1000kPa) respectively. Such a configuration is therefore unlikely to be the optimal choice for a building connection and would need careful analysis before being adopted.

Indirect connection for space heating with instantaneous production of DHW

This solution, although more expensive than the direct connection arrangement, provides a high degree of separation between the consumer's heating system and the primary mains, hence significantly reducing risks associated with faults within the building as well as ensuring compatibility with heat networks operating at higher temperatures and pressures. This configuration is recommended particularly where a central heat network substation has not been installed.

Indirect connection for space heating with DHW cylinder

This solution requires the installation of a hot water storage cylinder within the residential unit. It is therefore likely to be more expensive than any of the instantaneous generation systems described above, as well as requiring extra space for the cylinder.

Space heating is produced instantaneously via a PHE, whilst DHW is brought up to the desired temperature through heat exchange in a cylinder.

This is not a typical arrangement and is normally not recommended as it results in higher supply temperature and a higher return temperature. With this solution, particular care must be taken to maintain the supply temperature to the hot water tank, so that a stored temperature of 60°C can be achieved, in order to avoid any risk of Legionella bacteria growth. For additional guidance on the management of Legionella, see Legionella section.

Figure 22: DHW is produced instantaneously via a PHE

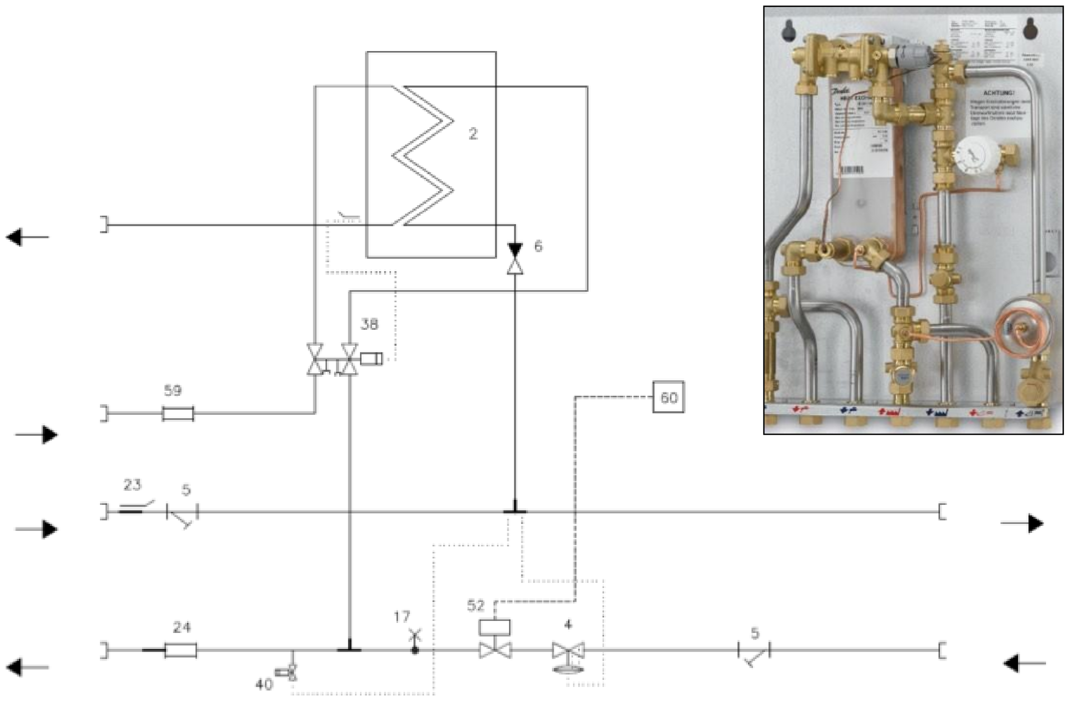


Figure 23: Both space heating and DHW are produced instantaneously via a PHE

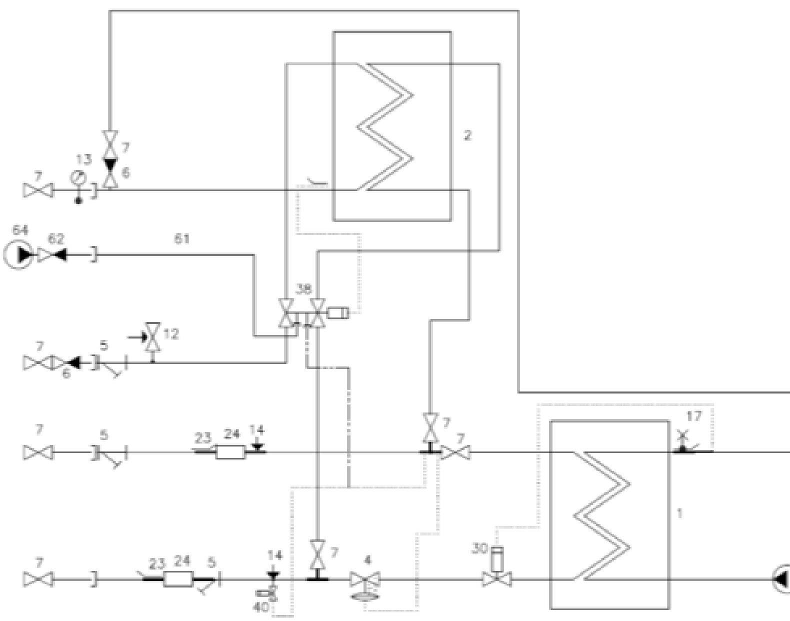
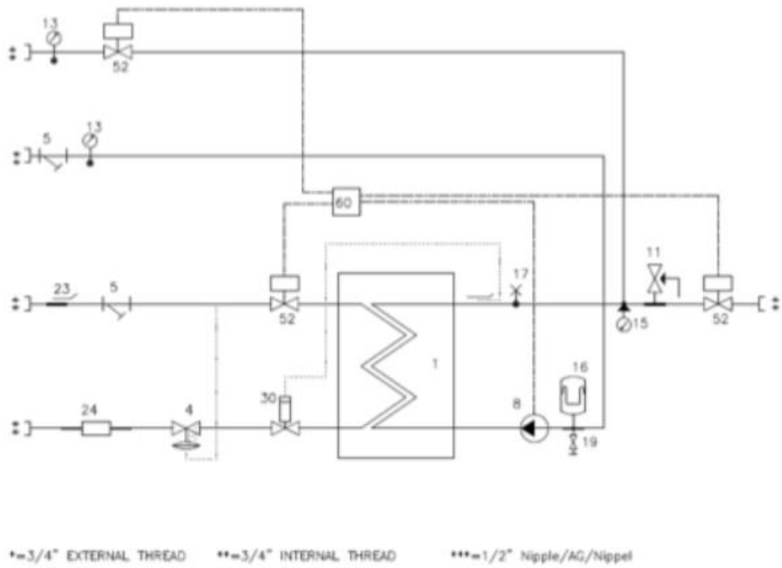
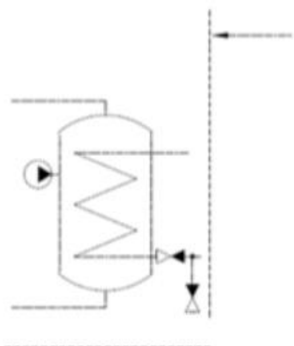


Figure 24: Indirect connection for space heating and hot water storage for DHW





Heat exchange design parameters
This section sets out the basic parameters to be used in the design and specification of heat exchangers.

Careful consideration of heat exchanger design is necessary in HP applications, where the supply temperature governs system efficiency. In order to reduce the HP output temperature as far as possible, levels of hydraulic separation (and the heat exchangers associated with this) should be minimised.

Whilst many heat exchanger types exist, in heat network applications it is most common to use PHEs with counter current flow. PHEs should be designed to exchange the maximum rate of heat under the design temperatures. The maximum required rate of heat is determined by the building's or dwelling's peak heating requirement. Temperatures are determined initially for the end use heat emitter (e.g. radiators, FCUs or UFH systems), working back to the energy centre, accounting for all levels of heat exchange present in the system.

The rate of heat transfer is proportional to the log-mean temperature difference between the heat transfer fluids, the PHE surface area and the heat transfer coefficient. To reduce the return temperature on the network, the approach temperature should be minimised (below 3°C for best practice)[34]. In order to meet the required rate of heat while minimising the approach temperature, the PHE heat transfer coefficient and surface area should be maximised.

HIUs are typically specified for new developments, with space allocated for their installation during the design and construction. There is a trade-off between maximising surface area and heat transfer coefficient and minimising pressure loss across PHEs (and hence pump power). In specifying an interfacing heat exchanger, its design maximum allowable pressure losses should be as indicated within Table 5.

Table 5: HIU pressure loss design parameters

	Max pressure loss [kPa]
Primary side	20
Secondary side	20
DHW (hot/cold)	20/30

It should be noted that these are allowed pressure losses for heat exchangers only. For the whole heat substation unit, including piping and control valves, a 60kPa pressure loss should be allowed for the primary side. This enables sufficient heat network flow when the circulation pump pressure difference control, of the main network, is set to maintain the minimum 1 bar (100kPa) difference for a reference customer, as is normal practice.

Typical space requirements for heat exchange substation equipment is given in Table 6.

Table 6: General indicative space requirements for heat exchange substation equipment for building plant rooms

Heating Capacity (space heating + ventilation) [kW]	Approximate building size [m^3]	Space required by the heating equipment [m^2]
30	1,000-1,500	2
200	10,000-15,000	4
400	20,000-30,000	5
800	40,000-60,000	6

Heat substations are normally provided and maintained by the heat network operator and access will be required by the operator to maintain the plant and correct any faults that occur.

Secondary side control
Through the application of variable volume-controlled operation of heat networks, the reduction in volume flow rate when heat demands are reduced has a substantial impact on reducing pumping energy costs and heat losses. Under part-load conditions, when the building heat demand falls, a reduction in the mass flow rate ensures that the right amount of heat is transferred to the building, without the return temperature increasing. This control philosophy also allows the adoption of VSD pumps and it further ensures that generation assets, such as CHP, HPs and low-grade heat recovery systems, can operate at their optimal efficiency.

The control of the interface between the primary and secondary sides of a heat network is crucial to achieving efficient and effective operation. This section explores the control of the interface, based on a variable flow, variable temperature regime.

Two-port valves are a key customer-end requirement in variable flow heat networks. They modulate to achieve a target secondary side flow temperature (or air temperature if applicable), resulting in a change in differential pressure across the valve. Pump speed (i.e. flow) is then adjusted in response to the change, to maintain a fixed minimum differential pressure. Further details on the specific characteristics of two-port valves can be found in CIBSE: CP1[34].

Overheating in communal areas
The London Plan requires that development proposals minimise the risks of overheating by following a cooling hierarchy. While this is primarily aimed at improving the comfort of building occupants in summer, there are several important considerations to keep in mind when designing, specifying, installing and operating any communal building heating and hot water systems, including, but not limited to, heat networks.

The design and installation of communal heating and hot water systems should minimise thermal loss within buildings. In many cases, thermal loss from internal building pipework has been found to be significantly higher (in percentage terms) than for heat network infrastructure installed in the street. Updates to CIBSE CP1[34] state that networks should be designed to have less than 10% losses on the primary network, and less than 876kWh/dwelling/year on the secondary network (around 25% of the average 3,500kWh/dwelling/year).

When designing communal building heating and hot water systems, the issue of overheating can be reduced through a number of strategies, including:

- Minimising the length of pipework, especially the lengths of lateral pipework installed in corridors – this can have implications for the DHW delivery times and layout of risers (buildings in the form of block level dwellings should be designed to accept a heat network with numerous dedicated risers thus ensuring short laterals);
- Increasing the thickness of insulation on pipework and fittings;
- Ensuring that insulation is correctly installed to the specification and inspected;
- Reducing the operating temperatures of the supply and return flows within buildings (e.g. through 4G and 5G networks);
- Increasing the differential between supply temperature and return temperature as this enables smaller diameter pipes to be installed, reducing the rate of heat loss from pipes which is proportional to the surface area for heat transfer;
- Ensuring that pipes are sized appropriately;
- Tertiary DHW pipework in dwellings should consider the amount of stored water within them. Long runs of pipes and flow restrictors will result in water/energy wastage and slow delivery times for DHW;
- Ensuring that return temperatures are well controlled under part load summer conditions by minimising the flow rates for keep warm facility in HIUs and avoidance of fixed bypasses.

CP1: Heat Networks Code of Practice for the UK[34] recommends maximum flow temperatures of 70°C and maximum return temperatures of 40°C and 25°C for space heating and DHW circuits respectively[34]. It should be considered that CP1 is an evolving document and therefore the most recent update should be referred to.

The implementation of these simple design features can make a significant difference to the comfort of building occupants and operating costs through reducing the heat losses on the network. For guidance on assessing the optimum economic level of thermal insulation for a system, see Thermal insulation section or review BS5422:2009 Annex G[35].

Where these requirements cannot be met through minimising the heat loss from pipes, it may be necessary to apply natural or mechanical ventilation to dissipate the remaining heat; however, this will increase the rate of heat transfer and therefore increase operating costs. When assessing the economic level of insulation to specify in the communal building heating and hot water system design, this additional operational cost should be factored into the calculation as an avoided cost, thereby enabling investment in a higher grade of pipe insulation.

Provision for future connection

Development precedes a heat network

The economics of heat networks can mean they remain at the planning stage for long time before installation. Where a new development commences in an area where there are plans for a future network which has yet to be installed, the London Plan requires new development to allow for future connection. This should involve, as a minimum:

- safeguarding of the route for the interconnecting pipework from the network to the plant room;
- provision of pipe connections and space in the plant room to allow for installation of a PHE to enable heat import to the building; and
- minimising heating supply temperatures on the building secondary side to ensure wide range of compatibility with different heat network designs.

The design should allow the connection to be made with minimum disruption to building occupants and local roads and utilities. In the scenario where connection is likely to happen in the short term, gas boilers may prove to be an appropriate, temporary technology. However, if connection is a longer-term prospect, a low-carbon technology should be installed.

Heat network precedes a development

In the event that a future connection is anticipated at a point in the heat network, with connection design fixed and a connection date known with some degree of certainty, it is normally sensible to pre-install the connection point and isolation valve. As a rule of thumb, if the new connection is expected to be more than one year into the future then the connection works should be deferred. However, factors such as access to pipework may lead developers to undertake the connection earlier. The connection of the development to the heat network can be made before or after the network is operational. Connections can be made during planned maintenance works, or ‘hot tapped’ if the network is to continue operating during the connection.

Heat metering

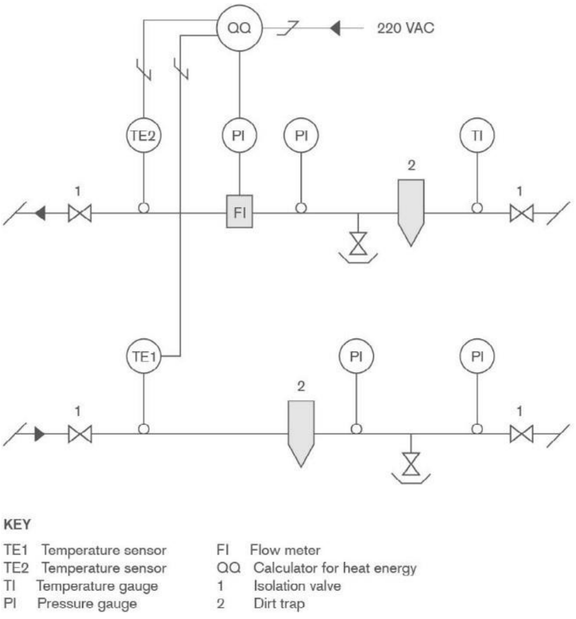
Accurate metering is normally required at any point where heat is bought and sold. Meters allow consumers to be billed based on actual energy consumption; they provide a fair billing solution and can incentivise customers to reduce their heat usage. They also offer benefits to network operators in terms of improved understanding and management of consumption and inefficiencies.

The Heat Network (Metering and Billing) Regulations[18] came into force in December 2014. This states that new buildings, or those undergoing major renovation, which are supplied by heat networks must be fitted with individual meters(where these are cost-effective and technically feasible)[18]. Furthermore, London Plan policy SI2 requires post-construction monitoring of major developments via an online platform, including performance of heat networks[2].

The metering location must be chosen to consider heat losses and will dictate who is financially responsible for losses in that part of the network. As a result, metering is usually placed at the consumer connection, meaning that the entity responsible for the operation of the network is financially incentivised to ensure that it is efficiently managed and maintained.

A phased build out of a development should consider the low flow conditions which exist at the early stages of a network. In general, meters are accurate to +/-5% within the design flow rate range, therefore it may be useful to consider the installation of a jockey (smaller) meter in the early design phases of the network to ensure accurate energy flows are recorded.

Figure 25: The general arrangement of heat metering



The components of the meter, as shown in Figure 25, include a flow meter, temperature sensors and a heat calculator. The flow meter measures the volumetric rate of circulating water in the network. The pair of temperature sensors constantly measures the temperatures of the water flowing into and returning from the metered space. Based on the readings of the flow meter and the temperature sensors, the heat calculator determines the thermal energy used by the building. The calculator automatically considers the water density and specific heat corresponding to the temperature.

As with electricity and gas networks, meters will normally be owned, installed and maintained by the heat supplier. Meter readings may be recorded by the heat purchaser and corresponding data either collected manually and sent to the supplier, or via the installation of an electronic billing system, depending on the connection arrangement and heat volume.

Automatic meter reading

The new generation of meters incorporate automatic meter reading (AMR) systems. AMRs collect data from remote metering devices and transfer the data to a central database for billing and analysis. Meters may communicate wirelessly, via a mobile radio network or over optical fibre. This reduces operational costs by obviating manual meter readings and provides detailed information on consumption patterns. *CP1: Heat Networks Code of Practice for the UK*[34] recommends full AMR systems for larger schemes with more than 250 dwellings[34].

Smart meters

Smart meters are the most advanced type of meters. The technology is still emerging and no industry standard has yet been established, but they will provide more functions than AMR systems, including: real time, near real time reporting; heat outage notification; and heat quality monitoring.

Although there are no standard smart heat meters, recommended solutions include the following characteristics:

- Remote meter reading;
- Remote change over from credit to prepay modes and vice versa;
- In-home display conforming to Code for Sustainable Homes requirements;
- Remote diagnostics;
- Engineering transactions to be performed remotely such as change in tariff; and
- Secure electronic communication and transactions.

Given the significant potential for improved system efficiency and viability from better meter systems, heat networks should incorporate meters with AMR as a minimum. Smart meters should be considered carefully to ensure early adoption once they are technically proven and their benefits quantified.

In selecting a meter supplier, it is important to ensure that the data is presented by their system in an open protocol format usable by more than one metering and billing services provider, to avoid being tied to a particular provider.

Data security is also an important consideration when selecting the communications system between the meter and the central database for billing and analysis.

Consumer demand and behaviour
There is strong evidence to show that consumers can achieve significant energy and cost savings through the installation of meters and controls into existing unmetered network connections. As residents are provided with the ability to monitor and control their own consumption and link it directly to the amount they pay, behaviour changes and consumption reduces. However, installing individual meters has a significant cost, adding to which the meters have a limited life. Therefore, the expected reduction in heat consumption would normally have to exceed about 15% for the retrofitting of individual heat meters to be cost-effective. Although, meters should be installed as standard for all new networks.

Legionella
Legionella bacteria (*Legionella pneumophila*) can develop in warm water and cause Legionnaires' disease, a pneumonia-like illness which is potentially fatal. It is therefore important to control the growth of legionella bacteria in all systems that contain water to be used directly by humans (e.g. DHW systems).

The bacteria grow fastest in conditions in which the temperature is between 20-45°C. In temperatures above 46°C the bacteria numbers decline, with further decreases with every temperature increase (see Figure 26). Where DHW is being stored, for example, in individual dwelling hot water cylinders or in commercial buildings such as hotels, most guidance specifies a storage temperature of 60°C or greater. This implies a minimum required energy centre output temperature of approx. 70°C which has a knock effect for HPs, as it would lead to lower efficiency.

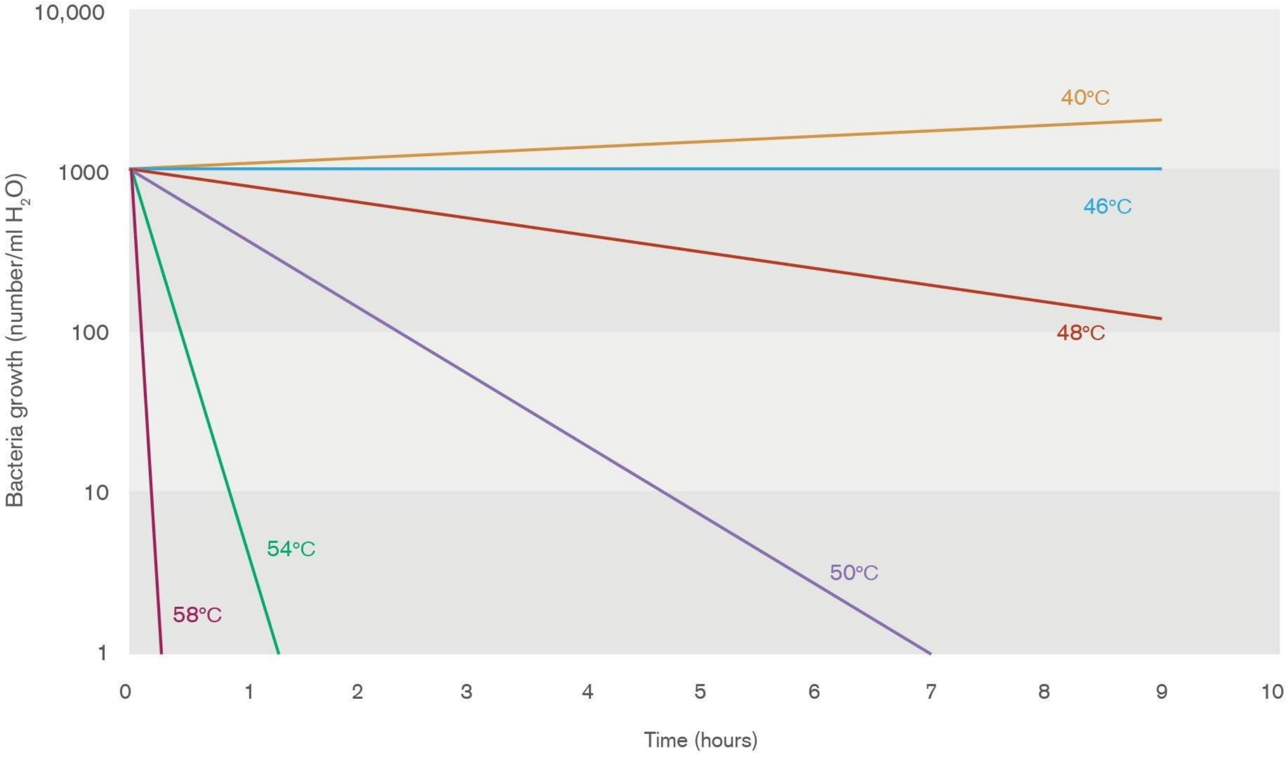
While the UK maintains a strong track record in relation to the control of legionella bacteria, there is no room for complacency. The risk of the bacteria developing in a heat network may be reduced by:

- Minimising as far as possible storage of hot water and pipework lengths. Generating DHW instantaneously, i.e. with a PHE in each flat. This may not be possible due to the higher peak heating requirements associated with instantaneous production.
- Avoiding ‘dead legs’ in the network design. These are sections of the pipe network where water does not flow continuously and may include runs of pipe that are shut off at an isolation valve. To avoid this, isolation valves are positioned as close to connection points as feasible; when a connection is isolated the amount of stationary water is minimised. Stationary pockets of water do not maintain the bulk flow temperature, and can often fall to within the optimal temperature range for legionella bacteria growth, from 20°C to 45°C.
- Operating the network above 55°C; this provides a safety margin for operation to allow for the occasional excursions from the design set point. Across Europe the preferred temperature for operation of heat networks differs slightly, whereby the UK has historically taken a comparatively safe view. As London heat networks develop, and with the requirement for those networks to be both safe and efficient, the preferred minimum temperature for continuous operation is now recommended at 55°C, in line with Danish, Swedish and French heat networks.
- 4G and 5G networks may operate below 55°C; in the case of low temperature networks, this will require management from a legionella perspective, through one of the following means:

  - regular pasteurisation of DHW cylinders by raising the temperature to a minimum of 60°C weekly, for an hour, to kill any legionella bacteria within the system. Figure 26 shows the impact of time and temperature on the growth rate of legionella bacteria. At a pasteurisation temperature of 60°C or greater, the population of legionella bacteria can be reduced significantly within less than an hour;
  - generate DHW instantaneously at point of use (i.e. with an electric heater), avoiding storage of water and minimising the volume of water at risk of legionella growth; or
  - store DHW above 60°C by either using an immersion heater in the hot water cylinder or a dedicated DHW water-to-water HP to raise the DHW temperature to the required storage temperature.

A significant amount of guidance on the control of legionella bacteria exists in the UK, including CIBSE Technical Memoranda TM13 (2013)[41] and the Health and Safety Executive Approved Code of Practice and Guidance (ACoP) L8[42]. Readers are referred to these documents for detailed guidance.

Figure 26: Legionella bacterial growth rate relationship with water temperature and time



Interconnecting heat networks

The strategy for transition from small to area-wide networks, of the type envisaged by the LES, involves the development of both new large-scale networks and the interconnection of those that already exist across the capital. There are a number of reasons for interconnection, including:

- Their aggregate thermal demand allows for better operation and utilisation of low-carbon or low-cost heat supplies; or
- Their joining improves the heat supply resilience on one or both of the networks.

Networks may either be connected directly and share supply water, or be hydraulically separated with a heat exchanger. Where they are connected, the operating parameters and pipework materials require consideration in designing the connection.

To facilitate the connection of existing or smaller networks there may be circumstances in which plastic pipes have been used or may be specified on the basis of reducing installation cost.

Plastic pipework is cheaper and easier to install than steel, however, its heat carrying performance is limited by lower pressure and temperature ratings. Its use is sensible in small area networks, especially those with direct consumer connections.

Since plastic pipes are less commonly used for transporting bulk heat over long distances, the available pipe sizes are also typically smaller.

Plastic pipes can be physically connected to steel pipes, provided that the correct transition pieces are specified and installed. However, the consumer connections and pipes must be capable of the higher network pressures and temperatures.

Alternatively, the plastic pipework can be hydraulically separated using a heat substation as illustrated in Figure 19 in the Building connection section.

Development of area-wide networks involves the connection of medium scale and kick-start networks. Hydraulic separation may negate some operational benefits since one of the key goals for the efficiency of these networks is to keep the return at as low a temperature as possible.

Design parameters for small community networks, such as those associated with estates and a small number of connected buildings. are likely to be hydraulically separated from the large area-wide heat network (existing or future). This allows for these systems to be designed on maximum efficiency and lower temperatures as pipe distances are lower and the pipe costs for larger pipes are less prohibitive.

Heat network standards

The preceding section set out the general principles of network design, including network configuration and selection of operational parameters. In this section, specific standards are provided for networks developed in London. Consistent adherence of these standards will strongly benefit the future interconnection of networks. The GLA will, wherever appropriate, seek to ensure these standards are applied by network designers and developers in London. These design standards have been drawn from international, European and British standards, referenced accordingly.

General design standards

Heat networks should be designed according to following main standards, including standards for bonded pre-insulated steel service pipe systems and for plastic service pipe systems.

All the specified material requirements should be understood as minimum requirements. Equipment suppliers should provide heat network pipe systems that meet the requirements of this specification.

Table 7: General design standards

Standard number	Standard name
EN 253:2009+A2:2015	District heating pipes. Pre-insulated bonded pipe systems for directly buried hot water networks. Pipe assembly of steel service pipe, polyurethane thermal insulation and outer casing of polyethylene
EN 448:2015	District heating pipes. Pre-insulated bonded pipe systems for directly buried hot water networks. Fitting assemblies of steel service pipes, polyurethane thermal insulation and outer casing of polyethylene
EN 488:2015	District heating pipes. Pre-insulated bonded pipe systems for directly buried hot water networks. Steel valve assembly for steel service pipes, polyurethane thermal insulation and outer casing of polyethylene
EN 489:2009	District heating pipes. Pre-insulated bonded pipe systems for directly buried hot water networks. Joint assembly for steel service

Standard number	Standard name
	pipes, polyurethane thermal insulation and outer casing of polyethylene
EN 13941:2019	District heating pipes. Design and installation of thermal insulated bonded single and twin pipe systems for directly buried hot water networks. Design and installation
EN 14419:2009	District heating pipes. Pre-insulated bonded pipe systems for directly buried hot water networks. Surveillance systems
EN 15632:2009	District heating pipes. Pre-insulated flexible pipe systems
EN 15698:2009	District heating pipes. Pre-insulated bonded twin pipe systems for directly buried hot water networks
DIN 16892	Crosslinked polyethylene (PE-X) pipes. General quality requirements and testing
DIN 16893	Crosslinked polyethylene (PE-X) pipes. Dimensions
EN ISO 15875:2003	Plastics piping systems for hot and cold water installations. Crosslinked polyethylene (PE-X)
DIN 4726	Warm water surface heating systems and radiator connecting systems. Plastics piping systems and multilayer piping systems

Heat metering services

Applicable standards for heat metering on heat networks are presented below.

Heat meters:

- EN 1434-1:2015 Part 1: General requirements
- EN 1434-2:2015 Part 2: Constructional requirements
- EN 1434-3:2015 Part 3: Data exchange and interfaces
- EN 1434-4:2015 Part 4: Pattern approval tests
- EN 1434-5:2015 Part 5: Initial verification tests
- EN 1434-6:2015 Part 6: Installation, commissioning, operational monitoring and maintenance

Communication systems for meters and remote reading of meters:

- EN 13757-1:2014 Data exchange
- EN 13757-2:2018 Wired M-Bus communication

- EN 13757-3:2018 Application protocols
- EN 13757-4:2019 Wireless M-Bus communication
- EN 13757-5:2015 Wireless M-Bus relaying
- EN 13757-6:2015 Local Bus

Summary of recommended network design requirements

This section summarises the network parameters outlined in this manual for heat networks, which may form part of a small or large network of pre-insulated bonded heat network with steel service pipe. These parameters are presented in Table 8.

For plastic pipe systems the maximum operation temperature is usually limited to 95°C and pressure to 4-6 bar (depending on pipe diameter, thickness and operating temperature) as the design life is shorter at higher temperatures. In regimes where the operating conditions fall within these criteria, plastic products could be considered as an alternative to steel pipe in area-wide networks.

Table 8: Heat network parameters

Network parameter			London Heat Network Manual design standard	External reference
	1	Design life	Minimum of 30 years ($T_{MAX,}$operation = 120°C). Aspiration of 50 years ($T_{MAX,}$operation = 115°C).	IEA: District Heating and Cooling Connection Handbook, 2002 EN 253:2009 4.5.5.1
Pressures and temperatures	2	Pressures	16 bar g (maximum design gauge pressure).	HVCA TR/20, 2003
	3	Temperatures	140°C (maximum design temperature); 120°C (maximum operating temperature). CP1 recommends a minimum temperature difference between flow and return at peak design to be 30°C for supply to new buildings and 25°C for existing buildings.	HVCA TR/20, 2003 Heat networks: Code of Practice for the UK (CP1)
	4	Temperature flow and return	95°C maximum design flow temperature. Less than 70°C return temperature for supplies to existing buildings and less than 50°C for supplies to new buildings.	Heat networks: Code of Practice for the UK (CP1)
	5	External design temperature	-5°C (design air temperature). Design ground temperature variable with ground and depth.	CIBSE Guide plus -1°C margin. CIBSE AM11 and TM48 simulation of future weather patterns

Network parameter			London Heat Network Manual design standard	External reference
Pipework	6	Pipework material	Steel (for primary network mains, secondary network mains, branches and consumer connections). Steel quality P235TR1 for all pipework, or alternatively P235GH for pipework DN300 mm and above.	EN 10217-1:2019 EN 253:2009 EN 13941 EN 15632 (1-3) (polymer pipes)
Heat flow	7	Volume supply control	Variable due to use of two-port control valves at substations and within buildings.	
	8	Carbon intensity of consumer heat supply	Maximum 0.18746kgCO_2e/kWh (on a Gross CV basis for Scope 1 emissions).	DECC/Defra 2018 GHG Conversion Factors for Company Reporting[43]
Heat transfer	9	Supply temperature	Supply temperature shall be variable following the supply temperature curve linked to outdoor temperature.	
	10	Heat metering	Recommended AMR system with consumer interface complete with trend reporting.	BS EN 1434-1:2015
	11	Heat interface units	**Space heating (new development)** Primary side flow 90°C to 70°C; return 45°C max. Secondary side flow 70°C max; return 40°C max. **Space heating (renovation), existing network** Primary side flow 110°C to 70°C; return 45°C. Secondary side flow where reused existing radiators to suit heat loss calculation. Secondary side flow for new radiators design to 70°C max; return 40°C max. **DHW** Primary side flow 70°C max; return max 25°C. Secondary side flow 55°C; return 10°C.	Heat networks: Code of Practice for the UK (CP1) Heat Interface Units (BG 62/2015) **Building Engineering Services Association HIU test regime**
Monitoring and maintenance	12	Leakage detection and monitoring	Pipe network shall be provided with leak detection system, which can be connected to the remote monitoring system. Datum measurement required as part of commissioning process.	BS EN 14419:2009
	13	Water quality & Pre-	pH 9-10 Alkalinity < 60 HCO_3/l (mg/l)	BS 2486:1997

Network parameter			London Heat Network Manual design standard	External reference
		Commission Cleaning of Pipework Systems	Oxygen level < 20µg/kg Total Fe < 0.1mg/kg Total Chloride < 50 Cl mg/l Total hardness < 0.1dH	BSRIA Guide is BG29/2020
Thermal storage	14	Thermal storage	Designed to optimise utilisation of low-carbon heat supplies within the constraints of heat demands, heat supplies and site requirements.	

Heat network construction

This section covers the physical works for the construction of a heat network. The reference network types are a large-scale transmission network and a smaller scale distribution network comprising insulated steel pipe sections. The standards are directed towards the typical scenario of a buried pipe network located within the public highway.

This section includes:

- Installation supervision;
- Construction principles; and
- Construction standards.

Variations for other typically encountered installation scenarios (e.g. soft dig, private land) are considered briefly at the end of this section.

This section also addresses appropriate space requirements for safeguarding corridors for future heat network routes.

Installation supervision

Heat networks may be well designed and quality materials specified, however, experience shows that one of the most important factors for long-term economic sustainability of a network is correct installation. Installations must be completed by experienced and qualified contractors under experienced and strict supervision. It is good practice for inspections to be carried out at each stage during the construction and installation of networks, as a prerequisite to move on to the next step. Example inspection points include:

- Setting out
- Trench construction
- Sand bedding
- Pipe laying
- Welding/pressure and other tests (x-ray, visual, ultrasonic, etc.) on the steel pipes;
- Alarm wire connection and testing;
- Insulation casing joint installation and testing;
- Initial backfilling
- Final backfilling
- Surface (top soil/tarmac); and
- Final acceptance.

The contractor must maintain full, detailed and accurate records of all the welding operations and the insulation casing jointing works so that all work can be monitored and assessed for quality.

If works are covered up before inspection then any remedial works become very costly to implement and may involve considerable disruption and inconvenience to the system and delay to the operation of the service.

Construction principles

The safety of construction operatives and the public must be the highest priority consideration for the installation of heat network apparatus.

The contractor responsible for installation must comply with and be cognisant of:

- Current legislation, including NRSWA 1991 and attendant codes of practice;
- On-site directions by authorised persons such as highway authorities, police and other statutory authorities;
- Current industry standards and specifications, including National Joint Utility Group (NJUG) standards and recommendations;
- Manufacturer's design, installation and commissioning requirements and recommendations;
- Relevant health and safety regulations. Contractors must provide risk assessments and method statements in accordance with the requirements of the Construction (Design and Management) Regulations 2015[44], or subsequent replacement;
- Environmental regulations, particularly in relation to the control of waste and the avoidance of local nuisance impacts including noise, dust, odour and air pollution;
- Specific requirements of the highway authorities where the route runs in traffic- sensitive or congested streets;
- Specific requirements of landowners where the route runs outside the public highway;
- Specific requirements of statutory undertakers whose apparatus is affected by the works;
- Specific requirements of transport organisations who may be affected by the works;
- Specific requirements of those buildings along the route whose occupiers or users have special requirements with respect to access, noise, dust, etc.;
- Any licence or other consent granted under the New Roads and Street Works Act 1991, the Traffic Management Act 2004 and other relevant Highway legislation; and
- Building Regulations requirements and any conditions attached to planning conditions, where relevant.

Construction industry good practice principles for the set up and operation of worksites should be observed to ensure the safety of and to avoid inconvenience to businesses, residents and other members of the public affected by the works.

Construction standards

This section sets out some of the key construction standards to be applied in the construction of heat networks. Included are typical trenching details, standards for testing and commissioning of pipe and insulation, and valves and valve chambers.

Typical trenching details

Figure 27 shows a typical construction detail for a heat network mains pipe trench in the public highway, using a pair of pipes for flow and return. The minimum distance from the top of the pipes to ground level is 600mm. The pipes should not be located within the road structure as defined under NRSWA. The dimensions of the excavation depth (d) and width (w) and the separation distance between pipes (a) and from the excavation edge (b) depend on the size of pipe and the highway construction. Table 9 provides the suggested relevant trench dimensions for typical pipe diameters.

An alternative arrangement is shown in Figure 28, with both the flow and return heat network pipes enclosed in the same insulation. Such arrangements can allow a narrower trench (though it may be slightly deeper), though are normally only feasible on smaller pipe sizes.

Figure 27: Typical installation arrangement for separate flow and return pipes

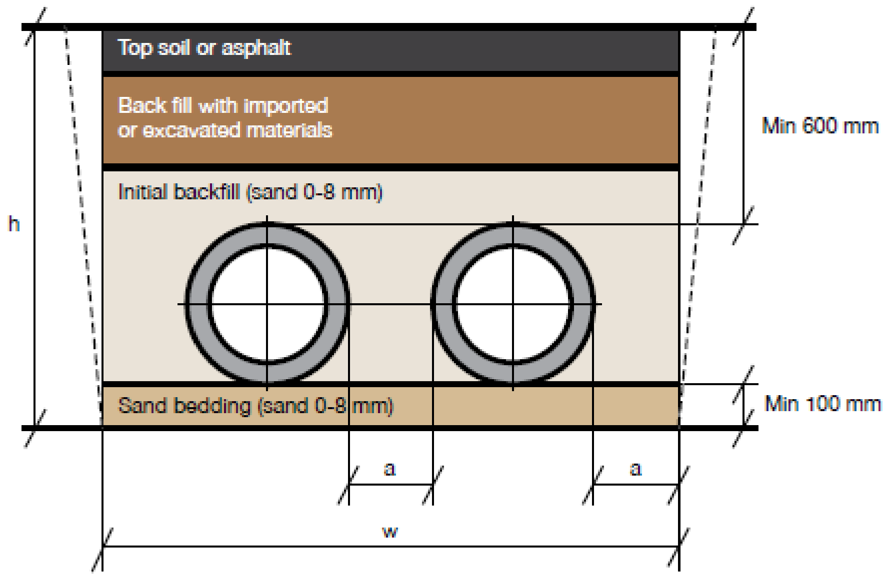
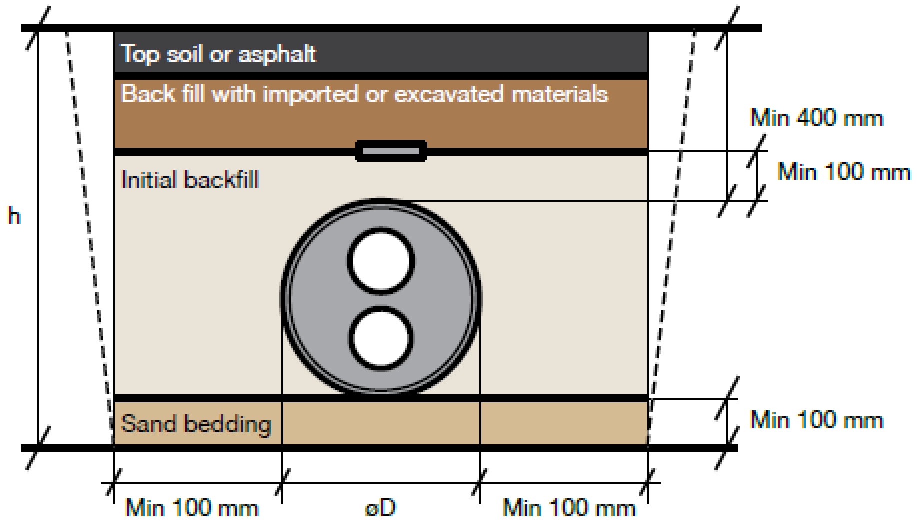


Figure 28: Typical twin-pipe installation arrangement



When the trench is located within the public highway the depth, surround, backfill and reinstatement of the trench must comply with the NRSWA Specification for the reinstatement of openings in roads. When backfilling, the initial surround of up to a minimum 100mm above the heat network pipes should always be completed with specified, imported and screened sand. If the backfilling sand is a different colour to that of the surrounding sand, it can help to reduce the likelihood of pipe strike during later service works.

Table 9: Pipe Trench minimum dimensions (for standard side-by-side pipe installations)

DN (carrier/ casing)	a [mm]	b [mm]	w [mm]	h [mm]
DN80/160	150	150	770	860
DN80/160	150	150	770	860
DN100/200	150	150	850	900
DN125/225	150	150	900	925
DN150/250	150	150	950	950
DN250/400	200	200	1400	1100
DN300/450	200	200	1500	1150
DN400/560	200	200	1720	1260
DN500/630	200	250	1910	1330
DN600/800	250	300	2400	1500
DN700/900	250	300	2600	1600

The excavated trenches should be surveyed to determine high and low spots of the installed bonded pipe network. This information should be used to inform where the optimum positions for air release valves and drainage valves are to be located.

It should be noted that additional space at welding points, corners, valve locations and spurs will be required.

Where a heat network is installed in proximity to other existing utility and service apparatus, the installation of the heat pipes should endeavour to comply with the principles of separation from other apparatus. Separation will depend upon the congestion of the area and consultation with owners of the existing apparatus is recommended.

Where a heat network is installed in new developments where no other apparatus exists, the installation should endeavour to comply with the principles within the National Joint Utilities Group Guidelines (NJUG) on the Positioning of Underground Utilities Apparatus for New Development Sites[45].

It is not always possible or feasible to install heat network pipework underground. Installation can take advantage of existing tunnels or ducts, or run along the outside of buildings.

Crossing barriers such as railways and highways may necessitate above-ground installation. Such installations can introduce additional legal and technical details with regard to structural reinforcement, requirements for work permitting and access for operations and maintenance (O&M).

Testing and commissioning of steel pipe welding
Pipework should be tested as detailed in EN 13941. Typical requirements which should be included in the works specification are:

- All steel pipe welding is to be undertaken by certified coded welders. Certification must be in compliance with current British and European Standards. Welders may be subjected to a welding test with at least the same acceptance criteria as the criteria for the finished work, with reference to EN 25817;
- A testing regime must be established for welded joints e.g. non-destructive testing of 10% of welds as detailed in EN 13941. Visual inspection of welds is required;
- All pipework installations should be pressure tested, witnessed, and signed off by a competent engineer. All equipment used for testing should be fully calibrated and the test procedures and monitoring proposals must be agreed before the tests commence;
- Following completion of a satisfactory pressure test the site closures must be made in strict accordance with the pipework manufacturer’s specification;
- The leak detection system must be tested and certified; and
- Systems must be flushed and treated prior to being put to service.

Testing and commissioning of insulation case joint welding
Typical requirements to be included in the works specification are:

- Joint assemblies for the steel pipe systems, polyurethane thermal insulation and outer casing of polyethylene shall comply with BS EN 489. The joint assemblies shall be installed by specially trained personnel according to the instructions given by the manufacturer. Fusion welded insulation joints shall be implemented to join the pre-insulated steel pipe systems;
- All joint assemblies must be manufactured by same manufacturer as the steel pipe systems and/or approved by the steel pipes systems' manufacturer for use with their pipes;
- The joint should be pressure tested to confirm it is air tight;
- Polyethylene welders shall possess evidence of valid qualifications, which document their ability to perform reproducible welding of the quality specified.

Valves and valve chambers
Where necessary spindle extensions must be provided on valves in a heat network, to enable operation of the valves buried at depth or located within manholes where it is otherwise unnecessary to enter.

Where valves are housed in specific chambers then these chambers should be sized to accommodate the apparatus within them and to enable easy operation of the valves. The valve chambers and associated items must be designed to withstand the likely traffic loads applicable to their location. These shall be free-draining and not liable to flooding. Valve chambers should be clearly marked such that the location and contents of the pipes are easily identifiable.

Plastic pipework
As network temperatures are driven down, designers will increasingly turn to plastic pipework to reduce cost and labour requirement on site (i.e. through reduced welding requirements and ability to prefabricate more elements off-site). Construction of plastic pipe networks will have the following considerations:

- Higher pipework flexibility, allowing easier routing of pipework around other existing buried services;
- Lower insulation requirements (due to lower operating temperatures and lower thermal conductivity of pipe material), further improving ability to route pipework around other services and in some cases making trenches smaller;
- Higher thermal expansion coefficients leading to greater movement under use – this requires more expansion joints and anchor points around the network;
- Press fit couplings available on some types, allowing easier joining of pipework lengths. Otherwise pipes are butt fusion welded together;
- Polymer pipes should comply with EN 15632. Plastic pipe systems should undergo pressure testing after installation, prior to filling and commissioning.

Smart controls

Introduction to smart controls

This chapter gives an insight into the huge potential offered by smart controls to improve the efficiency, regulation, cost and performance of heat networks.

Smart control technology is becoming more widespread in the energy sector and the benefits it provides will be key in delivering the transition to low-carbon energy. The challenges of scheduling the growing contribution of DE, controlling demand peaks, reducing consumer costs and improving delivery and reliability of heating can be tackled through the integration of smart controls. The following sections describe the importance of, and gives guidance on, designing and implementing smart-enabled networks in preparation for their emergence into the market.

Definition of smart controls

Smart controls utilise advances in computational power, machine learning, advance process control and the Internet of Things (IoT) to improve interaction between system components, with the aim of optimising the overall performance of the network. Sensor data and external inputs are collected by the control system, while automated algorithms learn user demand and usage profiles from historical data. This informs the future operation and interaction of the network to optimise the system along business and policy objectives while simultaneously considering operating constraints.

Smart controls improve the prediction of heat load and thus improve the demand response. This enables adaptability of the heat generation mix to maximise the use of renewable and waste energy resources, as well as the integration of thermal storage and improved consumer control. Smart controls can be used to enhance the performance of the system for a range of user specified parameters, including whole life cost, reliability of operation, carbon emissions, energy consumption and customer satisfaction. They are equally suitable for networks with centralised generation plant and those served by multiple distributed heat generation sub-systems.

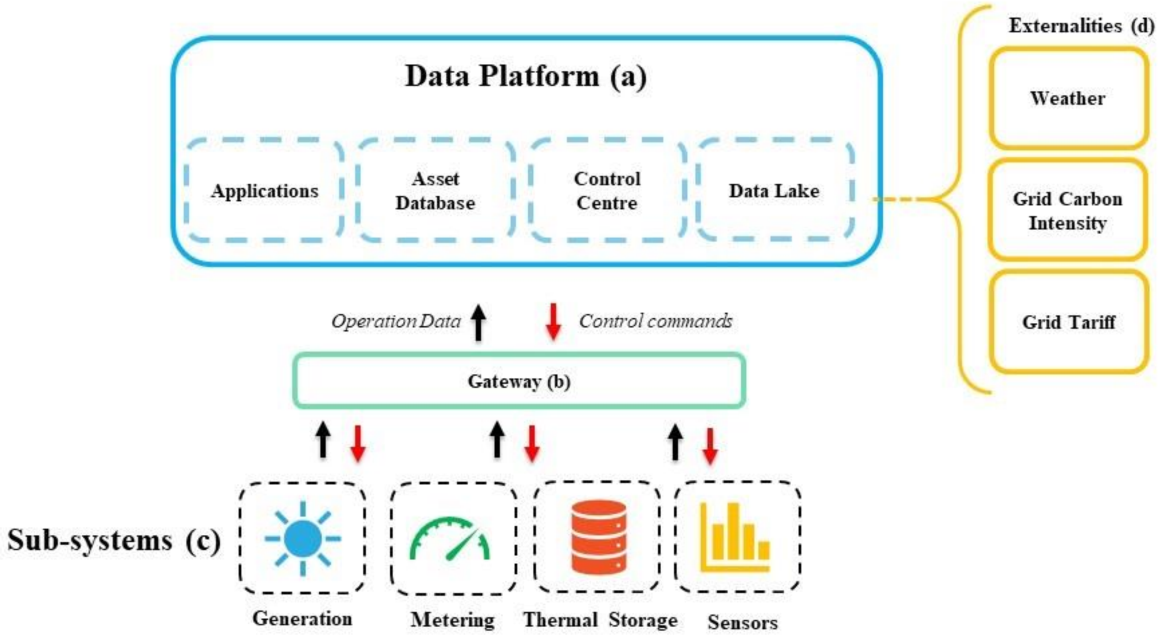
At the most basic level, smart controls consist of:

- Data sensors within a range of connected sub-systems (e.g. generation, metering, storage);
- Gateways to translate data to a common language (where required);
- A data platform which operates as a high-level form of control, incorporating different applications, data processing and storage;
- An actuation layer that operates at a local level to provide control and make adjustments to different elements within the system.

The output is a control feedback response, based on the analysed data. Extensions to the system can also include human machine interfaces (HMIs), which provide visual representation of the actions and impacts of the smart controls, geographic information systems (GISs), or supervisory controls[46].

The data acquisition system gathers input from sub-systems, such as temperature, pressure, energy storage and heat usage data in the network, as well as inputs from external factors, such as weather conditions, grid carbon intensity, heat price tariffs, user behaviour in the buildings or production elements in the network. This is analysed and computed into an appropriate control response signalled to the sub-systems.

Figure 29: Structure of a smart control system for a heat network



Difference to traditional controls

Smart controls enable optimisation of more complex systems and can apply more varied and granular data to achieve greater performance towards defined objectives. Traditional controls work in a reactive manner, controlling the operation of sub-systems through simple ‘if-then’ rules, using data fed from sensors in the system and limited parameters; known as feedback controllers. Smart controls add in an additional dimension to feedback control, using advances in computer-based control problem solving, combined with field sensors and actuators, to integrate multiple parameters, such as collected data and external predicted conditions, to forecast the demand profile, respond faster and optimise operations when compared with traditional discrete control techniques. This can reduce primary energy demand, improve scheduling of heat generation technology, and allow incorporation of short-term and long-term heat storage.

These can be self-learning systems, developing through continuous monitoring of consumption, adapting to consumer behaviour, occupancy rates, meteorological models and building characteristics. Automated demand forecasts can increase security of supply to consumers through improved scheduling of heat generation technology and incorporation of short-term and long-term heat storage. Demand forecasting can also ultimately reduce primary energy demand, predict or avoid breakdowns associated with unexpected load peaks, and add transparency to network operation through cloud-based interfaces.

As traditional controls, as outlined above, are reactive there is a time lag between a change of conditions in the system and the resulting control response. This makes it difficult to match the heat demand with the most effective supply source, resulting in over consumption and wasted heat. The more informed and accurate response available from smart controls can enable more effective control operation of the heat network.

The ability to forecast demand also allows more effective scheduling of intermittent renewable energy sources. Heat load prediction and management of available heat storage and network temperatures allow reductions in overall heat demand and can enable a greater supply contribution from low-grade heat sources.

Key systems and components

Heat networks with integrated smart controls consist of various sub-systems and external inputs (labels (c) and (d) respectively in Figure 29).

Data and communication

A common method of communication in smart control systems is the IoT, enabling assets and the data platform to send and receive data. Therefore, an integral component of the smart control system is a general-purpose data acquisition layer. Although the latter can operate at a local scale, a cloud-based data acquisition layer is preferable because it presents significant benefits, including allowing multiple control systems to interact, providing optimisation at scale and enabling new assets or networks to be added to the system.

As different sub-systems and assets usually have different operators, they tend to work in different technological languages, such as Modbus or BACnet. These differences can be overcome by setting a common language in the data platform or with an integration layer or gateway. The data flows between the sub-system and the data platform via a gateway ((b) in Figure 29) which translates the language used. The gateway allows the control system to be compatible with any sub-system and therefore new or updated technology to be easily integrated into the network. It also removes unnecessary vertical infrastructure, freeing up storage, reducing maintenance costs and offering a simpler model for scale-up and replication.

From the user side, heat networks using smart controls provide a different type of interface to satisfy the needs of the different users. For consumers, interfaces can allow more specific inputs in terms of preferred comfort levels, while for network operators, asset owners and policy officers the interface provides a mechanism for selecting objectives. This is further explained in the User interaction section.

Control strategy
Currently, most heat networks which feature at least a basic level of smart control, primarily use a rule-based controller. However, to have fully integrated smart controls across the entire system, model predictive control (MPC) is a more effective control mechanism. The main benefit is that MPC works over a predicted future timeframe, rather than single time steps, which allows estimation of future heat demand to be used as a system input. In the coming years, as heat networks become more smart-enabled, it is expected that most smart controllers will move to using MPC or other advanced process control (APC) strategies, such as fuzzy logic controllers (FLCs) or particle swarm optimisation (PSO), which are able to solve optimisation problems of significantly greater complexity.

MPC solves for a control objective or objective function, based on constraints and parameters, including real-time data inputs. A smart control system can be designed to optimise for multiple objective functions. Predictive models can be developed, through machine learning techniques, using historic data inputs to improve prediction in required system response.

As heat networks are complex multi-input, multi-output systems, they can be better managed with MPC. A smart control system would have traditional, rule-based control (i.e. a proportional integral derivative (PID) controller with if-then control) on individual sub-systems, which may be based on maintaining a set point, to add resilience to the overall network. This control would then be overridden by the MPC controls, while still minimising deviation from set points.

The MPC analyses historic data and makes a trend prediction, which is used to determine a control system setting. Additionally, data such as outside temperature can be monitored in relation to weather predictions and historic heat consumption to better forecast heat load and adjust the generation accordingly. This allows faster and more effective response to a change in weather, reducing energy consumption and heating costs, as well as improving consumer comfort.

Time-samples for MPC are typically 15 minutes, allowing for communication latency and computation time. This sample time is too long for robust operation of the lowest control layer, associated with PID and rule-based controlled actuators, valves and pumps. In the control hierarchy, the MPC-layer generates set-point trajectories which are fed to the autonomous actuation layer, which is designed and operated in a standard fashion. Such an arrangement is typical in process control to ensure robust operation in cases whereby the predictive layer falters. Further details on control mechanisms associated with smart controls are outlined in the report *Smart energy systems for sustainable smart cities: Current developments, trends and future directions*[47].

Benefits of smart controls

Heat networks with integrated smart controls have improved connectivity between the system architecture, yielding more efficient and effective operation implemented at a relatively modest cost. The result of integrating smart controls is normally a cost or carbon saving, depending on the control objective. The benefits of smart controls over traditional controls include:

- Prediction of heat demand, reducing the time lag of the response and in turn potential to reduce the primary energy consumption and carbon emissions. Information on renewable energy availability and live grid carbon content, enabling the controller to schedule and match primary energy generation to multiple sources, in order to maximise the demand met by low-carbon sources. Similarly, during periods of high grid carbon intensity or high tariffs, minimising the use of electricity dependent heat generation and prioritising other heat generation plants.
- Improving the prediction of peak load, combined with thermal storage management, to achieve peak shaving (i.e. reducing the amount of energy demand and fuel consumption during peak demand hours). The controller can pre-regulate the required thermal storage to reduce the peak load and avoid purchasing energy when the tariffs are highest. This reduces OPEX for the network operator.
- Minimising supply temperatures according to the requirements and parameters of the various buildings, assets and external conditions, with the additional benefits associated with low temperature and ambient networks. A lower supply temperature results in reduced distribution heat loss, thus reducing primary consumption and operating costs for the network.
- Forecasting and managing the heat demand of individual buildings on the same network, optimising any localised heat generation and/or thermal storage and adjusting networks parameters (e.g. flow temperature).
- Detailed forecasting of heat loads for future network expansions or new phases based on existing data. This allows peak shaving and downscaling of energy centre and network infrastructure.
- Flagging up malfunctions of the system before they can cause major disturbances. This allows the heat network operator to move towards a predictive maintenance strategy rather than a reactive one.
- Monitoring heat loads, via smart meters in individual buildings within a smart controls integrated network, raising awareness of consumers' personal consumption and giving more control and incentive to reduce energy use. Smart interface platforms allow users to interact with their heat demand, improving prediction algorithms (e.g. logging future holidays).
- Using data on consumer behaviour and trends in demand to predict desired temperatures or a personal 'comfort level'. This allows the smart system to optimise the heating input to the building to maintain the comfort set point with minimal heat demand,

without the need for the consumer's control. This concept disrupts the traditional commercial model of paying per consumed energy, to paying per comfort level which has been provided.

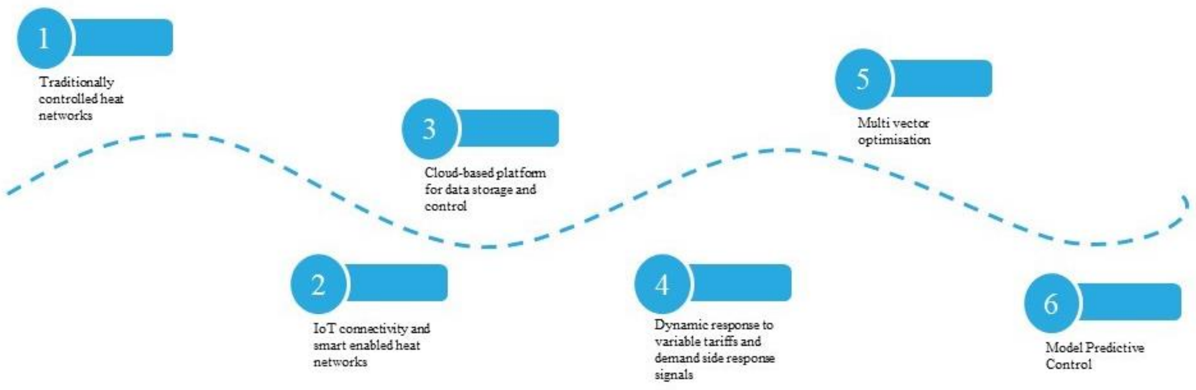
Recent developments and potential for the future

Heat networks have typically been designed with individual monitoring and control packages, stand-alone communication networks and little to no sharing of information between systems. However, with smart controls becoming increasingly integrated into networks, with varying levels of complexity and functionality, the first step in transitioning from traditional to smart controlled networks is smart enablement (as shown in Figure 29).

Smart enablement, meaning that a system is physically and technically capable of using smart controls, should be a design aim for all new networks and, where possible, integrated into existing systems. It is easy to embed smart enablement into a network at the beginning of the design process, with little effect on CAPEX and low associated risk. This ensures future-proofing because it enables the operator to adopt smart controls at their discretion and less expensively than retrofitting a traditionally controlled network.

The transition from smart enabled to smart controlled networks can be achieved through a modular approach, gradually including applications and optimisation modules as they become available on the market, and when deemed appropriate by the operator. Compared to smart enabled networks, the key changes occur at the data platform level, with software enhancements, additional applications and more advanced optimisations.

Figure 30: Timeline of development of heat network control technology



Smart enablement
There are a few best practice principles to adhere to in order to ensure a heat network is smart enabled. As outlined above, this can be done with a modular approach making the transition to smart control achievable for any heat network. This means that a developer can choose devices which are technologically as basic or complex as they need.

Working with the IoT from a cloud-based common data platform is key to ensure that a large quantity of real-time data from multiple devices can be processed and stored. Using a common data platform with an open protocol communication means that the information is collated in a single storage area. The benefits of the IoT and a cloud-based server include the added security to data, the removal of data storage capacity limitations, and improved communication between individual devices and sub-systems.

Improved communication is particularly important as heat networks can have multiple asset owners and operators for the different sub-systems, which need to intercommunicate, but may operate in different languages and are not physically connected in the network infrastructure. This can be managed through a common internet protocol (IP) between all the sub-systems, provided by a single owner network and/or through integration at the cloud level. This enables interoperability of devices from multiple vendors, which also increases the longevity of the systems as users can change their assets freely as technology updates, and avoids the system being locked-in to a single vendor, as users have the flexibility to switch providers.

The system should adopt a consistent naming schema across the physical devices and control points to enable easier querying, analysis, management, discoverability, tracking of building devices and application deployment. The system architecture should allow for high-level programming and automation of system wide functionalities, to enable ‘smart’ functionalities and desired user journeys. There should be horizontal IP connectivity of all IoT gateway devices that produce or consume data to allow for direct access. It should be possible to see the state of all of these devices on the IP network, through the network connection of IoT.

Additionally, it should be possible to manage and update devices and firmware over the IP network, which will simplify systems maintenance and apply security fixes. All devices connected to the network should have suitable security, with appropriate testing, to prevent the devices being compromised or non-compliant devices being connected to the network.

User interaction

Smart controls can enable consumers to have more sophisticated and intelligent control over their heating system.

The user interface can allow occupant comfort control and preferences to be fed to the control centre, enabling the controller to better manage heat generation and distribution against individual building demand.

The interface provides information to the user including energy tariff periods and times of peak demand, allowing them to adjust their usage accordingly and have more control over their energy bills.

Commercial considerations

Ownership and sharing of data is an important consideration due to the multiple owners and stakeholders involved in heat networks. As data privacy legislation evolves, data collection and anonymisation will be a key challenge for those systems.

Traditional heat networks are procured within the scope of the construction contract. For smart systems, the higher-level application programming interfaces (APIs), applications, databases and authentication are removed from the construction contract and provided by separate contracts with a client-side business owner. There is less requirement for direct interoperability between sub-systems as this is facilitated by the gateways, with simpler coordination between sub-contractors for commissioning.

For a network with integrated smart controls, the developer has the flexibility to easily adapt the system to their business model. For example, if the network is smart-enabled from the design stage, it has the adaptability and flexibility to incorporate future technological advances, such as new, more efficient controls, plant or software. This can help reduce operating costs and emissions.

Smart controls also make it easier for system operators to develop costing models such as ‘comfort-as-a-service’ for consumers, rather than the traditional heat rate per kWh, as the controller can evaluate the customer’s usual ‘comfort level’ based on their consumption data and set this as an objective function. The smart control then takes full control of the heating settings for the building, rather than the traditional consumer-controlled thermostat. For this reason, the customer would not pay per energy consumed but per comfort delivered by the system.

This also makes it easier to incorporate costs for both heating and cooling, such as in 4G and 5G networks, where buildings will be expected to consume as well as produce heat. With the traditional commercial model, consumers would effectively both buy and sell heat to the network, which makes pricing more complex. However, with comfort-as-a-service, consumers could pay for a given level of comfort and the smart control would manage the required bi-directional transfer of heat.

Applications

Asokodit, Finland [48]

Asokodit is one of the largest Finland-based housing owners. It adopted smart heat network technology in 2016, starting with a pilot for eight housing estates. By 2017 around 1,040 flats had the technology installed.

On average, the use of real-time measurements and AI to control the system has reduced the peak demand by 21%. The system has also led to reductions in overall energy consumption, with associated cost savings.

Ronneby, Sweden [49]

Ronneby in Sweden installed a Smart Heat Building software in 2016, including a self-learning algorithm which calibrates with the heat controllers in each of the buildings. The combination of new control systems in buildings, hydraulic heat balancing and the smart software was estimated to have reduced the energy use by 50%.

FORS, Roskilde, Denmark[50]

FORS district heating in Roskilde Denmark has recently installed smart prediction and control systems in their network. Effectively algorithms use weather predictions and metered data to accurately forecast heat loads. The software allows the district heating scheme to operate more efficiently and reliably by optimising the heat production plan, such that customer demand is met while network restrictions are taken into account and heat production costs are minimised.

Companies implementing smart controls for heat networks already exist, such as Leanheat and Noda. However, through integrating an open protocol, the market is open to various companies working with the IoT, as they could easily develop and integrate their software into the platform. This means that the market can be competitive with non-specialist companies (i.e. well-established software/technology companies).

Definition of key terms

Table 10: Definition of key terms for smart controls

Acronym	Definition
API	*Application programming interface* A set of subroutine definitions, communication protocols and tools for building software
Data lake	A centralised repository to store structured and unstructured data, at any scale.
Cloud-based	Stored, managed or created on a network of remote servers on the internet
IoT	*Internet of Things* The extension of internet connectivity into physical devices and everyday objects
IP	*Internet protocol* A set of rules governing the format of data sent over the internet or other network
Gateway	A software device through which all data travels to be converted to a standardised format or language

Acronym	Definition
GIS	*Geographic information system* A system to capture and present spatial or geographic data
MPC	*Model predictive control* A method of control based on feedforward, predictive response to satisfy a set of constraints while optimising for a single, or multiple variables

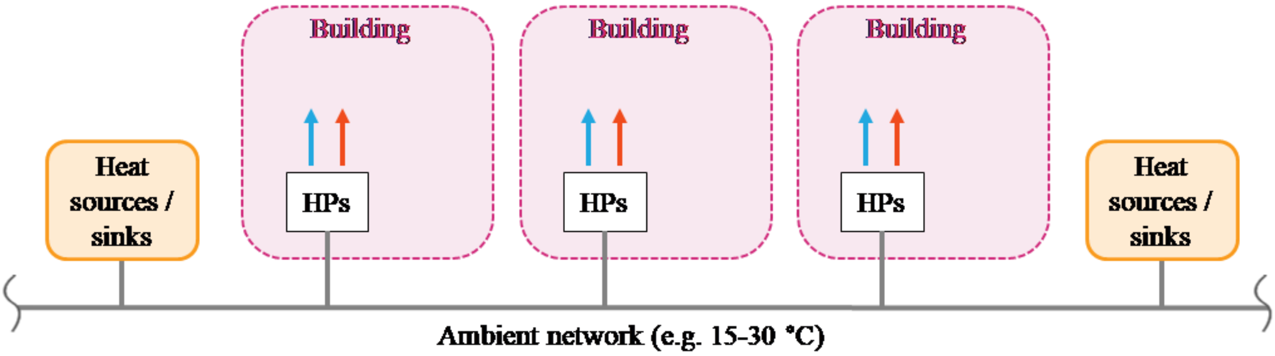
Ambient networks

This section considers the future direction of the DE industry, in particular with regard to 5G heat networks, also known as 'ambient networks'; a new, evolving concept, already being trialled in some areas of the UK, such as by Plymouth City Council[51].

An ambient network consists of a primary distribution system with ambient temperature fluid (e.g. typically operating between 15 – 30°C) connected to each building or dwelling. The temperature of the network is maintained through heat sources and sinks, located in a centralised energy centre and/or distributed plant rooms. In some cases, a heat sink (an environment capable of absorbing heat) is required to maintain the network at the required temperature and provide cooling to the buildings. The primary network configuration and principles of operation are described in the Primary side network design section. Some studies have further explored the concept of ambient networks, or 5G district heating and cooling systems, and should be referred to for more details.[52]

Water-to-water reversible HPs, located in each building (either in basement plant rooms or individual dwellings), can extract or reject heat from/into the ambient network depending on the building's energy requirements. A backup heating plant might also be included in the plant rooms of each building for increased resilience, in case the HPs are unavailable or cannot meet the peak demand.

Figure 31: Ambient network principle



Benefits of ambient networks
Ambient networks are highly aligned with the London Plan's energy goals, because of the benefits associated with their low operating temperature. These benefits include reduction in primary heat losses and hence, heat requirements, as well as the potential to integrate low-grade heat sources and sinks for balancing the network temperature (e.g. heat from the London Underground). For more on these points, see the Reduced operating temperature section.

Ambient networks also enable thermal energy sharing between and within different buildings. When there is coincidental demand for cooling and heating, heat rejected from one building which requires cooling can be used as a heat supply for another building which requires heating, giving potential reductions in overall energy requirements (despite increased pump power requirements).

One of the additional benefits of ambient networks is the ability to tailor the supply temperature to each building depending on its requirements. In contrast, the supply temperature for conventional networks is determined by the building with the highest temperature requirement. Separate HPs in each building can be used to supply the temperature for space heating and for DHW as required, with potential improvement in COPs compared to a centralised HP which would have to operate to supply the highest temperature required by any building.

For these reasons, ambient networks can result in significant carbon savings compared with traditional heat networks.

Ambient networks are highly suitable for developments with a mix of new and existing buildings. Due to their ability to share thermal energy, they are particularly applicable for groups of buildings with a simultaneous demand for heating and cooling (e.g. office buildings requiring cooling and residential buildings requiring DHW). However, new developments in the vicinity of an existing higher temperature network should consider connecting to this, as opposed to installing a new ambient network.

The most suitable low-carbon resources for ambient networks are those that can act as both sources and sinks for heat, including:

- Environmental sources (e.g. air, ground, water); and
- Waste heat sources (e.g. sewers).

In some instances, additional heat-only sources can be integrated into ambient networks:

- Ventilation extracts from underground railways
- Heat rejection from cooling systems (e.g. chillers in buildings and cooling plant for data centres)
- Waste water treatment plants
- Industrial processes
- Power stations (including energy from waste plants)
- Electrical substations

Further information can be found in Appendix 2: Heat Sinks. Depending on the source/sink temperatures in relation to the network temperatures, heat can either be recovered or rejected into the network directly, or mechanically through an HP or chiller.

Primary side network design

Primary distribution in ambient networks has multiple possible configurations; typically these are conventional flow and return or bi-directional flow arrangements, although alternative configurations are evolving.

The temperature difference available in ambient networks is 10-20°C, which is less than that possible in traditional networks, which is in the range of 30-40°C. This means that flow rates in an ambient network are higher and the network pipes need to be of greater diameter. However, this will not necessarily lead to higher CAPEX, since the lower operating temperature means that the pipes could be uninsulated.

The minimum temperature of the network needs to be controlled to avoid freezing of the fluid. Biodegradable glycol (frost protection) could be added to the fluid, which would prevent freezing and enable sub-0°C temperatures. However, there are environmental and health and safety considerations with the use of glycol, therefore, it would be preferable to avoid its use by utilising alternative methods of control.

The pipe sizing is also impacted by the energy supplied through the network: the energy that is transferred through the ambient network is less than in a traditional network as some of the energy is provided by electricity used by the building's HP.

Secondary side network design

Heat can be extracted or rejected from or into the primary ambient network through the use of secondary side HPs and/or chillers, either located in plant rooms or in individual dwellings. The location of the heat generating technology affects the temperature of the secondary system, as well as the maintenance and access requirements, therefore, it should be considered carefully during the design process. Generally, as the supply temperature is reduced, space heating in ambient networks will require slightly larger emitters, such as UFH, to ensure that the same temperature is met as a traditional network with a smaller (but higher temperature) radiator.

Depending on the HPs' supply temperature, additional systems for DHW temperature top-up might be required to minimise Legionella risks, see the Legionella section for further information. This requires that DHW is supplied (or regularly pasteurised) at a minimum temperature of 60°C; therefore, systems designed to increase the DHW temperature might be necessary, if DHW and space heating are delivered through a single service below this minimum temperature.

When the temperature top-up is located in basement plant rooms, because it is centralised and larger-scale the benefits include ease of maintenance and accessibility, reduced space requirements in each dwelling, and potential economies of scales in terms of CAPEX and replacement expenditure (REPEX). Whilst, when located in individual dwellings, the benefits are much lower secondary heat losses with an attendant reduction in the risks of overheating in corridors and risers.

Varying levels of hydraulic separation may be necessary depending on building heights and pressure requirements. To reduce the temperature losses across heat exchangers, the number of hydraulic separations should be minimised when possible. With reduced hydraulic separation, isolation valves are key to protect against contamination and manage the system if there are leaks within buildings.

Key components for ambient networks

The components for ambient networks vary depending on the approach to temperature adjustment; whether it is in building plant rooms or individual dwellings. Table 11 presents a colour coded and annotated guide to the variously located components, with general components in green, components relating to HPs in plant rooms in orange, and those relating to HPs in individual dwellings in blue.

The table does not include costs for energy centre(s), utility connections and any on-costs (e.g. design, preliminaries, testing and commissioning). Installation and labour costs are included, except for items installed in each dwelling (HIUs / CIUs, heat / coolth meters and domestic heat pumps).

Table 11: Key components for ambient networks, with associated CAPEX rules of thumb

Component	CAPEX rules of thumb	Notes
Plant for heat extraction or heat generation – examples: • ASHP • WSHP/GSHP/HPs using waste heat • Heat recovery from underground railways/processes	Based on plant over 300kW: • ASHP £350-750/kW • WSHP/GSHP/HPs using waste heat £500-2,000/kW • Varies for heat recovery systems	WSHP and GSHP can vary significantly depending on configuration, type of system (i.e. closed or open loop) and additional components required (e.g. water filtration). Heat recovery systems vary significantly depending on the design and source.
Primary ambient network pipes (including trenching, installation and fitting, for flow and return)	£1,000-1,500/kW (based on urban/suburban plastic pipework for 16-315 OD)	This can vary significantly depending on the pipework route and size.
Secondary network pipes	Varies	Depends on the system design and the buildings
Ancillary equipment (e.g. pumps, thermal storage, heat exchangers) and controls	Varies	Varies depending on the system design and the buildings
Water-to-water HPs/chillers in building plant rooms	£350-450/kW for HPs £85-130/kW for chillers (based on plant over 300kW)	Additional CAPEX required for ancillary plant. If units are simultaneous/ reversible, i.e. capable of

Component	CAPEX rules of thumb	Notes
		providing heating and cooling, prices are higher.
Domestic HIU and heat meter	£1,700-2,300 per dwelling	Excludes installation costs. Dwellings with both heating and cooling would require interface units and meters for both heat and coolth, with increased overall cost.
Dwelling water-to-water heat HPs and DHW cylinder	£3,000-6,000 per unit	Excludes installation costs. This varies depending on the HP size (typically 3-6kW), design and inclusions such as: • DHW cylinder • Module to deliver active/passive cooling • Heat/coolth meters • Internal circulating pumps • Controls and supply temperature(s)

Case studies

London South Bank University, UK[16,53]

A 5G heat network is currently being trialled at London South Bank University, supplying heat to two existing buildings. The aim of the installation is to provide a low temperature, cost-effective, flexible and scalable alternative to traditional networks.

The scheme abstracts water from a 110m borehole, distributes the ambient groundwater around the network and rejects the water into another 110m borehole. The water is extracted from the London Chalk Aquifer at ~14°C and returns the water at ~10°C. The aquifer has sufficient underwater flow to maintain the extraction temperature relatively constant throughout the year and thus far, there has been no temperature reduction observed.

Ambient groundwater is distributed to the two existing buildings and two 300kW HPs (located in each building) are used to extract heat from the network and deliver water up to 80°C. The overall seasonal COP on the system is approximately 3.

Although the design initially included a new building with cooling, the construction of this building was cancelled until further notice. This meant that the full benefits of the system have not been realised yet.

ETH Campus HÖNGGERBERG - Switzerland[54]

ETH campus has installed a smart ambient network of heat sources and sinks in combination with a dynamic geothermal storage system. Installed heat capacity reached 5.5MW in 2015, with 83% of heating and 65% of cooling demand met by the network.

The ring-shaped ambient loop, comprised of warm and cold pipe circuits, connects the individual clusters with each other and also the geothermal storage system. The temperature level of the network varies between 8°C and 24°C, with the cold circuit typically operating at a 4°C differential from the warm circuit. A third pipe serves the geothermal storage system and is used to control excess waste heat when required.

Heating and cooling demand in the clusters is covered by means of HPs and heat exchangers respectively. The ring structure allows a continuous expansion of the network, since the heating demand has a decentralised supply in the clusters. Additional clusters and geothermal storage systems can be integrated at any point.

Exergy

Why exergy?

This chapter introduces the concept of exergy, because the use of exergy analysis can potentially play a role in improving the sustainability and resource efficiency of energy generation systems. For this reason, exergy is particularly relevant to heat networks, where the energy generation technology can be flexible and the use of secondary heat sources is increasing. The aims of the chapter are to outline the principles of exergy in a more accessible way and also to highlight its potential future role as a policy tool, to implement resource efficiency as a requirement in energy system selection, alongside the current metrics of energy efficiency and CO_2 savings.

Exergy analysis is normally used in the field of industrial ecology, in which, the study of material and energy flows through industrial systems enables resources to be used more efficiently. As such, it is a key property in assessing sustainable development.

To achieve agreed targets for reducing global CO_2 emissions, cities must become more resource-efficient. Chapter 10 of the Mayor's LES[1] presents the policies and proposals that he will implement to catalyse this transition. His ambition is to change economic development from a linear to a more circular approach.

In the low-carbon circular economy, and as natural resources become increasingly scarce, cities that maximise resource efficiency will enjoy a growing competitive advantage. For example, by using local energy sources, such as waste heat, cities can reduce demand for fossil fuels and increase their energy security and resilience. However, in implementing such approaches, currently only two strategies are considered: energy efficiency and material efficiency. The concept of exergy analysis suggests there is benefit in consolidating the two into a single metric.

This more effective approach to minimise energy resource-use, involves employing a resource efficiency metric based on the thermodynamic concept of exergy. It is a useful way to identify the extent to which it is possible to design more resource-efficient energy systems. It also allows for a comparison of systems that, at face value, are highly energy efficient but in terms of energy resource-use are very inefficient. Such systems do not align with the Mayor's advocacy of a circular economy.

Currently, interest in exergy is primarily confined to academia. Therefore, further advocacy is needed for exergy to be accepted and used as a mainstream measure. This manual provides the first steps towards this, but more work will be required to provide simple guides, training and software tools to facilitate wider use of exergy efficiency in the resource efficiency policy narrative.

Definition

While energy is about quantity and can never be destroyed – the first law of thermodynamics: energy is never destroyed during a process (it is always conserved and transferred or converted from one form to another) – exergy is a measure of both quantity and quality and is always destroyed when a process involves an energy change - the second law of thermodynamics: exergy accounts for the irreversibility of a process and is destroyed when a process involves a change in temperature. The term 'quality' refers to temperature; energy at high temperature can be regarded as being high quality or high-exergy, whereas space heating at 21°C can be considered low quality or low-exergy. Therefore, exergy and its quality, can be understood as a measure of the value of energy.

As high-exergy energy carriers are more versatile, because of their ability to do more work, they can be postulated to hold more economic value. This can be seen in the prices of energy carriers; high-exergy energy carriers, such as electricity, tend to be more valuable than low-exergy ones, such as waste heat. This price differential has led, when possible, to the substitution of high- with low-exergy energy carriers which often requires higher system investment to allow their use. For example, in heating systems higher investment is required to allow the use of low-exergy energy sources (waste heat and environmental energy resources). Thus, high-exergy content is being substituted with capital investments.

An example of a seemingly high efficiency heating process with poor exergy efficiency is the use of natural gas for space heating. Natural gas burns at a flame temperature of 1950°C in air and is used in a system to maintain an inside air temperature of 21°C. In this case, the potential 'usefulness' of 1929°C of temperature difference (1950°C– 21°C) is lost from the system. This energy could be used for higher value applications, such as generation of electricity, mechanical drives for industrial process or chemical process, before being finally used for space heating. The potential 'usefulness' or 'work' has been lost during the temperature change and represents exergy destroyed.

An example of energy efficiency vs exergy efficiency

A simple example of the energy and exergy efficiencies of a domestic boiler application maintaining a room temperature at 20°C (294°K) against an outside air temperature of 5°C (278°K) is provided below.

The exergy content *B* of a heat flow $\dot{Q}$ at temperature T is given by:

$$\dot{B}_q = \left(1 - \frac{T_o}{T}\right)\dot{Q}$$

Where T_o = temperature of surroundings.

Referring to Figure 32, energy efficiency of the boiler, η, is given by:

$$\eta = {}^{Q_2}/_{Q_1} = {}^{80}/_{100} = 80\%$$

Also,

$$\eta = \frac{Q_2}{B_{prim}}$$

Where:

the initial exergy (J) = B_{prim}

and the exergy (work) available from the boiler supply (J), B_{min} is:

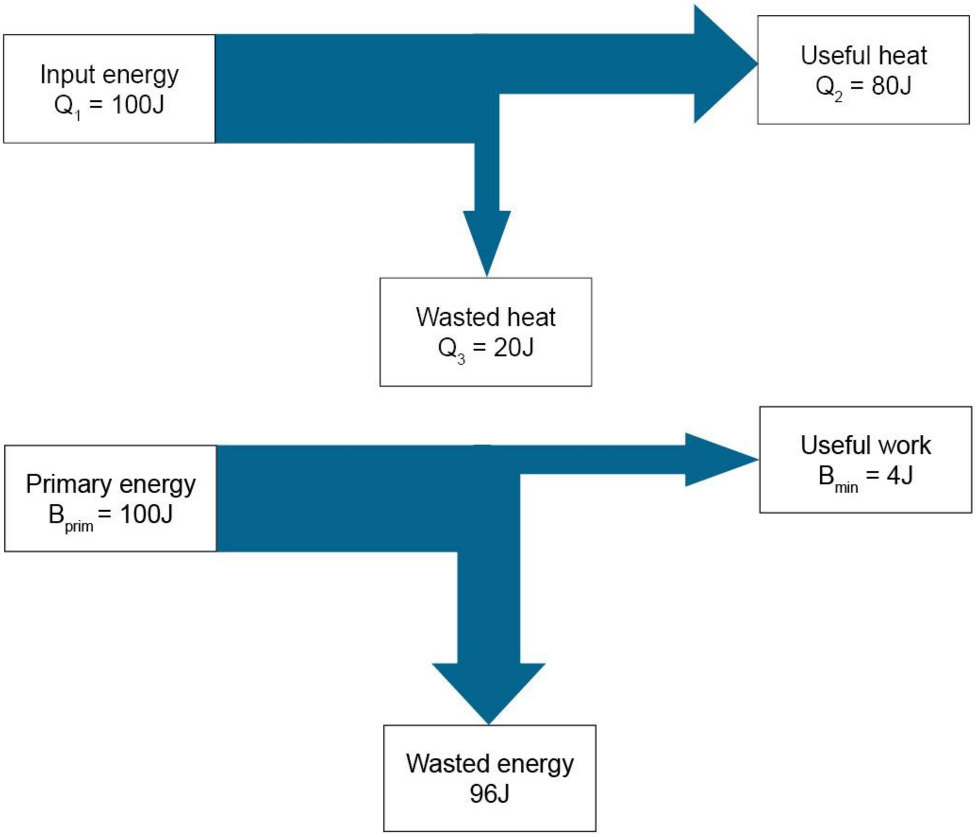
$$B_{min} = Q_2 \left(1 - \frac{T_o}{T}\right)$$

The exergy efficiency, ϵ, is given by:

$$\epsilon = \frac{B_{min}}{B_{prim}} = \frac{Q_2 \left(1 - \frac{T_o}{T}\right)}{B_{prim}}$$

$$= \eta \left(1 - \frac{T_o}{T}\right) = 0.8\left(1 - \frac{278}{293}\right) = 0.041, or\ 4.1\%$$

Figure 32: Domestic Heat-Only Boiler Sankey Diagrams for Energy and Exergy[55]



The energy efficiency of the domestic boiler example is 80% compared with an exergy efficiency of 4%. The implies that boilers are extremely wasteful in terms of effectively utilising energy resource for space heating.

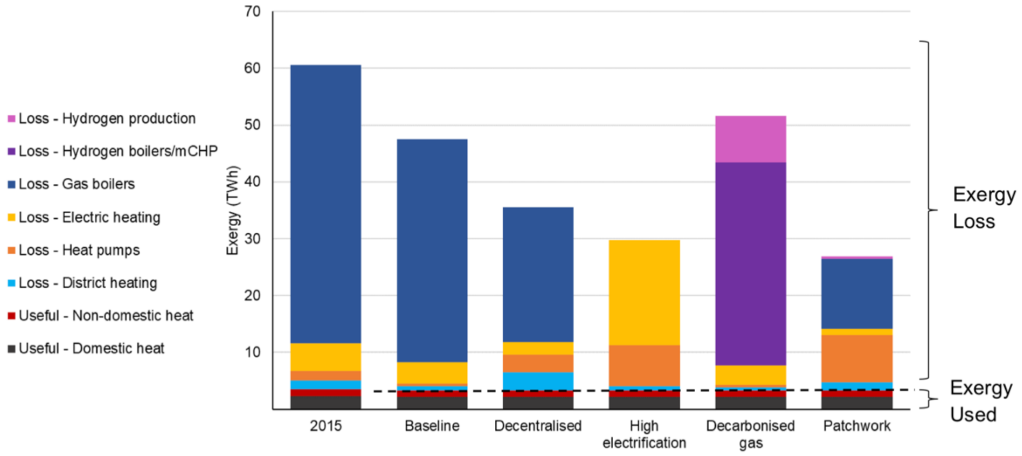
Exergy efficiencies of London's decarbonisation strategies

In the 2018 report, Zero Carbon Energy Systems report[56], Element Energy analysed possible decarbonisation pathways for London, which formed part of the evidence-base for the LES[1]. The study investigated a number of scenarios in which various technology options were deployed to decarbonise heating and transport. Five scenarios were considered as representing different pathways to meeting London's decarbonisation goals. These scenarios relied on a mix of technologies requiring different supporting policy, but were intended to represent a similar overall level of policy ambition.

Figure 33 shows the report's exergy analysis of the scenarios in 2050 relative to 2015. The useful (available) exergy delivered for heat is the same across all scenarios in 2050. It is represented as the bottom two segments of each stacked bar, below the dotted line, for domestic and non-domestic heat. All segments above the dotted line show the exergy loss (destruction) and refer to the exergy loss associated with the different heating technologies.

The total exergy destruction is least in the Patchwork scenario due to high use of low quality (temperature) heat (waste heat and heat from the environment) in building-scale HPs and through heat networks. The Decarbonised gas scenario results in the highest exergy destruction, mainly due to the combustion of hydrogen in boilers and lower utilisation of heat from the environment. This can be interpreted as a less sustainable solution as it consumes more natural resources.

Figure 33: Exergy delivered and destroyed for heating technologies in each scenario in 2050[56]



The exergy effectiveness is lowest in the Decarbonised gas scenario. Although this pathway could deliver on carbon targets, its linear economy principles would frustrate the transition of heat to a more circular economy.

The most efficient use of energy resource occurs in the Patchwork scenario, due to the high use of low-exergy environmental and waste heat sources. This scenario best aligns with the Mayor’s strategy to transition London to a low-carbon circular economy.

Overall exergy analysis has potential to be a useful metric in planning and designing heat networks to optimise the resource efficiency of heat sources.

Delivery models and commercial structures

This section identifies the delivery vehicles and commercial structures needed to support the growth of DE systems in London at scale. In dense urban areas the development of heat networks is central to delivering the potential for DE, in linking low and zero carbon sources of heat with the locations where the heat is consumed.

London has a large number of heat networks, but with limited exceptions they are small and mostly confined to single housing developments. New business models are needed to deliver the potential for networks in London. The delivery vehicles, often known as special purpose vehicles (SPVs), and the contract structures needed to create effective commercial relationships are an important element of that. Some insight into appropriate governance structures, particularly where local authorities are participating in schemes, is also needed at an early stage in a project's development.

Delivery models for heat networks

In their simplest form heat network developments do not require an SPV, for example a network installed in a social housing development owned by a local authority. The construction of the network may be integral with the housing development, the heat source located on the same premises and in the same ownership, and the occupiers of the housing all committed to taking their heat from the system. Under these circumstances, barely any commercial structure separates from the management systems already within the housing department of each local authority is required.

For larger heat network schemes serving premises that are not all constructed, managed and owned by the same party, the scheme must be 'commercialised'. That is to say, business relationships must be formed and made legally binding to introduce investors and finance for the project, enable the installation work to be instructed, and the risks associated with the establishment of the project, and its subsequent management and operation, to be arranged between the parties. This process will usually follow the point at which the technical and economic feasibility of the project has been established and a business plan drawn up to show how the project can be developed, financed and operated.

Other than for the simplest of projects, a contract structure is needed to secure the construction, operation and financing of heat networks. A private sector energy company could design and deliver the heat network and operate it under a concession to the local authority. In other cases, commercialisation will involve an SPV to manage the construction, the initial phases, at least, of the project operation, and to regulate the interests of the parties involved.

The role of London Boroughs in development of heat networks

The role of local authorities is central to the development of heat networks at scale, because there are certain resources and capabilities available to local authorities that enable them to de-risk projects, in a way that is not possible for private sector. Through their own property holdings and their ability to 'broker' the delivery of heat loads by developers and businesses, local authorities can play an important part in collecting the required consumers for heat supply. Their planning powers and, in many instances, their role as highway authorities, facilitate network development. In addition to their access to cheaper capital available from public sector sources. Some local authorities will see the development of networks as part of their climate change mitigation agenda and as supporting their agenda for relieving fuel poverty, thus providing direct policy incentives for promoting networks in their areas.

Below is a list of the particular opportunities and formal and informal powers which enable local authorities to de-risk large-scale heat networks:

- Local authority housing and other premises can provide the basis for initial 'satellite' networks and for securing and retaining heat loads to underwrite heat transmission infrastructure. They are also well-placed to bring interested parties together to offer heat loads;
- Local authority planning powers can facilitate the development of networks through consenting to them expeditiously and with realistic conditions, and by setting planning conditions on new development which require connection to an existing or planned network;
- Gaining highways consent is more complex with larger-scale networks, as a result of substantial lengths of transmission infrastructure being situated under the highways rather than, for example, confined to private land on development sites;
- Many local authorities have an environmental or social agenda, connected with targets for carbon reduction in their area and reduction of fuel poverty;
- Local authorities have access to cheap capital (available at public sector rates) that may be important, particularly at the earlier stages of network development before the stability of heat loads and volume of income streams can attract commercial sources of finance;
- Financial and political accountability and the deployment of the required capacity and political will within local authorities means that they need to create effective internal governance structures to manage their interest in the SPV;
- Larger network systems may cross local authority boundaries, involving synchronising all these activities between different authorities;
- Local authorities may be motivated to ensure long-term network objectives are realised, where the private sector may have a shorter-term (less ambitious) interest.

Choosing a delivery model

In deciding upon the appropriate delivery model, the first step is to identify the factors which will be the major considerations in determining their design. Models may be formed from formal corporate entities, such as with an SPV, or utilise existing organisational structures. Networks may also be funded, owned and operated entirely by the private sector, the public sector or somewhere in between the two.

Allocating parties to roles depends partially on commercial interests and the potential opportunities; and also requires finding the means to distribute and reduce risks in line with the capacity of each of the parties. A series of workshops between potential stakeholders can be used to define roles and thus choose the appropriate delivery model.

Four main types of delivery models exist, which broadly follow the categories outlined in *CP1: Heat Networks Code of Practice for the UK*[34]:

- Private sector led
- Public-private shared leadership
- Local authority/housing association led
- Community company (CoCo)

The following sections give an overview of each of these models and the benefits and limitations of each.

Private Sector Led
(For example, King's Cross Central Limited Partnership, pg 86 [57])

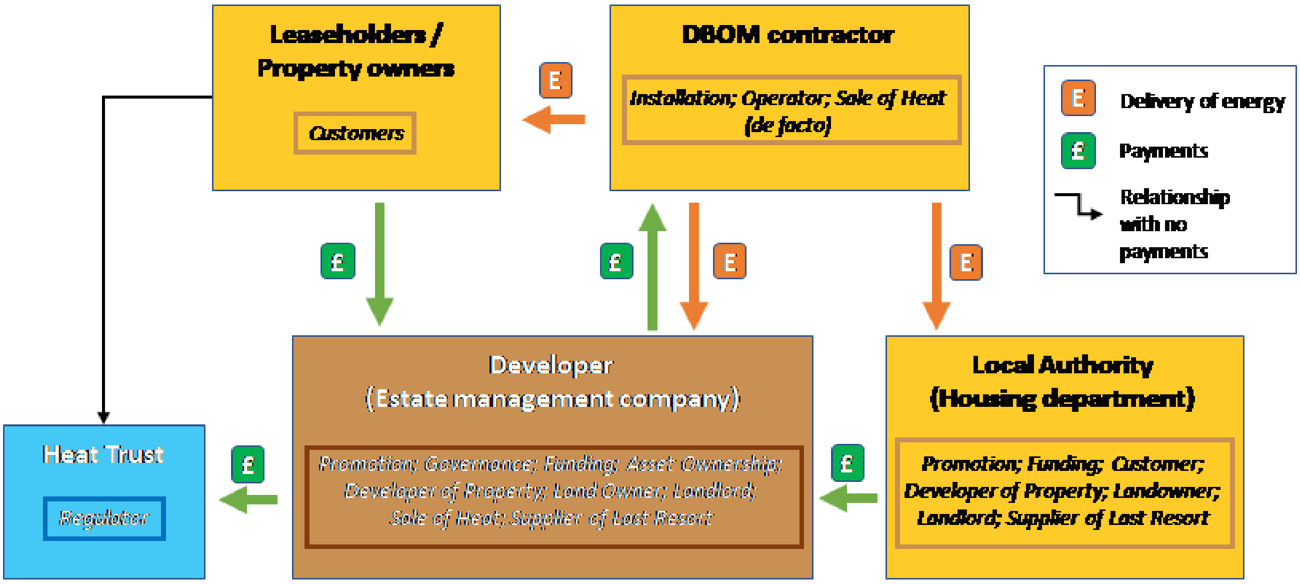
In a private sector led delivery model by definition most, if not all, of the funding and hence ownership of assets and operation lies with an ESCo or private developer. Not all roles will necessarily be carried out by the same party, and often a concession will be granted to a third party provider to design, construct, install and operate, who will maintain the network for 25 years or more.

Generally, a private sector led model occurs on private developments as a means of complying with planning policy and obligation to build a heat network. Typically, there will be one master developer, but there may also be opportunity for private property developers to part fund the network to reduce costs for their customers.

Private sector led models benefit from the developer's wider expertise in management and risk mitigation. Conversely, this also means that a higher return on investment is expected and therefore the structure may be more expensive for the developers.

This model also tends to be attractive to local authorities who are wary of risk and do not wish to take on key delivery roles themselves. In this case, the local authority will likely act as project promoter, property developer and customer. Figure 34 presents an example of a private sector led model whereby the local authority and developer both hold responsibility as the supplier of last resort if the operator fails to supply heat to the residences.

Figure 34: Example private sector led model structure



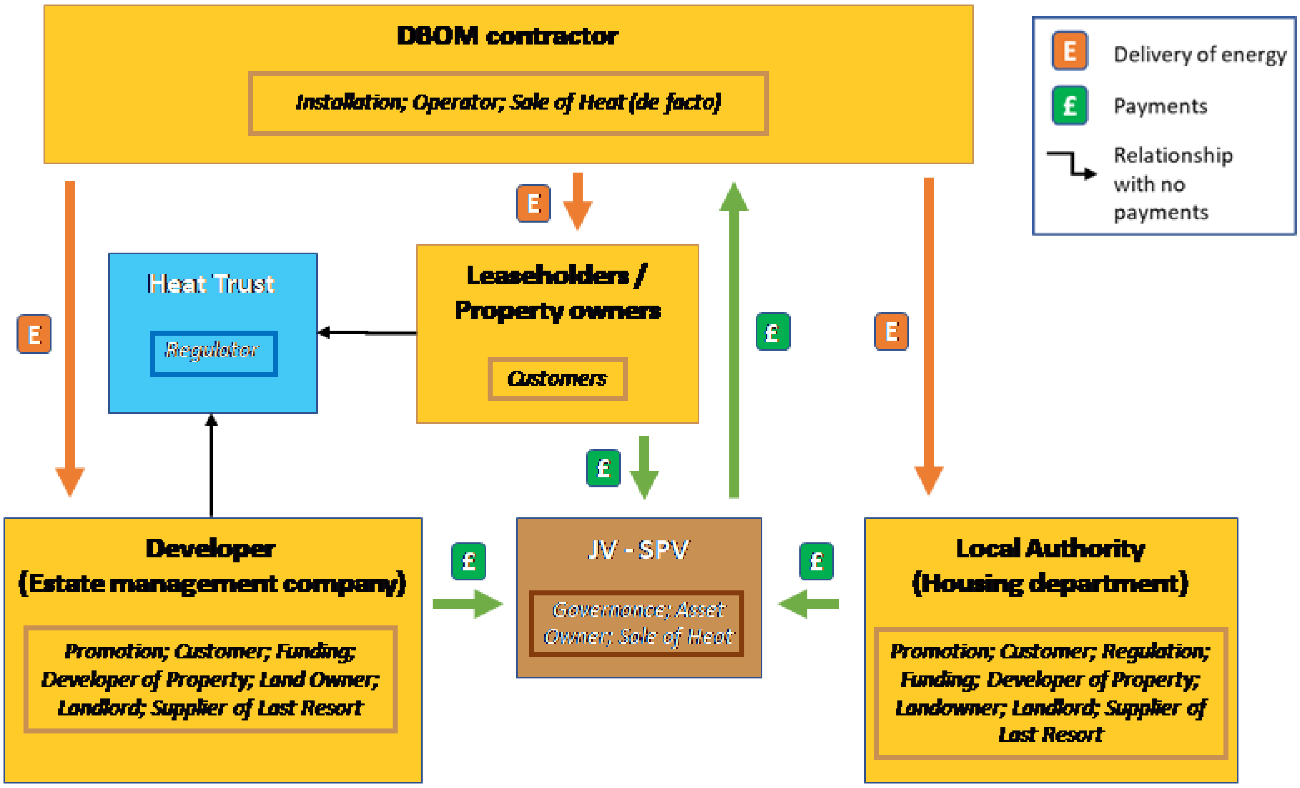
Public-private shared leadership
(For example, Birmingham District Energy Scheme[58])

The shared leadership model is defined by governance and funding being split between the public and private parties, and often also features both public and private sector consumers. As the arrangements between the parties are slightly more complex than with other models, generally public-private shared leadership models require more robust documentation and clear assignment of roles and responsibilities, which also results in higher set-up costs.

A public-private scheme particularly suits a network with a large anchor heat load or significant development land from a local authority or other public sector organisation, which tend to be reliable, long-term customers. The local authority may also benefit from this model if they supply assets to the private sector and in return collect revenue from the network.

This model benefits from the private sector expertise in management and risk mitigation and carries the advantage of low cost public sector finance or demand guarantees. However, the private sector has higher expected returns and therefore may cause additional cost for developers. Due to the added complexities of the shared responsibilities, this type of scheme can take several years to implement, with a risk of slow project decisions. It may also require that a joint venture be set up, which may add further delay to development.

Figure 35: Example of a public-private sector led model structure

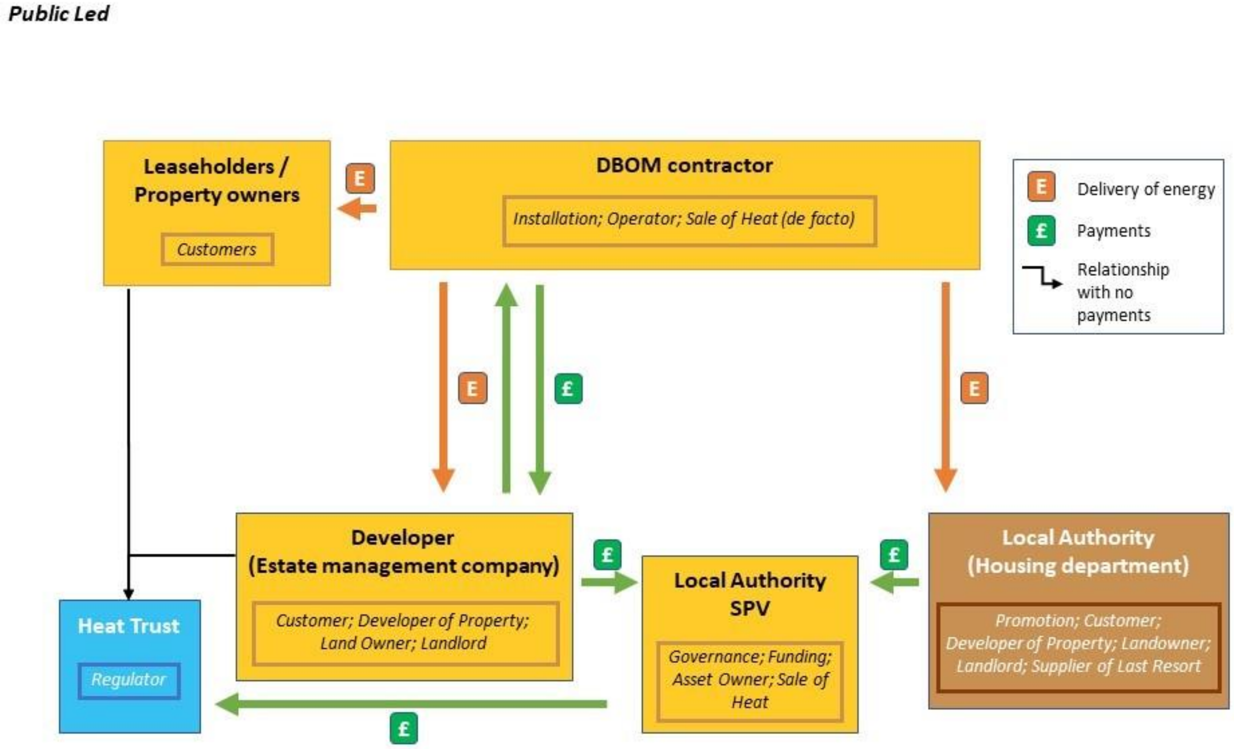


Public sector led
(For example, Islington, pg 94 [57])

The key characteristics of a public sector led scheme are that funding, asset ownership and project promotion are undertaken by the public sector. It is also not uncommon for all other roles to be the responsibility of the public sector. If so, then regulation of the scheme is frequently taken on by an independent third party, such as Heat Trust[60] as shown in Figure 36, to ensure the scheme does not abuse its monopoly.

Public sector models suit networks aiming to offer social value, such as reducing fuel poverty or carbon emissions by more than the legal requirement. The public sector has lower return thresholds and therefore schemes which are not highly economically attractive can be realised. However, the public sector tends to have less capacity and expertise in management and operation and, if all roles are taken on by the public sector, consumers have limited recourse if there are issues with the services provided. Although they do have access to the local authority through democratic processes.

Figure 36: Example of a public sector led model structure



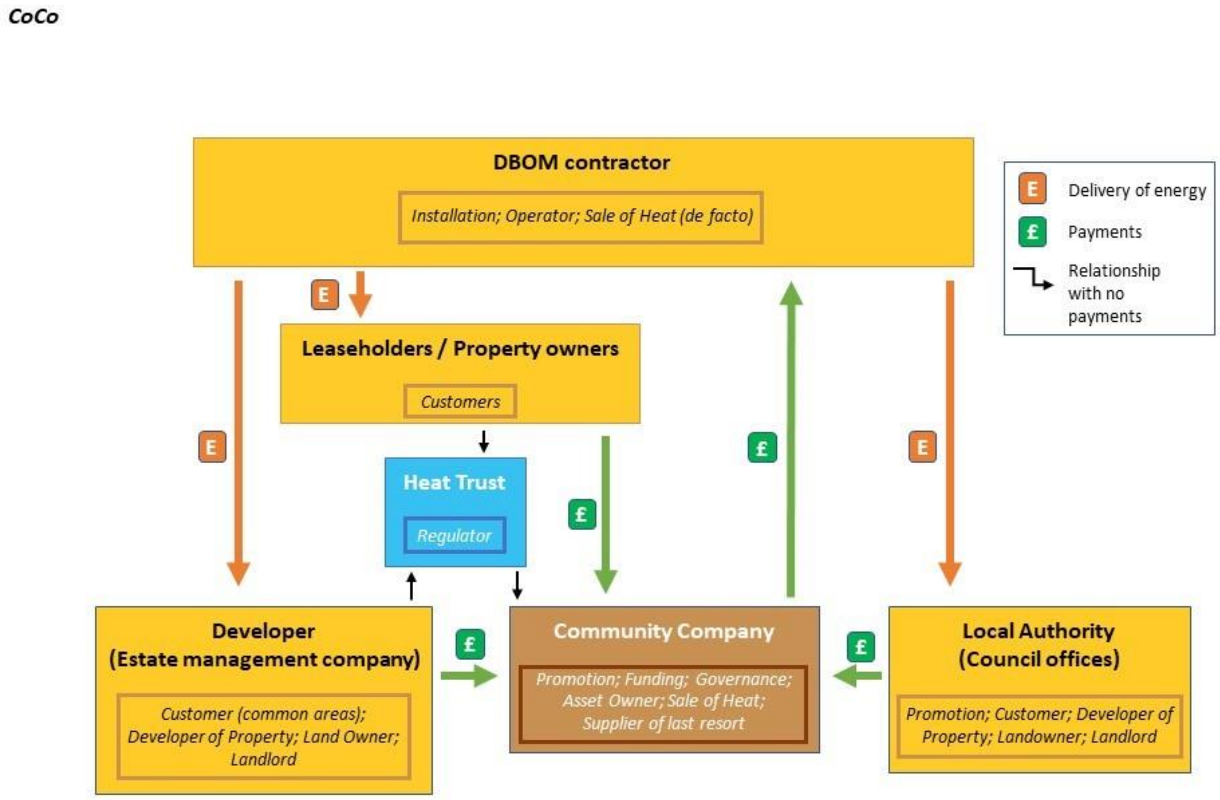
Community company (CoCo)
(For example, Springbok, Alford, Surrey, pg 96 [57])

A community led scheme will have a community body as the central governance, as well as potentially also generating and selling the heat. Depending on the scheme, this body will also take on many of the other roles, such as funding. Alternatively, it can introduce a third party or private sector company for other activities, or procure installation and operating contractors while undertaking metering and billing itself.

A CoCo scheme suits a project born from a community benefit society or a community interest company, where the aim is not profitability and the main assets of the company are in the network itself. For this reason, there is a higher risk of the scheme failing as there is less assurance of the CoCo raising the funding required. Concern would also lie in the quality of the delivery and limited protection of consumers from changes to costs.

If all goes well, the main beneficiary of a CoCo scheme will be the consumers, who gain both low-cost heat and a return on investment. CoCo models suit networks designed for residents of a new or existing housing site, who play the role of both property owners/leaseholders and main consumers. The estate management company would then purchase heat for the communal areas. Both consumers and the estate management company would have recourse to Heat Trust if issues arose that could not be resolved amicably. Community led schemes would normally be well supported by the local authority.

Figure 37: Example of a community led model structure



The choice of legal entity

The term ESCo is often used for commercial entities or companies delivering heat networks. However, the acronym is used in so many contexts as to be of limited use in this context. The entity delivering the network need not be a company formed and incorporated under the Companies Act; it could, for example, be a partnership, trust or provident society. Examples of any of these differing forms can be found although they are generally more suitable for smaller projects which are, for example, community led and owned. In practice for the larger schemes described in this section the usual vehicle is a company limited by shares or in some instances by guarantee.

The decision to set up an SPV or to establish an ESCo is therefore not in itself a solution to the management of any of the risks and issues described above and others, because the purpose and structure of that SPV or ESCo will be driven by decisions made concerning those issues.

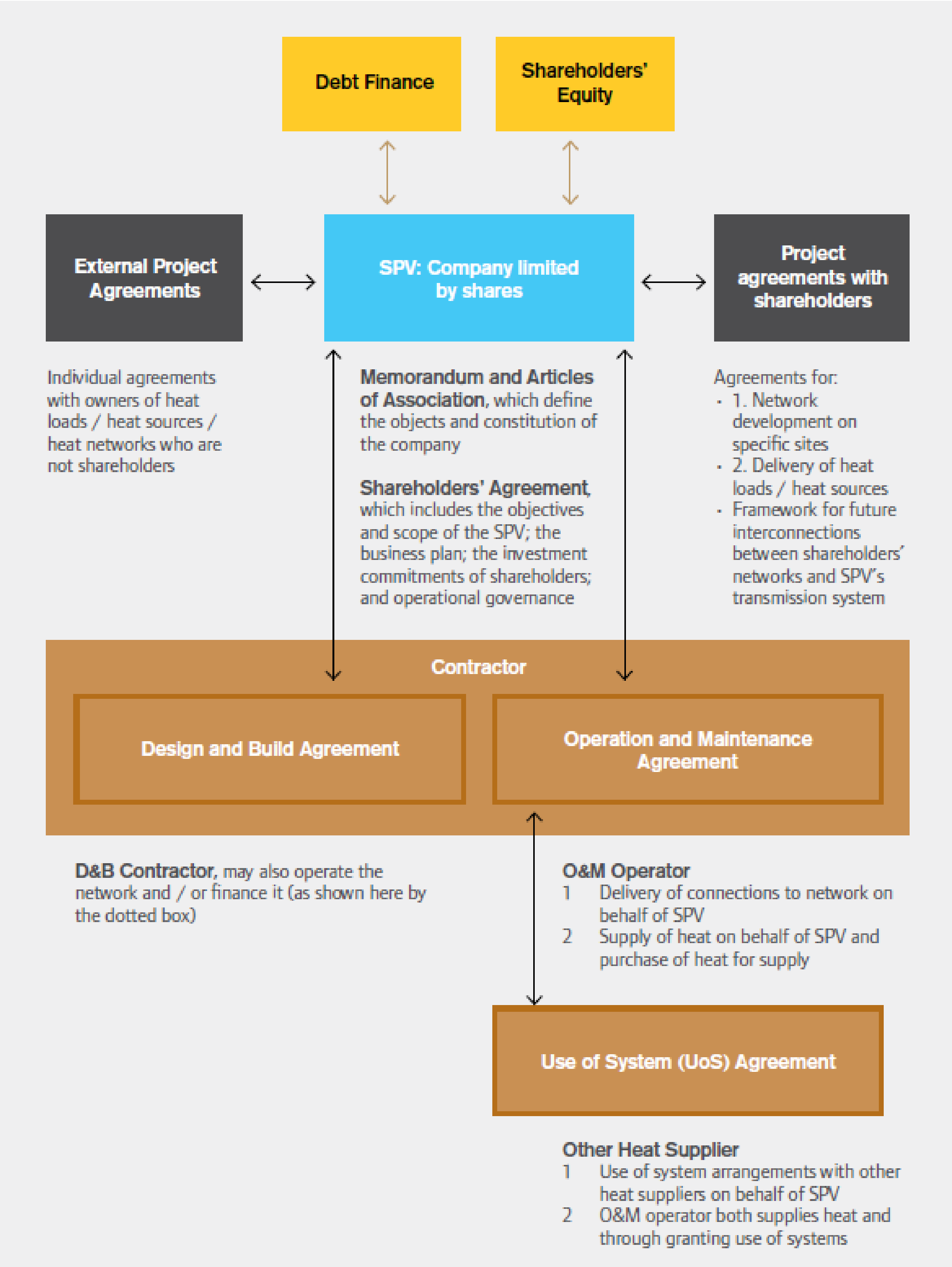
Set out in Table 12 is a summary of principal issues which will drive the structure of the SPV. Figure 38 contains a corporate structure diagram within which the commercial and policy interests involved in the development of a large-scale heat network might be managed. Individual projects will not share a uniform corporate structure, but they will share important common features.

Table 12: Delivery models (SPVs) matrix of principal objectives and risks

Objectives/requirements	Risks	Solutions/options
Securing progressive growth of area-wide network	Commercial decision making in the SPV is too short-term and does not take account of long-term strategic objective	Secure acceptance by the SPV of a long-term business plan with milestones/thresholds for future investment stages
Delivery of competitive service provision and price despite lack of consumer choice	Network operator offers terms of heat supply that compare unfavourably to options available outside the network	Secure price transparency and adherence to available consumer codes
Rights of access by heat suppliers who are not owners or operators of the network to customers connected to it	Provision of heat by multiple heat providers connected to network is discouraged through lack of access to consumers and their premises	Connection of existing and new satellite systems made conditional upon competing suppliers having access to heat consumers, subject to arrangements to support stranded assets
SPV has efficient systems of management and control	The different interests of the shareholders in the network (notably as between local authority, private property developers and investors) renders management ineffective	Shareholders' agreement must separate commercial from political/social objectives and apportion costs to the owners of those objectives
SPV has a long-term business plan adopted by shareholders sufficient to satisfy external financiers which is not abnegated by conflicting policy ambitions	Conflicting policy or political ambitions compromise agreement to or execution of business plans to the extent of making them un-bankable	Separate commercial from political and social objectives and cost separately as above
Long-term agreements are reached between local authority interests and investors to ensure that revenue shortfall caused by fuel poverty programmes is made good	Revenues are compromised by heat prices charged and revenue earned being depressed by the fuel poverty objectives of individual local authorities	Fuel poverty objectives should be separately costed as above
Long-term concession to a private sector party to whom the future development of the network is outsourced	The contracted outsourcing partner or energy company will not commit to a pre-planned chain of projects and investment, and may be	The scope of subcontracting to an ESCo or other delivery contractor is limited to what is necessary to deliver the business plan, retaining

Objectives/requirements	Risks	Solutions/options
does not compromise network growth and delivery of business plan	reluctant to invest towards the end of the concession period.	freedom to engage others to undertake future development.
Connections of satellite networks to the principal network can occur effectively, despite their being under different ownership	The operational and financial potential of connecting networks is frustrated by conflicting commercial or political ambitions	The SPV adopts a network delivery plan which the owner of a satellite network must agree to prior to the connection being made

Figure 38: SPV structure[61]



Financing mechanisms
Financing mechanisms are likely to need to accommodate the requirements of external finance and also of private sector developers of the network. Although perhaps not initially, when funding from its public sector promoters may be the mainstay of the development, networks developed strategically are likely to involve capital investment which goes beyond that which the promoters or developers of the scheme are willing or able to accept. That means the finance providers will need to see a structure for the SPV which is capable of securing the scheme's cash flows to finance their loans, in addition to management structures, which provide for efficient operational arrangements and the necessary degree of accountability and control to the providers of external debt and equity.

Commercial considerations for area-wide networks

Interconnection of heat networks
The strategy for transition from small community to large-scale networks, of the type envisioned by the LES, involves both the development of new large-scale networks and the interconnection of existing networks across the capital[1].

Joining existing networks together means connecting schemes which may have been established upon different business models; successful integration therefore requires the structuring of a new commercial relationship to enable the networks to operate at one level as a single business and the resolution of operational difficulties at the interface between the two networks. Also, the ability to cope with technical and operational difficulties between the two networks which could arise, for example, when introducing a link to existing private or social housing schemes.

The commercial arrangements reached between the network owners have to include managing the interface issues between interconnected networks, including:

- The possibility, particularly in the case of existing networks serving social housing, that the consumers connected to the network are not metered for the heat they use. This may restrict those consumers from being supplied directly by other commercially financed heat sources connected to a wider network, since such consumers cannot be invoiced for the heat they actually use. In these circumstances the existing network owner (for example, a housing association) may need to buy and be invoiced for the heat in bulk and continue to supply the tenants themselves;
- Some interconnection arrangements may include a change of heat supplier, particularly if the distribution of the heat is separated out from its supply, as the network grows with more heat sources. For that to happen, the consumer agreements for the supply of heat need to be assignable;
- The credit rating of some of the heat users in a scheme to be connected to a wider network may not be satisfactory to the prospective providers of heat in an expanded network;

- There may be differences in the temperature at which the heat is produced, delivered or returned within a scheme to be connected to a wider network which may reduce thermal efficiency or involve capital cost.

Some or all of these interface issues may arise in making connections between systems and will need to be factored into the connection terms between networks. The circumstances of the connection opportunity may differ widely. In some cases, the connection is between networks where the existing network owners remain responsible for the distribution and sale of the heat to their consumers. In other cases, the interconnection may be part of a process of merging the networks, consumers joining the same supply arrangements, perhaps not only with the network with which the connection takes place but also with other networks to which it becomes indirectly connected.

Network extensions
For local authorities and other network developers or owners there is a strong policy driver to ensure the steady growth of networks once they are up and running. The extension of networks can often reduce risk associated both with heat loads and sources of heat supply and introduce economies of scale. Yet design, build and operate (DBO) and O&M contractors only have weak incentives to extend the network, and even ESCos may be reluctant or unable to commit the financial resources required to extend a network in advance of firm orders for connection that would fully remunerate the investment.

Methods of overcoming the poor incentives to extend a network include:

- Requiring through policy and legal agreements association with consent that new developments connect to an existing network if the development is within a defined distance. The net effect of this rule is to increase the density of the heat load served by the network;
- Imposing an obligation on the operator to connect new customers on standard terms where the premises to be connected are within a defined distance of the existing scheme. The additional costs to existing consumers due to new connections should be considered and minimised where possible; and
- Providing refundable finance for the cost of a new connection.

Where the heat network is in separate ownership from the energy supplier (the prevailing model in the UK utility sector and in Danish urban heat networks), rules are required to determine the allocation of the costs of new connection.

The underlying logic of network extension in a UK context can be most clearly illustrated in relation to the rules governing gas connections. To connect a building to existing gas infrastructure, a developer would hire the services of a utility infrastructure provider (UIP), which would charge the full cost of making the connection. If the nearest gas infrastructure was some distance away, the developer would seek out an independent gas transporter (IGT), which would invest in the necessary infrastructure and be remunerated in part by the developer and in part through future charges for gas transported over the infrastructure. With gas, the balance between these two sources of funding for network extension is determined through competitive tendering among IGTs. With heat networks, that opportunity does not exist and so will need to be determined on the basis of rules. The current absence of formal regulation of city-scale heat networks means that the rules are required to be written into the relevant contracts each time.

Satellite networks
The cost of heat networks is likely to mean that heat loads some distance from an existing network cannot be connected economically. However, as there are economies of scale in network operation, there would often be a commercial case for setting up satellite networks to deliver heat to such distant consumers. While a new energy source and network would be required, O&M arrangements, particularly including metering, billing and customer services, can simply be extended to the satellite network, without requiring a new SPV or contractual arrangements.

The 'unbundling' of networks
The role of SPVs in the development of heat networks at scale is particularly focussed at the establishment, construction management and if necessary the early operation of networks. An important consideration in the structuring and strategy of SPVs is the unbundling of networks in the medium to long term, since the continued administrative burden of the SPV may not be the most efficient means to manage the network once the scheme is operationally stable. The Mayor of London's DE prospectus, *Powering ahead*,[62] refers to project structures which, as the projects expand, unbundle themselves into their underlying constituent businesses. This may include a heat generation company or companies, possibly in different ownership from the network itself. This is already true, for example, in the case of many networks served by energy from waste plants owned by local waste authorities and waste heat taken from industrial plants. The businesses and risks associated with heat transmission, or distribution, or both may be separated from that of heat generation. The result is the need for a structure of control which recognises the role of these parties as contractors, but at the same time accommodates their common reliance on the network's operation and economics.

Risk mitigation for area-wide heat networks
Set out in Table 13 is a matrix of principal objectives and risks applicable to the development of large-scale heat networks.

Table 13: Development requirements, matrix of principal objectives and risks

Objectives/requirements	Risks	Solutions/options
Heat sources • availability long term • low/zero carbon • cost of heat compatible with market	• single sources of heat disappear • no access to low/zero carbon heat	• add heat sources to deliver security of supply • new heat sources include low/zero carbon fuels/waste heat

Objectives/requirements	Risks	Solutions/options
	• alternative sources of heat may not track gas prices	• diversity of heat supply
Heat loads • critical mass of heat load secured • risk of loss of heat load within acceptable margin	• owners of heat loads may lack incentive to commit long term • over long payback period of heat networks future of heat loads unpredictable	• identify demand clusters or satellites with diverse heat loads • secure anchor loads/interconnections to expand range of heat loads
Installation of heat networks • adequate access to private land and highways • supply chain costs economic	• access denied or delayed • construction/supply chain costs over budget	• secure access in contract terms with owners of land and premises served by network/early arrangements with highways authority • pass construction cost risks to contractors best able to take it
Interconnection with other networks • technical compatibility of networks • certainty of heat loads and heat sources available from connected networks • consumers on connected network are metered • heat supply agreements are assignable • connected network's heat source is capable of required control and efficiency	• different temperatures/physical compatibility of connection interfaces • small network may be open to loss through redevelopment of site/lack of income to finance cyclical refurbishment • consumers are not metered and do not pay for heat actually used • no clear option for connecting network to supply or permit supply by others than the existing satellite network owner/operator • the connected network operates inefficiently and cannot synchronise heat production/heat	• early master planning to identify/secure compatibility of networks • retain and grow connections to satellite networks and multiple heat loads • retain consumer interface with existing network operator and supply operator bulk • secure option as a condition of interconnection with the network, retaining if need be the existing operator as the consumer interface as above • a management structure put in place for all the interconnected networks so that they are managed as a single operation

Objectives/requirements	Risks	Solutions/options
	supply with larger network requirements	
Electricity – securing best price from sales of electricity from CHP units operated to supply heat.	The small packets of power exportable by the CHP scheme do not attract competitive offers from the market	Explore potential of a private wire (a private electrical network), or Licence Lite
Government financial support for other heat and local electricity production technologies do not create a competitive disadvantage	RHI/FiTs/ROCs available for other forms of heat and electricity production without the infrastructure costs of pipe systems make the heat provision uneconomic relative to supported competitors	Influence government policy and investigate sources of zero carbon heat which attract support

Bridging the gap – delivering a bankable proposition

Securing funding sources for large-scale heat networks presents a major challenge to deployment of DE infrastructure across London and this section focusses on the underlying issues and presents some guidance on potential strategies to bridge the gap.

Financial indicators

A common method of measuring the viability and potential of a project to attract finance is through the related concepts of net present value (NPV), internal rate of return (IRR) and required rate of return (RRR).

NPV and IRR are frequently used to measure the return that can be made from alternative long-term projects, allowing for the time difference between when the investment is made and when revenues are received. The NPV calculation discounts projected cash flows to allow for the time delay in receiving them at the RRR. The IRR informs the return on investment; the rate. NPV also informs how profitable the project will be by the end of the defined time period, in terms of absolute cash, and therefore is better for comparing projects. A high return project yielding £1m may not be as interesting as a low return project yielding £10m. The RRR is usually the cost that is incurred to fund the project (the cost of capital) or the established minimum return that an organisation applies to all its potential investment projects, and so is often used as the discount rate in NPV calculations. The IRR is the discount rate which sets the NPV to zero.

NPV and IRR calculations take no account of risk, although risks can be factored into the RRR and therefore, the discount rate applied to the NPV calculation. For example, the European Commission publishes reference rates for investments which are essentially risk-adjusted RRR[63]. Additional risk adjustments may need to be made, for example, by applying a discount to future revenues or adding a premium to costs (a contingency).

A project may be considered an acceptable investment if its IRR is greater than the RRR once adjusted for risk, although one limitation is that it indicates the rate rather than the magnitude of return.

In the case of large-scale heat networks, as detailed throughout this section, projects are strongly influenced by the need to reduce risk. The key project risk may lie, for example, in the magnitude and type of heat loads that are available to provide the planned cash flow, the continued availability of heat at an economic price, and uncertainties that may arise in the construction of the network itself, including ground conditions and project delays. All of these risks, unless reduced to acceptable levels and adequately managed, may create a barrier to investment.

The challenge for heat network development
Establishing an adequate financial return and reducing risk levels to an acceptable level are challenges for heat network projects, notably in the early years of development. Ascertaining these requirements begins with the EMP process and is developed through subsequent technical and economic assessment and business plan development. As heat networks are developed to their full potential, key challenges and opportunities include:

- The heat loads increase in number and diversity;
- Long-term heat sources are established, of which there may be several, spreading heat cost risks in some cases through gaining diversity of heat source; and
- Economies of scale are achieved, through the assets being used more intensively.

These factors and others mean that as a large-scale heat network develops its business model may change, with the potential for progressive improvements in IRR and progressive reduction of risk. A private sector investor or provider of loan capital may be looking for a project that has an IRR of at least 10-12%, compared to 3-5% for a public investor rate, to ensure a return on capital or repayment of loans within an acceptable period. Since an IRR at that level is not regarded as good by most sources of external funding, the investor or lender may also be expecting a low level of risk, perhaps akin to that normally associated with utility investments such as gas or electricity distribution. Many large-scale heat networks may expect to attain that level of bankability in time through the advantages of scale, but how do they get there?

Bridging the gap
The principal challenge in funding heat network development is bridging the gap between the early stages of network development, which may have lower rates of return and higher levels of risk, and the middle and later stages when the network attains scale and diversity of heat load and with it, the features of a stable, profitable utility business. If, as in the case of other utility infrastructure businesses, the risks are low and the revenues and returns

assured by a stable demand for the heat, then networks have the potential to take on the features of investments attractive to institutions, such as pension funds looking for stability rather than higher returns. One way to bridge that gap is to plan the growth of a heat network incrementally, with each phase of development earning an acceptable return. Another is to use different methods of finance for early and late phases. At the outset, relatively small levels of funding may be available at lower rates yet tolerant of higher risk; at later stages of development larger scale funding should become available on commercial terms.

Funding sources

The sources of funding for DE projects may be both from public sector sources and private sector debt, equity funding or capital contributions. Examples of 'free' funding include grants, revenue from Renewables Obligation Certificates (ROCs), Feed-in Tariffs (FiTs), Heat Networks Investment Project (HNIP) and the Renewable Heat Incentive (RHI), or proposed funding from 'allowable solutions'. Public sector debt or equity may be available as part of a local authority's policy package for the development of a heat network in its area, perhaps fully or partially funded through borrowing from the Public Works Loan Board. As a heat network will in many cases provide an alternative to a gas connection and contribute to meeting carbon commitments, private developers will be willing to make an upfront capital contribution for each connection. It may be expected that developing large-scale heat networks will tend to be reliant substantially upon such public sector sources of funding in the earlier years. Examples of public sector sources of development funding include MEEF, LEA and DEEP.

Designing the delivery vehicle to accommodate the funding mechanisms

The contract and corporate structures for delivering large-scale heat network projects have to be designed around not only the ambitions of their promoters and developers (including and in particular local authority promoters) but also the requirements of the providers of finance to secure their investment or lending. What those requirements are will evolve as the network develops and the delivery vehicle for the project must be flexible enough to accommodate change.

Contract structure and management

This section considers the forms of contract under which heat networks are procured, constructed and operated It also shows how the selection of a particular contract structure should reflect the particular circumstances of the project and its sponsor, including the size and type of network being developed, the type of organisation responsible for its delivery and the type of consumers.

The objective of the Mayor under the Decentralised Energy for London programme is to support the development, growth and interconnection of large-scale, low-carbon networks, leading to the creation of a London-wide DE network. Sponsors will be expected to take account of that policy objective alongside their project-specific drivers for contract structure and terms. This includes ensuring that contracts facilitate and, where possible, incentivise:

- network expansion and new customer connections;
- interconnection with other networks; and
- connection of new low-carbon energy supplies.

The development of networks in London at the scale and volume envisaged in the Mayor's strategy means that the retrofitting of premises and localities for compatibility with heat networks will become mainstream, overcoming the current bias towards new property development.

Clarity about the project-specific drivers and wider policy objectives, and the associated forms of contract to be used is essential if the costs of procurement are to be contained.

Contracting options
The most appropriate type of contract for a particular heat network project depends in part on the main contractual elements – works, services and property rights:

Works elements
- Design
- Construction of energy centre and heat network
- Connection of premises

Services elements
- Energy purchase (supply and off-take)
- Generation of heat and electricity
- O&M
- Metering and billing
- Connection of new customers

- Supply of heat or heat and electricity to connected customers
- Customer services

Property agreements
- Sale or lease of operational land and buildings
- Easements, rights of way and access arrangements on private land and buildings
- Street works licence

Heat networks can be procured, constructed and operated in a variety of ways. The spectrum of possible structures runs from individual contracts for each of the elements listed above, to a bundle of services and works procured under a comprehensive agreement. However, in practice only a few contract structures are commonly used. These are summarised in Table 14 and developed further in the sections which follow.

Table 14: Commonly used types of contract for heat network schemes

Type	Description	Contracts required
Energy supply (ESCo)	An ESCo undertakes to supply heat to the customers, and for that purpose to build and operate the heat network. This could be set up with a defined set of consumer buildings to be connected, or to provide the service to developments within a defined area.	• Master agreement • Connection contract • Heat supply contract • Service level agreement (SLA) • Property leases
Wholesale supply of energy	A sponsor appoints a single DBO contractor/owner, to supply wholesale heat and electricity. The sponsor sells the energy retail to consumers and may be a consumer itself. ESCos often prefer wholesale supply to multi-occupant commercial buildings.	• Master agreement or DBO contract • Wholesale heat supply contract with SLA • Connection contract • Property leases
Network delivery and operation (DBO)	A sponsor (such as an owner of tenanted properties) appoints one or more DBO and O&M contractors for a heat network, but remains the asset owner and contracts to supply heat and electricity to consumers. The sponsor may also purchase the fuel required.	• DBO contract or a combination of design & build (D&B) contract and O&M contract with SLA • (Metering and billing contract) • (Connection contract)
Network operation (O&M)	An operator is contracted to run a heat network that has already been constructed, for example under a main building contract. The operator may also be contracted to undertake metering and billing and customers services.	• O&M contract with SLA • (Metering and billing contract)

Shaping the design of the contract structure
The following development requirements will shape the contract structures required to deliver large-scale heat networks:

- Infrastructure may be installed at the outset which includes future-proofing capacity planned for use following the initial network build-out, thus ensuring that a network is capable of future extension in line with a known strategy;
- Connection of a large-scale heat network to satellite networks, whether existing or developed, as part of the strategy and involving the interconnection issues and commercial relationships referred to in paragraphs above;
- Investment in heat transmission infrastructure to link networks, the transmission infrastructure carrying risk of heat loads not materialising when planned, or at all, or disappearing, particularly if relying substantially on retrofitted connections;
- In the case of many planned large-scale heat networks, a significant proportion (if not most) of the heat load results from retrofitting a connection to existing premises. Retrofitting connections carries different risks, because occupiers of existing buildings tend to retain a choice between buying heat from a network or using their existing source of heat supply;
- A requirement in the future, if not initially, for arrangements between the owners of the assets and operators of the network to accommodate unbundling;
- The size of capital investment involved in building-out the large-scale heat network and the demands it places on the introduction of commercial debt or equity;
- Greater need for access to installation space under highways, space occupied by other public utilities, including railway, canals and private land, on account of the reach of the transmission infrastructure between sites; and/or
- Ensuring a transition to stable and competitive long-term heat sources that will reflect expectations of declining carbon content in the heat. It will be expected that the heat transmission assets have a long life (for example, 50 years, and may be amortised over around half that period).

However, because of the different characteristics of these smaller projects, their development contracts and SPV structures will usually need to be adapted to fit within a broader framework.

Choosing the main contract structure
The following notes provide guidance on the main considerations to help a project sponsor decide which contract arrangement is most likely to be suitable. They are intended for guidance only; a detailed assessment of objectives and options should be undertaken prior to a decision being made. Each of the common contract arrangements set out in Table 14 is explored.

Master agreement or concession
The master agreement with an ESCo has to be long-term to allow enough time to recover the investment it agrees to make. The term of the agreement may relate to the economic

life of the generation assets (15 years or more), the life of the network (50 years or more) or the expected life of the premises to be served (60 years or more).

If the ESCo is expected to finance the construction of the heat network, then provision of a demand guarantee, or other means of moderating demand risk, is essential if the cost of capital is to be contained.

Where future demand is unpredictable, or the sponsor is unable to give a comprehensive demand guarantee, the master agreement may take the form of a concession. The concession may provide for exclusivity within a defined area and/or period of time. Concessions are mainly associated with new developments where the sponsor or developer is well-placed to offer exclusivity or a demand guarantee. The ESCo would then normally expect to own part or all of the assets comprising the heat network scheme, albeit the assets may revert to the sponsor upon termination of the agreement. The ESCo would take responsibility for design and construction of the assets as well, enabling a complete transfer of project risks from the sponsor.

Several variants of the concession contract can be envisaged, as alternatives to the demand guarantee or exclusivity methods of keeping the cost of capital down. The project sponsor may advance some of the initial funding required, either as advance connection charges, as a loan or loan guarantee or as an outright grant or capital contribution. Which of these options is used will depend on the perceived risks of the scheme and the relative cost of capital to the project sponsor and the ESCo.

A project sponsor who is a developer might take on part of the construction activity itself and then transfer the assets to the ESCo for an agreed fee (which may not exactly match the cost incurred). The installation of HIUs and secondary networks is commonly undertaken by the developer, but this approach has on occasion been extended to include the heat substations, the pipework that connects premises to the heat network and the energy centre building.

Where more than one developer or house builder is to connect to the heat network, the terms of connection would typically be specified in a template connection contract, which the ESCo would be obliged to adhere to. In principle, this ensures that the terms agreed between the sponsor and the ESCo are reflected by those the ESCo agrees with developers and house builders. The connection contract effectively recapitulates the key provisions of the master agreement, and in addition sets out in detail the connection process and cost. As the ESCo has a commercial advantage within the concession area or timeframe, the charge for connection should be controlled through the template contract.

Where the connection is to existing premises and no property developer or house builder is involved, the ESCo’s freedom to offer its own terms will depend upon the requirements contained in the master agreement, with the counterparty usually being a local or public authority.

Template heat supply contracts for residential and commercial customers would be drawn up as part of the master agreement. These would specify the prices that could be charged and define the quality of service, so that the consumers could in future deal directly with the ESCo and not need to involve the sponsor in disputes. The supply agreements would also define the procedures for consumer complaints and the penalties that apply in the event of failure to deliver the promised level of service. Residential and commercial consumer tariffs and services differ, so it is normal to draw up separate agreements for each group. Any supply agreement between landlord and tenant would need to comply with landlord and tenant legislation.

The SLA works at several levels to assure a sound alignment of commercial incentives between the project sponsor, ESCo, developers and consumers. At the highest level, the sponsor and the ESCo would agree the DBO of the network as a whole, including carbon performance, flow and return temperatures, reliability and downtime. At the next level, developers and the ESCo would agree how the connection is to be achieved, including lead times and compensation in the event of delay. Finally, consumers and the ESCo would contract for utility standard levels of service quality, with equivalent levels of compensation in the event of poor performance. This is the basis on which Heat Trust has been established to promote best practice for heat networks, setting standards and ensuring consumers are treated fairly[60]. Accordingly, the provisions of the SLA should align with those set by Heat Trust.

All these SLA provisions can be included in the master agreement or be distributed amongst the master agreement, connection contract and heat supply contracts. The advantages of a single SLA document are that consistency of performance standards can more easily be assured and that all interested parties then have access to an overview of the standards to which the heat network is to be operated. In any event, it is good practice to provide residential customers with a plain English summary of key performance standards and their rights to compensation if these are not met. The levels of compensation would differ significantly between commercial and residential consumers.

The SLA documentation should also provide for the actions that can be taken when things go wrong. There are two main lines of enforcement of service standards:

a) The agreement should provide for an escalating series of actions that can be taken by the sponsor, management company or other counterparty to the ESCo. At the basic level, the SLA should contain incentives to maintain a good standard of service; at the next level, there should be provision for the parties to agree on remedial action to be taken if poor performance persists. Finally, the master agreement may provide for the sponsor or a management company to have step-in rights in the event of a fundamental failure by the ESCo. Early termination may involve compensation to the ESCo for loss of profit opportunity.

b) The heat supply agreements should set out the steps that consumers could take to ensure a good service and secure compensation when it is not provided. Normally, consumers should have first recourse to the ESCo; correspondingly, the number and frequency of consumer complaints should be a key performance indicator in the SLA. The manner in which the ESCo responds to complaints should also be governed by contract terms, and include an escalation procedure. Where the ESCo's final offer does not resolve an issue, Heat Trust provides for investigation and resolution by the Energy Ombudsman. This service is free to heat network consumers that have joined Heat Trust's scheme.

Property leases

Property agreements are normally separate contracts, even when the parties are the same as in the main contract. A standard arrangement is for the buildings or spaces housing the energy centre and other equipment to be leased long-term to the ESCo at nominal rents. The ESCo may also need easements and rights of access. The lease, easements and other such rights would normally be coterminous with the master agreement.

Wholesale heat supply

Wholesale heat supply is more appropriate where the landlord wishes to retain a direct relationship with customers. It can be implemented either under a concession or through a DBO contractor, the essential difference being that the DBO contractor would not normally own the energy assets, though it may have the obligation to pay for asset repair or replacement. The operator would typically supply heat wholesale to the point of entry to each building, while the developer or landlord would be responsible for selling it retail to consumers. In this way, the project risks are distributed; risks associated with the provision of heat are with the operator, demand and credit risk with the landlord.

The D&B and O&M aspects of a wholesale heat supply contract would normally be considered together, in order to ensure optimal lifetime costs. For the same reason, the contract would normally be for at least 15 years. At the end of the contract, the assets would normally be handed over to the sponsor.

The wholesale heat supply agreement would set out the basis for setting the price at which heat is supplied by the operator. The price would reflect any financing that the operator has provided and its share of the risks of the project. The pricing formula would also need to take into account the price of fuel and, where applicable, the revenues to be secured from the sale of electricity with technologies such as gas CHP. Responsibility for the supply of fuel or the sale of electricity would be assigned to whichever party can secure best value. For a long-term agreement, there should also be provision for periodic rebasing of the pricing formula to ensure that it does not get out of line with market comparators. A common error is to index-link prices over the long term without making due allowance for productivity improvements that accumulate over time and with increasing scale.

The operator would normally be responsible for connecting consumers to the scheme, although the connection contract may be between the sponsor and the occupier or developer of the premises to be connected.

Network DBO contracts
Network DBO contracts would be appropriate where demand is dominated by a limited number of consumer types, such as council-owned buildings, social housing, or a shopping centre. The project sponsor (typically the landlord) would be responsible for pricing of heat and for the consumer interface and would normally pay for and own the assets.

In this arrangement the owner takes the majority of operating risk of the service, absorbing any losses consequential to the non-availability of the heat supply. The owner might also retain responsibility for new connections and the expansion of the network, though these functions could also be assigned to the contractor. Risk associated with appropriate DBO of the system is carried by the supplier.

One of the strengths of this approach is that it can make the best use of the sponsor’s access either to lower cost fuel supplies or lower cost capital where that is available. It also ensures the sponsor retains control over prices at which energy is sold to consumers.

The contract will likely include some provision to ensure efficient O&M. There are a wide range of options for the creation of performance guarantees to ensure this, such as an incentive to maximise electricity output from a CHP.

While service reliability can usually be assured through a DBO contract structure, the incentive to minimise the total cost of ownership only exists at the point where the contractor is selected. Thereafter, the contractor is likely to seek opportunities to increase the D&B cost through variations, and the O&M cost through early replacement of assets and a range of other techniques. In short, getting good value through a DBO contract depends critically on the quality of contract documentation, including SLA, at the time of contract award. Procurement and getting to contract is therefore likely to take considerable time and effort.

The components of the D&B and O&M contracts should be considered separately because the form of the contract would be different in each case, but may be awarded together, as performance risk will be mitigated by assigning responsibility for DBO to one contractor. Both contracts would outline the requirements the sponsor has of the supplier and outlines that relationship.

The D&B and O&M specifications for this contract type usually require a greater level of specificity than with concessions or wholesale heat supply, because most of the risk associated with the scheme is borne by the sponsor. The D&B contractor may lack the incentive to provide a design consistent with the sponsor’s drivers. While, the supplier can be expected to design the network to meet the wording of the D&B specification and also to maximise O&M fees.

Methods that can be used to mitigate this risk include requiring the design proposals of D&B bidders to be more clearly outlined; appointing the O&M contractor in time for it to be able to approve the design, or be involved in commissioning the network; and requiring extensive warrantees from the D&B contractor for the operational efficiency of the plant installed.

In relation to O&M, one way of limiting the tendency for charges to creep up is to limit the term of the contract to, say, five years, and to use the opportunity to re-bid the contract periodically to ensure contractors have appropriate incentives.

Connection and supply contracts, as discussed in the Choosing the main contract structure section, would also need to be in place between the sponsor and all energy consumers.

Operation and maintenance
An O&M contract may be appropriate where an existing network is being upgraded, or a new network is to be installed by the main building contractor. Note that in this case, the contract would be likely to leave virtually all risks with the asset owner and should be of relatively short duration, to retain the incentive to run the scheme efficiently.

An O&M contractor typically lacks the incentive to maximise revenues. This can be an issue where a heat network includes CHP. The merits of CHP are that it produces additional revenues from electricity sales and secures improved carbon performance in comparison with simple boilers. From an O&M perspective, however, running CHP involves considerable additional cost and complexity. Careful attention to incentives is essential to ensure optimal running of a CHP system under an O&M contract.

Whereas an ESCo and a DBO contractor can be penalised for poor performance, an O&M contractor would normally not be willing to accept contracts with penalty clauses. The contract value is usually too small for the risk of being penalised to be covered by prospective revenues under the contract, and the assignment of responsibility for service failure is likely to be disputed.

Common contractual issues

Metering and billing
Unless an ESCo contract is adopted, additional contract decisions will have to be made on how to manage metering and billing, including the consumer interface. A typical arrangement for local authorities or landlords is for them to retain metering and billing, revenue collection and consumer services, as they are already engaged with the heat network's consumers to collect rent or service charges. Several specialist firms exist who provide these services, other than accepting credit risk, typically under short-term

contracts; however, their charges vary widely. This is examined in more detail in the Metering and billing section.

Contract boundaries
Whatever the contract structure, it will be necessary to define the point of connection between the heat network and the consumer's own heating system.

A typical arrangement with an ESCo serving residential premises would be for the ESCo to own and be responsible for the entire network up to and including the HIU, and especially the meter within it. The ESCo has the incentive to make sure that the network equipment is working properly, and has a direct contractual relationship with consumers, and so logically should be responsible for maintenance, repair and replacement of all equipment used to provide service. The point of connection would then be at a valve on the consumer side of the HIU.

Alternatively, the developer may decide to own the secondary network in order to have control over all building services. The point of connection would then be at a valve on the building side of the substation serving it. The developer may still prefer the ESCo to be responsible for the HIU and heat meter, which require specialist maintenance.

DBO and O&M contractors do not have the same incentives as an ESCo and it might be more appropriate in these contracts for responsibility for HIU maintenance to belong with building management, especially if the building management also accepted responsibility for distribution of heat within the building. If that is done, then the DBO or O&M contractors would not need to be given rights of access to consumers' premises.

For commercial premises, the point of connection to a heat network would normally be at a valve on the building side of a basement substation. Responsibility for the distribution of heat around the building would then rest with the building management. This arrangement is usually more convenient for property managers, who are responsible for building services.

Other contract boundaries may be more straightforward to define, but in all cases the sponsor must consider interface risks, where they should reside and how best they can be mitigated. Typically, with DBO and O&M contractors, the client will retain all interface risks between them, unless expressly handed over, since the contractors would normally not have a direct contractual relationship with each other.

Aligning contract incentives
In general, an ESCo agreement can more easily achieve a sound alignment of incentives, as the operator is then responsible for all aspects of the delivery of heat to consumers. The transfer of roles, responsibilities and risks to an ESCo also enables the terms and conditions of the contract for the heat network to be focussed on outputs – the quality of service to be provided and the prices to be charged – and so avoid specifying the details

of DBO standards. The regulation of prices and quality of service would still be necessary, as the ESCo would effectively have a monopoly in relation to served premises. Pricing principles are examined in the Charges for heat and revenue management section.

If the ESCo owns the assets as well as the revenues from consumers, its commercial incentives should be appropriate. The ESCo is sometimes permitted only to lease the assets for the period of the concession, with an obligation to hand them back in good condition at the end of the term. This approach can work well, at least until the termination date approaches (given the long payback period on investment in heat networks, the ESCo’s incentive to invest in expanding the network disappears once there are fewer than about ten years left on a contract). Typically, this incentive problem is resolved by renewing the concession well before its expiry date.

Strong incentive effects can be secured by drafting and then enforcing well-defined termination clauses in the master agreement. To avoid the sponsor of the heat network having to take over the running of the system and to procure a new ESCo at relatively short notice, the termination clauses would need to contain detailed transition arrangements.

It would be feasible to set up an ESCo arrangement in which ownership of the assets was retained throughout by the landlord.

However, in such a case, the ESCo’s incentives are likely to be distorted: it could make more money if the assets were replaced more frequently, or if maintenance was skimped. In such a case, therefore, the ESCo contract would need to contain:

- A detailed asset register with expected asset lives, linked to the SLA (i.e. penalties for early replacement of critical assets);
- Detailed provisions about O&M standards and procedures;
- Strict record keeping requirements, and a periodic inspection regime.

Alternatively, the remuneration of the ESCo could include profit sharing; however, few heat networks are sufficiently profitable (or their operation profitable soon enough) for this to be a practical option.

Similar incentive issues arise with DBO and O&M contracts. The problem is more acute with DBO, as these are typically long-term (in order to incentivise good D&B). The mitigation measures in this case are as above.

While having detailed provisions on standards and procedures, and periodic inspection, O&M contracts are usually short-term (e.g. 5 years). The regular market-testing of O&M performance, with the credible threat of termination, helps to mitigate the adverse effects of these incentive issues.

Guarantees
As already noted, to be willing to take on investment in a heat network, an ESCo or wholesale heat supplier is likely to require some form of demand guarantee. A demand guarantee would typically take the form of compensation for excess costs incurred if the prospective demand for heat does not materialise within a defined period. For a small scheme, the guarantee may cover the entire development to be served. For a large scheme, it should normally be possible to limit the guarantee to the first phase of development, though given the importance of sustained network extension, it may be renewed as necessary to induce investment.

Where a heat network is to serve a new development, the developer may require a guarantee of heat availability to be induced to connect the development to the network. In effect, the network has to have backup heat generation facilities, as developers are rarely willing to make such provision themselves.

Similar guarantees would be made to consumers by the entity that enters into heat supply contracts with them. While utility-based compensation arrangements are usually put in place to cover temporary loss of heat supply, provision would usually also be necessary for a supplier of last resort (SoLR) to take on responsibility for the delivery of heat in the event that the contracted heat provider goes out of business. The SoLR may also have a role in managing the transition to new arrangements at the end of a concession period. This is a function that the local authority is often best-placed to fulfil.

Governance and Regulation
Where a local authority has successfully acted as promoter of a heat scheme, it may take a continued interest in the scheme once it is operational to ensure it continues to develop and provide good service to its consumers. Alternatively, the consumers themselves or a body acting on their behalf may take on this governance role.

Unlike electricity and gas utilities, heat networks in the UK are not subject to statutory regulation. As noted, however, Heat Trust sets consumer service standards and consumer protection requirements for heat providers based on utility standards. Promoters of networks can register their schemes with Heat Trust, essentially as a form of certification of quality. Heat Trust also offers independent adjudication: a dispute resolution service at no cost to heat consumers, once the heat supplier’s complaint procedure is exhausted.

Heat Trust does not regulate charges for heat, often the most sensitive issue for consumers. Pricing of heat is discussed in the Charges for heat and revenue management section.

Heat supply agreements
Table 15 provides an outline of standard terms to be included in an agreement where heat is supplied directly by an operator (the ESCo) to a residential consumer.

Examples of completed heat supply agreements are in the public domain. Gas and electricity supply agreements can also be referred to as a guide to the detailed provisions, such as compensation for not providing an adequate standard of service.

Table 15: Typical contents of heat supply agreements to residential customers

Supply agreement heading	Outline of contents
The served premises	Identification of the address to be supplied and contact details of the consumer.
Supply dates	Date of the agreement; date of first supply, if different; duration of the agreement.
Charges for heat	Fixed charge; variable charge; other charges that may be applied e.g. in the event of temporary disconnection.
Annual price review procedure	Description of the procedure the ESCo will follow each year to revise the charges. This will typically be a formula linked to relevant benchmarks (see Types of charges for heat section).
Reading the meter	Frequency and method of meter reading; consumer access to the meter and to consumption data; what to do if the meter reading is disputed, or the meter fails.
Billing procedure	Frequency of billing (not necessarily the same as for meter reading); content and format of the bill; methods of payment; time to pay; penalty for late payment; what to do if the amount owed is disputed. Where credit risk is a concern, it is important to provide some means of prepayment, either through a prepayment meter or a method of keeping an account in credit. The agreement would specify the conditions which would trigger a switch from payment in arrears to an in credit arrangement. In general, prepayment should not result in a higher charge.
Data protection	What the ESCo may do with the consumption data, with the consumer’s payments and with contact details.
Standards of service	The temperature of the heat to be supplied and permitted variation; permitted downtime and notification process; other performance standards; method of reporting performance; penalties for non-compliance. It is common practice for standards of service and penalties for non-compliance to be set out in a separate document which can be updated without requiring the entire supply agreements to be revised. It is also good practice to make this information available in plain English for residential consumers.
Changes to the service	Procedure for the ESCo to notify changes in the service to be provided (other than a price change). Procedure for the consumer to request a change to the service to be provided, and the method for calculating any charges that may apply.

Supply agreement heading	Outline of contents
Moving house	Procedure for the consumer to follow when leaving the premises and handing over the agreement to another person.
Access	Procedure for the ESCo wishing to gain access to the served premises (if necessary).
Liabilities	Listing of the liabilities of the ESCo and the consumer (e.g. for death or injury, for damage to property, etc) and any limits on liability.
Suspension and termination	The reasons and procedure for suspending the agreement (e.g. due to absence from the property or failure to pay bills). The reasons and procedure for terminating the agreement (e.g. ESCo's failure to perform). Protection for vulnerable consumer groups. Clarification of role of supplier of last resort, and transition arrangements to successor heat supplier.
Annex 1 The Energy System	Description of the energy system and of the connection of the premises to it (e.g. capacity)
Annex 2 Residential HIU	Whether the HIU will be located inside or outside flats and houses. Whether the ESCo, the landlord or the consumer will be responsible for the maintenance, repair and replacement of the HIU. Arrangements for inspection, repair and replacement of the heat meter if attached to the HIU.
Annex 3 Quality of service	Supply temperature of heat; Supply interruptions; Response time to reports of supply failure; Aspects of billing performance.

Metering and billing contracts

The costs of metering and billing exhibit economies of scale. With small heat networks, it is usually worth considering using specialist providers of these services that can offer to share the benefits of the scale (and experience) they have already achieved on other schemes. Gas and electricity suppliers that also operate heat networks can normally integrate their billing systems and consumer services, to the benefit of the networks that they operate.

The charges for metering and billing heat are likely to be higher than with gas and electricity supply, since the consumer base is much smaller and also because heat meters are not standardised and have a shorter life.

An ESCo would normally be responsible for selecting the metering and billing system to be used, with the contract ensuring that the relevant requirements of CIBSE/ADE's *CP1: Heat Networks Code of Practice for the UK* are complied with[34]. Even in this case, it is important to ensure that data is presented by the metering system in a format usable by more than one metering and billing services provider, in order to facilitate transfer on termination. Where a DBO or O&M contract structure is used, the importance of avoiding being tied to a particular service provider is even greater (see Metering and billing section for further information). Where meter procurement is the responsibility of the building contractor, these considerations should be incorporated into the specification of the building contract.

Metering and billing service contracts need not be as long as the ESCo concession or DBO contracts. However, a minimum contract duration of five years is recommended, both to reduce the transaction costs of procurement and to allow the metering provider to spread its initial set-up costs related to the scheme.

Credit risk and debt management

Specialist metering and billing service providers would not normally accept credit risk, but contract performance standards can be used to mitigate the risk for the client.

Debt management is achieved primarily through an escalation procedure that combines formal reminders of amounts due, telephone contact to identify specific issues, referral to Citizens Advice or other bodies to help those with financial difficulties and, finally, suspension of service. Follow-up actions can be helpful in identifying payment problems early but must be done with care to avoid incentivising aggressive or insensitive debt recovery practices, leading to negative consumer perception. Dealing with vulnerable populations in particular will require the balancing of revenue protection and consumer satisfaction objectives.

These stages of escalation will be documented within the consumer charter and, because of the potential risk to the health of the consumers, suspension is only permitted as a last resort and in accordance with specified procedures (e.g. during summer). Where a heat network is being operated under contract, such as under concession or on behalf of a local authority, the contract will set out the conditions under which suspension may be made.

Prepayment or requiring accounts to be kept in credit can be used in case of persistent payment problems. Prepayment and credit consumers should normally be charged the same prices as other consumers, as arranging prepayment does not normally entail additional costs of revenue management. Specialist metering and billing service providers usually offer online payment options, which are often a more acceptable method of prepayment.

Accurate metering and billing is essential to minimise consumer complaints and bad debts. A well-managed heat network should be able to limit bad debts to about 1% of revenues, which is the typical level for electricity and gas suppliers. If so, no specific allowance for bad debt would need to be made, since the benchmark tariffs will already include an adequate allowance for bad debt.

Consumer service

In the absence of existing recognised standards of service for heat providers, consumer protection must be built into the specific contract under which heat is supplied to consumers. The consumer protection measures have to cover all aspects of consumer service: charges for service, the quality of service provided and complaints procedures. Heat Trust and CIBSE/ADE Heat Networks Code of Practice provide substantial guidance on the scope and content of service standards appropriate for heat networks. However, the project sponsor may wish to consider additional or higher standards.

In practice, the way in which electricity, gas and water services are provided in this country offers practical reference points for determining what should be required of heat providers and the levels of compensation in the event of poor service. Most companies offering an ESCo service publish standardised consumer charters, typically based on utility standards of service, which can be referenced for a new heat network. The benefit of this approach is that it helps ensure that the standards of service for heat supply will be regularly updated in line with the generally applicable utility standards of service.

The agreed standards for consumer services can be attached to the supply agreement or can form a separate contractual commitment to the project sponsor. For more information on this see the discussion of SLAs in the Contracting options section. Other, more aspirational standards of performance, behaviour of ESCo staff and treatment of consumer, tend to take the form of a consumer charter, although the two types of document can overlap to an extent.

Charges for heat and revenue management

This section covers the revenue side of network operation, including the types and formulations of charges paid to the operator and the typical arrangements for metering and billing. As with the preceding section on contracts, this is provided as information and guidance to assist the development of well-managed, viable networks.

The principal source of revenue for heat networks is from heat charges; see the Types of charges for heat section). However, the additional revenue from the sale of electricity generated by CHPs, the potential charge for coolth, as a heat supply opportunity to the network, or other sources may be significant; see the Electricity revenues section.

Types of charges for heat
The charges typically levied by the service provider comprise:

- Connection charge: an initial charge for connecting to the heat network, which may be paid by the developer or landlord, but is not usually payable by consumers;
- Standing charge: the fixed component of the heat supply charge, normally paid by the consumer, but by the landlord of rented residential premises;
- Unit charge: the price per unit of heat supplied, normally paid by the consumer.

These charges can be set in several ways:

- Initially by the heat provider through competitive tender and then index-linked;
- Set expressly to recover DBO costs (cost-based pricing);
- Set to match the opportunity cost of using the heat network (avoided cost).

Each of these methods come with potential benefits and pitfalls. The avoided cost approach is normally best for ESCo contracts, as it best ensures that the heat network will continue to provide good value for consumers in the long term. Index-linking prices is liable to result in heat supply becoming uncompetitive in the longer term, as price indices such as retail price index (RPI) and consumer price index (CPI) do not expressly take into account productivity improvements.

Cost-based pricing, as is well known, tends to reduce the operator’s incentives to be efficient. Where the costs of provision of heat are recovered through service charges, cost-based pricing can work well if contracts awarded to service providers are competitively tendered at reasonable intervals.

Connection charges
Connection charges can contribute significantly to the commercial viability of heat networks.

The developer of new premises to be served by the heat network would normally be willing to pay a connection fee that does not exceed the cost to provide an alternative supply. Existing buildings/off-takers may be willing to pay connection fees when their current installed plant reaches end of life. This would be inclusive of the cost of a gas boiler or equivalent counterfactual, such as HPs, which for flats would be the cost of a centralised heating system, and also the cost of achieving an equivalent level of carbon reduction. As the network would contribute to reducing CO_2 emissions, the connection fee should take account of the cost of the most economical alternative method of achieving the same reduction. Taken together these constitute the avoided cost. The higher the carbon reduction standard to be achieved, the higher the avoided cost.

Once a local heat network is operational, the cost of connection to a larger network can be compared, in NPV terms, with the potential savings in heat costs. The operators of the two networks can be expected to share both costs and benefits, without need for an additional connection charge. Connected consumers should also benefit if significant savings are to be made.

The calculation of the avoided cost of generation plant replacement would depend on the location of the scheme and the type of property to be connected. Where local generation plant is underutilised, it may be able to contribute heat to the larger network via the connection. That is, a replacement plant would be dimensioned in relation to the heat export opportunity presented by connection to the larger network. Additionally, benefits to the developer and development are not limited to cost savings, but also floorspace savings and any resources required for the establishment or maintenance of a system.

Alternatively, it may be sensible to close it down completely. In that case, the property value that could be realised may be a significant factor.

Connection of local networks to city-wide networks
Once a local heat network is operational, there are several reasons for connecting it to a larger network:

- To reduce further the cost of provision of heat by, for example, spreading fixed costs;
- To improve the utilisation of existing heat generating plant;
- To avoid replacement of heat generating plant and maximise network diversity benefits; or
- To spread demand risk.

The cost of connection can be compared in NPV terms with the potential savings in heat costs. In this case some price guarantee may be offered to assure connected consumers that they will benefit from the savings made.

Heat charge
The pricing approach to be followed should be specified in the procurement process of any heat network.

For the reasons given above, prices charged for heat supplied by heat networks are normally set by reference to the equivalent cost of gas-fired heating (the avoided cost or counterfactual). For most residential consumers, individual gas-fired central heating is the relevant comparison, because this is commonly used and is the most cost-effective alternative form of heating and hot water. For high-rise and green developments, this may not be the case and another benchmark may be used, such as ASHPs.

Figure 39 shows typical costs of both gas boiler and ASHP comparators of 16 p/kWh and 22 p/kWh, respectively. Values for the gas boiler were based on 2019, with an estimated lifetime of 15 years. All estimates assumed a two-bed house with an annual consumption of 4,000kWh. The seasonal COP of the ASHP was assumed to be 2.68 with an estimated lifetime of 20 years. This was estimated through Arup’s counterfactual study taking into account the average annual costs that would be incurred with an independent gas boiler or ASHP for an individual dwelling, including fuel costs, annualised REPEX and maintenance. This p/kWh comparator includes both the fixed and variable costs and, as such, the equivalent overall annual bill of a proposed heat network should be checked against this. The higher ASHP comparator cost can be attributed to the higher CAPEX of the system resulting in a higher REPEX, and the higher price of electricity compared with gas.

Figure 39 also shows the difference in cost of an ASHP when RHI payments are included, which reduces the total cost to be 15 p/kWh, lower than that of the gas counterfactual. This underlines the importance of the RHI scheme, due to end 31 March 2021, to incentivise renewable energy sources. However, studies show that HPs, even without RHI, could provide a cost competitive form of heat if they are designed, installed, commissioned and operated correctly[28]. Figure 40 shows the breakdown of the costs associated with the total price of heat for gas boiler and ASHP comparators.

Figure 39: Annual total cost of heat from a boiler and an ASHP, with and without RHI

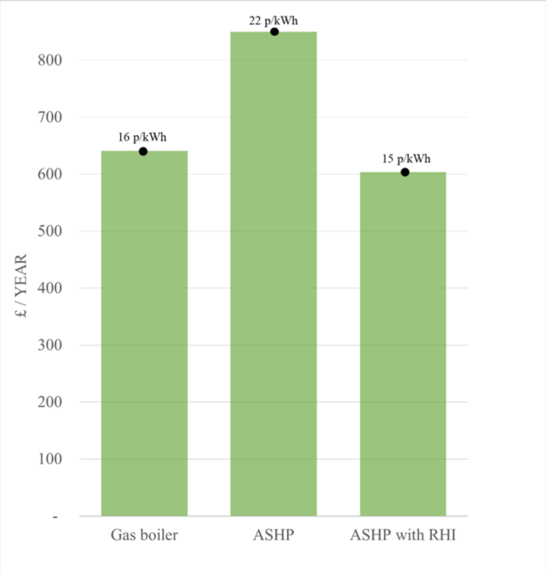
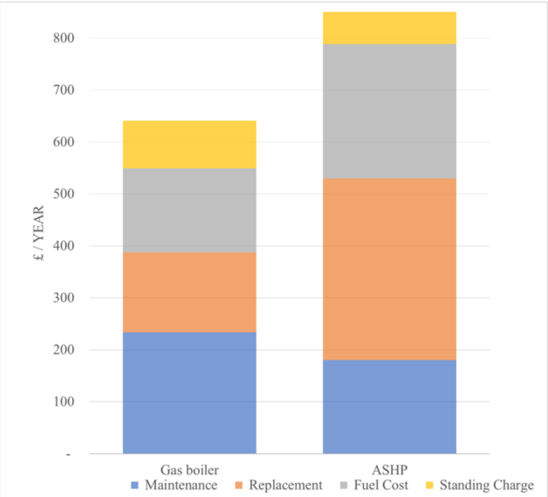


Figure 40: Breakdown of price of heat for gas boiler and ASHP



Whether the comparator uses gas or electricity, the retail price of the relevant energy source needs to be established so that the calculation can be made periodically. There is no specified process for making this calculation. Gas and electricity suppliers offer a multitude of tariffs, the take-up of which is not publicly known, and change their tariffs frequently. Gas suppliers are required to quote for an average level of consumption, specified each year by Ofgem. Almost certainly, the consumers to be served by the heat network will use less than this average. The level of consumption can be estimated though it cannot be known with certainty in advance.

For a long running contract, the reference energy price should be expressed generally and assumed to be constant for the analysis period. Following this, it is beneficial to perform a sensitivity analysis to determine the range of outcomes from future fluctuations in energy price. For example, the counterfactual could be stated as, ‘the average price, calculated from the cheapest tariffs available locally, on a dual fuel basis, from each of the six largest gas suppliers, for a consumption of 4,000 kWh/year'. Alternatively, the reference price could be taken from a published source, such as BEIS's Quarterly Energy Prices [64].

To convert energy prices to the equivalent heat price, a conversion factor must be applied. With modern gas boilers, an 85% or 90% efficiency should be assumed. In the case of an ASHP, to convert the electricity price to the equivalent heat price, the electricity price should be divided by the SCOP of the plant. Used primarily for provision of space heating, a domestic ASHP would normally achieve an SCOP of 2-3 over the year (better COPs are often quoted and may be higher for reference temperatures, but the annual average is affected by the tendency of performance to fall as the outside temperature drops). However, it should also be noted that for new developments DHW is more significant than for existing dwellings and will have an impact on the SCOP.

The heat provider typically maintains the energy system as well as supplying heat, so the price for heat should also take into account the value of this service. The value of a gas boiler maintenance contract can be determined by obtaining quotes. For example, in July 2019 the British Gas Homecare One with no excess (considered to offer a comparable service to that of heat providers) was priced for London consumers at £246/year, including insurance tax.

It is not advisable to revise prices for heat simply by linking the tender heat price to an inflation index. By doing so, there is a high probability that heat prices will quickly get out of line with consumers' expectations, which are based mainly on current energy prices.

It is also not advisable to base annual revisions to charges for heat directly on the actual costs of the heat network, as to do so risks removing the heat provider's incentive to be efficient and, perhaps more importantly, provides no assurance to consumers that they will continue to receive good value for money in future.

It is important that the tariff based on a counterfactual includes all charges to residential customers. As well as the fixed charge and the unit cost, heat providers may charge for late payment, for disconnection and reconnection, and for transfers when a dwelling changes hands; they may also offer a discount for paying by direct debit. All these extras should be taken into account.

Tariffs should be reviewed regularly. Residential consumers dislike the frequent tariff changes to which they are exposed by gas and electricity suppliers. With heat networks, there is the opportunity to limit price changes to one a year. Further certainty can be provided by basing the annual tariff adjustment on a formula that is made clear to consumers, for example, by its inclusion in the heat supply contract.

While in the short term, the gas price may be the best counterfactual for a heat tariff, this may change in the future to reflect changes in the general nature of heat production in the

UK. The contracts should allow for a review every, say, five years to see whether the gas counterfactual remains appropriate.

Fixed charge
Heat networks typically use a tariff that comprises both a fixed and a variable component, with the fixed charge for heat being significantly larger than for gas. The main commercial reason for their preference for high fixed charges is that heat demand is highly variable over the year and a fixed charge stabilises cash flow. It is beneficial for a heat supplier to have a higher fixed charge to recover some of the capital cost of the scheme, which is effectively a fixed annual cost. Also, a high proportion of the operating costs of a heat network are fixed in the short term.

In principle the fixed element should cover regularly recurring operational and maintenance costs and the variable element should cover energy use. For residential rental tenants, the maintenance costs must be charged to the landlord and so it is particularly convenient if the fixed charge exactly matches the relevant O&M costs.

Variable charge
Given an overall limit on what can be charged to the consumer, set by reference to a relevant external benchmark, such as retail or wholesale gas prices, then the higher the fixed charge, the lower the unit cost of consuming heat. In general, a low unit cost is not desirable as it reduces the incentive for consumers to economise on heat consumption. A balance needs to be struck between the interest of the operator in a steady cash flow and preserving incentives for consumers.

For heat networks that serve existing dwellings with a higher heat demand, it may be necessary to set more than one variable charge for heat in order to ensure that all consumers benefit from the system.

Commercial tariffs
The same tariff principles can be applied to commercial developments. Prices for heat chargeable to commercial consumers are generally lower than for residential, reflecting their much higher levels of consumption via a single connection and their reduced requirements for consumer services. Additionally, commercial consumers pay a lower tariff for gas which, when used as the counterfactual price, drives down heat network tariffs.

The market for gas supplies to businesses is more fragmented than the retail domestic market.

Many private sector firms have national agreements for gas supply and many public sector organisations participate in the Crown Commercial Service (CSS) framework agreement, Supply of Energy and Ancillary Services, or participate in the procurement service offered to local authorities by Laser Energy. These various agreements may provide a suitable benchmark for the avoided cost of gas supply.

Where reference to such agreements is not feasible, a gas counterfactual for commercial developments can be obtained using BEIS's Digest of UK Energy Statistics (DUKES), which publishes data on prices paid by industrial companies for gas[65].

For commercial consumers, the avoided cost of maintenance can be determined by reference to quotations from specialist firms for the maintenance of central heating systems, taking care to compare like with like.

Wholesale heat tariffs
Wholesale heat tariffs will be needed where a DBO contractor is paid for heat supplied via a heat network to the local authority or landlord who retails it to consumers, or where a local network is supplied with heat by means of a connection to a larger network. The price should be determined as part of the DBO competitive contract process and then indexed.

Wholesale heat tariffs can be developed following the same principles as for commercial consumers, set out above. As the scale on which heat is to be supplied wholesale is likely to be significantly higher, the avoided cost calculation is likely to produce a lower total price.

How the total wholesale price for heat is divided between fixed and variable components, will depend on the capacity of the connection and the expected total demand for heat, as this affects the commitment that the heat provider must make at the energy centre. The fixed element of the charge for heat may be constructed on a take-or-pay basis.

Heat as a service
An alternative method of charging residential premises for heat that has been trialled by Bristol Energy in partnership with the Energy Systems Catapult is heat as a service. Instead of the usual combination of fixed and variable charges, the cost of heat for the individual household is determined through a smart control system installed in each room. The single charge per month is then based on the schedule determined by the consumer for when each room is to be warmed.

Ambient heat networks, which provide uniform background heating, are normally also priced at a flat rate, which may be set per type of dwelling (e.g. one-, two- or three- bed flats) or per square metre.

In summary, heat as a service can either give the consumer greater control over comfort and cost, or simplify pricing, but leaves open how the overall level of charges for heat is to be controlled to ensure consumers get value for money.

Revenue management

As with other utilities, billing consists of reading the heat meters and collating the data into a database. Heat meters can be read in person or remotely, depending on the type of meter. Once the consumption data is collected and validated, a bill is prepared and issued to the consumer. Bills can provide additional information, including cumulative and average consumption and equivalent carbon emissions or carbon savings, as compared with a standard benchmark for that consumer type.

The normal position for a consumer with a good credit history is to bill in arrears, and not to place a deposit into the billing system. If their credit rating is poor, or drops due to persistent non-payment, the billing system can be kept in credit or a deposit held, while still allowing payment in arrears. Fixed monthly direct debit arrangements can be used to spread payments evenly over the course of the year; since demand will normally be high in the winter and low in the summer.

Alternatively, a formal prepayment system can be used. Prepayment is generally run by hardware in the HIU, and thus has a set-up cost.

However, with smart meters, prepayment can now be achieved solely through billing system software.

Electricity revenues

In the UK energy market, residential consumers typically take electricity and gas from the same supplier. These 'dual fuel' contracts can offer better value than electricity and gas sold separately, because the supplier incurs lower marketing, billing and consumer service costs. Heat networks based on CHP are exceptionally well-placed to secure the same economies, but are in practice unable to realise them. Heat networks are local, but local electricity supply licences are not available, and unlicensed electricity supply is only permitted at a scale too small, in most cases, for economic operation of a heat network (the licence exemption limit for residential customers of 1MWe per site, or set of private wires, corresponds to about 1000 dwellings). In consequence, residential consumers of heat networks are obliged to forego dual fuel benefits and heat networks are able to secure only wholesale revenues for the electricity they generate.

Prices in the wholesale market are generally low and variable; in recent years, wholesale prices have ranged between £35 and £65 per MWh. Moreover, heat networks which produce relatively small amounts of power, essentially as a by-product of producing heat, do not attract very competitive offers and may struggle even to achieve these price levels.

A CHP network providing heat to non-residential consumers may be able to increase its revenues from electricity by connecting them to a private wire. If a new cable has to be run down a street, it may be difficult to secure permission, since access to the public domain is normally limited to organisations serving the public interest. However, the electrical cable would normally be able to follow the same route as the heat network. To cover the capital costs associated with a private wire solution, it would normally be necessary to enter into a long-term contract with the intended consumers, in much the same way as for heat; consumers cannot, however, be tied permanently to the contract. The price at which electricity is to be supplied would normally be benchmarked, to ensure consumers obtain good value for money. The private wire can also be used to deliver other forms of renewable energy, such as solar power.

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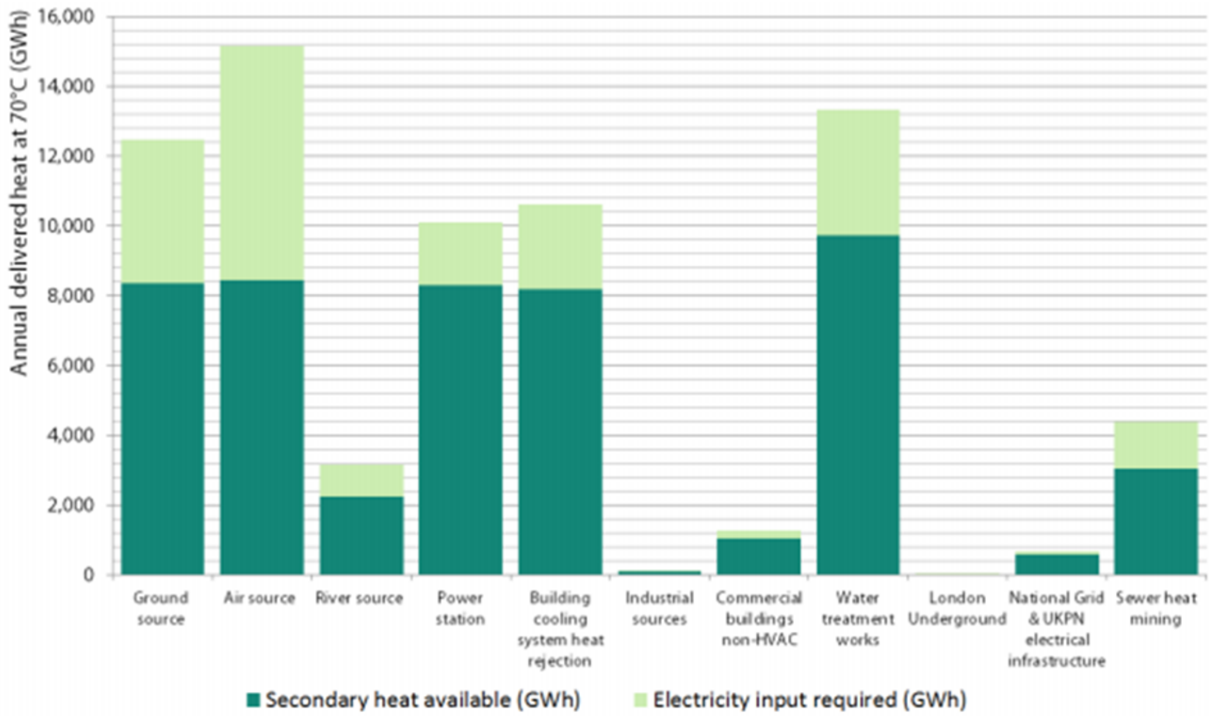
Appendix 2: Heat Sinks

Heat sources/sinks suitable for HP applications
Heat can be extracted or rejected from/into the environment (air, ground and surface water). These sources can have a high supply potential, as the heat extraction is effectively only constrained by the demand. Even though these sources are 'infinite', various techno-economic considerations often limit the realistic heat supply.

Figure 41: Delivered heat by source showing HP energy requirements[20]



Air source
Heat is commonly extracted or rejected from/to the outside air, using technologies such as air-cooled chillers (ACC) or ASHP.

The main advantage of using air as a source/sink is that it is 'infinite' and ubiquitous, as heat and coolth can be extracted from outside air in most cases (provided external space is available).

Other advantages of using air as a source/sink include the fact that it does not require very complex/expensive systems and the fact that air source heating/cooling generation technologies are relatively well-established.

The main disadvantage of using air as a source/sink is the fact that the air temperature varies throughout the year inversely to the heating/cooling demand. Indeed, heating is usually required during months with low air temperature, and cooling is usually required during months with high air temperatures. As the temperature difference between the source and the heating/cooling supply impacts the performance of HPs, ASHPs often have a relatively low COP, particularly during the coldest or warmest days of the year.

Air is also a poor heat transfer medium in comparison to water. It has lower specific heat capacity meaning a larger volume is required to deliver the same amount of energy, such that large fans are typically required to meet airflow requirements (with associated power requirements). Its lower thermal conductivity and thermal heat transfer coefficients mean that large surface areas or large temperature differences are needed to transfer a given amount of heat. Practically, it is often simpler to operate with larger temperature differences, but this reduces the HP evaporator temperature (bringing further reduction to COP).

Other disadvantages of using air as a source/sink are the risk of urban heat island or cool island effects (particularly if large quantities of heat/coolth are extracted from the air) as well as complexities when the temperature drops below around 5-8ºC, as refrigerant temperatures drop below zero and frost forms on the heat exchanger. In such cases, a defrost cycle is required to melt the build-up of ice, which comes at a cost to efficiency.

Ground source
Heat can be extracted or rejected from/into the ground through the following systems:

1. Closed loop pipework installations (vertical or horizontal)

2. Open loop systems which utilise groundwater and consist of a pair of wells (one for water extraction and one for water injection)

The ground can only be utilised as a source/sink in certain cases, as it requires land availability and/or early considerations in the development programme. The thermophysical properties of the ground vary with location depending on the subsurface rock composition. In all cases, it is necessary to understand the ground conditions and properties (including groundwater flow, which is necessary for open loop systems) to mitigate risks around the amount of heat extraction or rejection capacity available. Ideally a test borehole would be drilled in the area of interest, but desktop studies can also suffice.

One of the main benefits of using the ground as a source of heat/coolth is that ground temperatures do not fluctuate significantly during the year, usually staying around 10-15ºC, with more stability found with depth. This means that during the coldest or warmest days of the year the ground temperature is closer to the required supply temperature than the air temperature. For this reason, ground source heat pumps (GSHPs) often will normally have higher seasonal and peak COPs than ASHPs.

An additional benefit of using the ground with the closed loop systems is the ground's ability to provide inter-seasonal thermal storage. For example, during the summer, heat would be rejected into the ground, raising the ground's temperature; vice versa during the winter. Assuming there is little or no groundwater flow, heat or coolth will remain local to the borehole heat exchangers (BHEs) for use later.

Using the ground as a heat source/sink comes with an inherent level of complexity, a number of risks and higher costs when compared to ASHPs, but will have lower operational costs due to lower maintenance of the collector side, higher COPs and a longer lifespan.

In addition, open loop groundwater systems have risks inherent to the aquifer conditions and changes in available flow rates, while closed loop systems require balanced heating/cooling loads on an annual basis for efficient use of the source in the long term. Open loop groundwater systems can achieve higher flow rates and higher heat extraction/rejection potential compared to closed loop systems of similar physical size (or require more electricity for pumping to achieve similar heat extraction/rejection).

Open loop ground systems have requirements and restrictions by the Environmental Agency (EA) associated with water extraction and rejection from/to the aquifer. In most cases a groundwater investigation consent, an abstraction licence and an environmental permit for discharge activity are required. The environmental regulations are particularly stringent for consumptive licences (where water is extracted from the aquifer but not rejected into it) and in terms of maximum allowable water temperature differential (ΔT).

Surface water source
Heat can be extracted or rejected from/to various surface water bodies, including rivers, lakes/ponds and sea. Both closed loop and open loop systems can be utilised to extract/reject heat from/to surface water bodies.

Using surface water as a source of heat/coolth has benefits compared to using air as a source of heat/coolth, as the surface water temperature does not fluctuate as significantly as the air temperature during the year. This means that during the coldest or warmest days of the year the surface water temperature is closer to the required supply temperature than the air temperature. For this reason, surface water source heat pumps (WSHPs) may have higher seasonal and peak COPs than ASHPs.

Surface water temperatures within the UK might vary between 5-25 ºC, depending on various parameters including season, air temperature, recent weather conditions such as rainfall levels and hours of sunshine, etc. As the surface water temperatures generally vary throughout the year inversely to the heating/cooling demand and fluctuate more than the ground temperatures, using surface water temperature as a source of heat/coolth is less advantageous than using ground source.

Closed loop systems require lower maintenance and have less stringent environmental regulations compared to open loop systems. However, closed loop systems have lower flow rates and lower heat extraction/rejection potential compared to open loop systems of similar physical size (or require more electricity for pumping to achieve similar heat extraction/rejection).

Some of the main disadvantages of using surface water as a heat source/sink include requirements and restrictions by the EA associated with water extraction and rejection. In most cases an abstraction licence and an environmental permit for discharge activity are required, with additional environmental permits in specific situations (for example, if carrying out works near a flood defence). The environmental regulations are particularly stringent with heat rejection permits (as heat is viewed as a pollutant by the EA) and in terms of maximum allowable water temperature differential (ΔT).

Additional disadvantages of using open loop surface water systems include additional design requirements and maintenance requirements for filtration and anti-corrosion.

Lakes or ponds, depending on their dimensions and properties, might have the additional benefit of providing inter-seasonal storage, but they also have the possibility of overheating/overcooling if the heating and cooling load are very unbalanced.

Using sea water as a heat source/sink has advantages associated with the ‘infinite’ potential for heat extraction/rejection, but it has additional complexities, costs and risks due to the water salinity.

Other sources

In addition to the environmental sources described above, there are various other sources of heat arising as a by-product of processes and infrastructure operation which can be used for heat networks at reduced operating temperatures.[72] The heat supply available from these sources is often limited and relies on third-party infrastructure/processes, with associated risks. In all cases, there is a likelihood that the network operator will have to pay a unit rate for the low-grade heat.

Table 16: Secondary heat sources from processes and infrastructure operations[23]

Source/sink	Heating	Cooling	Temp. range	Notes/key considerations
Sewers	✓	✓	14-22°C	Designs must consider the fact that flow contains solid materials Heat extraction must ensure the sewer temperature does not fall below 10°C Can be used to reject heat as well as extract it

Source/sink	Heating	Cooling	Temp. range	Notes/key considerations
Water treatment works	✓	✓	14-22°C	Often far from urban heat demands Can be used to reject heat as well as extract it
Power stations	✓	×	35°C or much higher	Often far from urban heat demands Heat availability depends on operation profile of the plant throughout the year Heat often capable of supplying into conventional heat networks operating at higher supply temperatures (e.g. 90°C)
Energy from Waste (EfW)	✓	×	90°C or higher for steam turbine off-take	London's waste and recycling targets do not support further EfW plants in the city Often far from urban heat demands Heat often capable of supplying into conventional heat networks operating at higher supply temperatures (e.g. 90°C)
Electrical substations	✓	×	50°C	Only relevant at locations dealing with large amounts of power (e.g. 132/33kW step down substations) Distribution network operators (DNOs) have limited requirement for pursuing additional revenue streams, can be hard to garner interest
Cooling plant (e.g. chillers in buildings, cooling plant in data centres)	✓	×	28-40°C	Need to ensure continuity of cooling supply Must ensure supplier would see no rise in electricity bill associated with cooling Higher heat availability during summer, when heat demand is lower
Industrial processes	✓	×	35-70°C Highly variable	Various heat grades found in different industrial processes May require significant plant modifications to capture heat – typically payable by network operator

Source/sink	Heating	Cooling	Temp. range	Notes/key considerations
Ventilation extracts for underground railways (e.g. London Underground)	✓	✗	12-29°C	Similar to ASHP but typically with elevated temperatures when compared to external air conditions, with enhanced COP Air extracts can often contain high levels of particulates, adding requirement for filtration and maintenance

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