TOWN AND COUNTRY PLANNING ACT 1990
PLANNING AND COMPULSORY PURCHASE ACT 2004

Appendix 3 to the Proof of Evidence of Mr Tony Norton CEng, MIChemE, MBA, BSc (Hons) on behalf of Dorset Council

Appeal by Powerfuel Portland Limited
against the refusal by Dorset Council of Planning Application
Ref. WP/20/00692/DCC for the construction of an energy
recovery facility with ancillary buildings and works including
administrative facilities, gatehouse and weighbridge, parking
and circulation areas, cable routes to ship berths and existing
off-site electrical sub-station, with site access through Portland
Port from Castletown,

at Portland Port, Castletown, Portland, Dorset, DT5 1PP

Planning Inspectorate References:	**APP/D1265/W/23/3327692**
Dorset Council References:	**WP/20/00692/DCC**
Date:	**14th November 2023**

CONTENTS

1. Department of Transport, Use of maritime shore power in the UK: summary of call for evidence responses

July 2023

https://www.gov.uk/government/calls-for-evidence/use-of-maritime-shore-power-in-the-uk-call-for-evidence/outcome/use-of-maritime-shore-power-in-the-uk-summary-of-call-for-evidence-responses

Summary of responses

Overall, 73% of respondents were supportive of shore power as one of the available technologies to reduce emissions at berth, 12% were completely against it and 15% provided a neutral response.

There was a shared acknowledgement that there were several variables associated with the costs of shore power uptake and the level of GHG and air pollutant emissions at berth. A range of responses were subsequently provided on costs associated with shore power and emissions data across different locations in the UK.

There was also consensus over the barriers and incentives for shore power uptake in the UK. Most respondents highlighted high capital costs, demand uncertainty, high electricity prices and energy grid constraints as the most significant barriers to shore power growth.

Whilst most respondents were supportive of the government providing a greater coordinating function regarding the uptake of shore power, there was no shared consensus over what this role may involve and resulted in respondents providing different suggestions on the government's potential coordination role.

There were also a range of views provided on what topics should be included to maximise the value of government coordinated guidance on shore power projects.

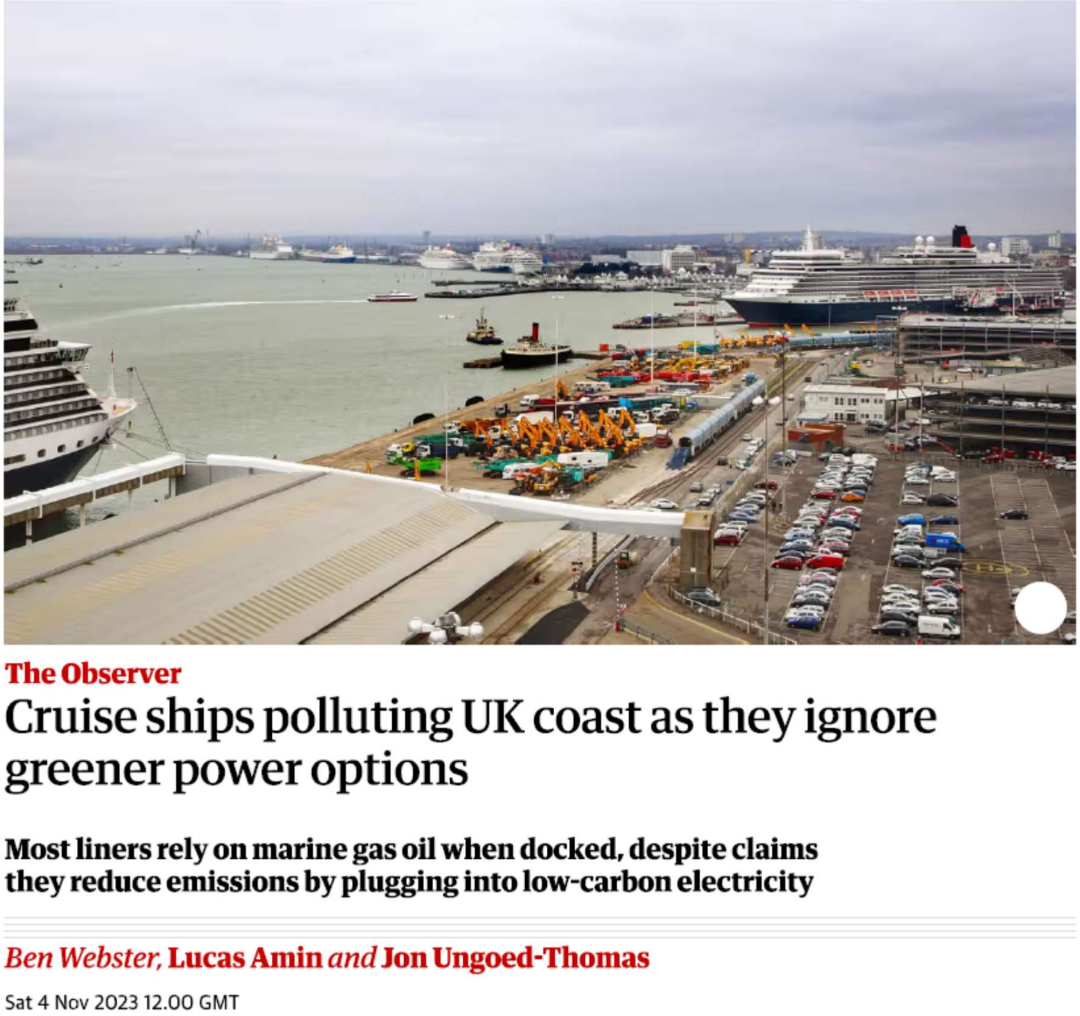
Views on a government mandate for shore power were clearer. A majority of respondents agreed to a mandate either on shore power or a technological neutral option combining alternative fuels, such as a zero-emission berth mandate. Respondents who were against a mandate outlined the various barriers that would make it difficult to implement.

A few respondents provided options for economic incentives. There was also general agreement for direct funding or access to funding to enable shore power uptake, there were a range of suggestions on where funding should be focused.

2. The Guardian, Cruise ships polluting UK coast as they ignore greener power options

November 2023

https://www.theguardian.com/environment/2023/nov/04/cruise-ships-polluting-uk-coast-as-they-ignore-greener-power-options



The Observer

Cruise ships polluting UK coast as they ignore greener power options

Most liners rely on marine gas oil when docked, despite claims they reduce emissions by plugging into low-carbon electricity

Ben Webster, **Lucas Amin** *and* **Jon Ungoed-Thomas**

Sat 4 Nov 2023 12.00 GMT

Cruise ships visiting Britain are frequently failing to plug into “zero emission” onshore power and instead running their engines and polluting the local environment with fumes.

The industry is under scrutiny over air pollution and contribution to greenhouse gases, with some European cities banning vessels from central ports. Cruise operators say ships can reduce emissions by switching off engines and plugging into low-carbon electricity when moored. But an investigation by openDemocracy has found that cruise ships regularly fail to use onshore power at Southampton, Britain’s largest cruise port.

They instead rely on marine gas oil, which contributes to local air pollution, or liquefied natural gas (LNG), which has lower air pollutants but leads to some methane being emitted into the atmosphere. Both fuels contribute to greenhouse gas emissions.

An analysis of ship schedules at Southampton found that between April 2022 and July 2023, there were about 300 days when at least one cruise ship was docked at the port, but the onshore power facility was only used 71 times over the same period.

Some ships have not been adapted to use cleaner onshore power, but the UK Chamber of Shipping says one factor is cost, because onshore power is more expensive than marine fuel. Cruise firms can also pay for their ships to be retrofitted with new technology so they can use cleaner onshore power.

Jon Hood, UK sustainable shipping manager at Transport & Environment (T&E), Europe’s leading clean transport campaign group, said: “There’s clean power available but the cruise companies don’t want to pay for it.”

He said greater transparency was required and cruise operators should be forced to disclose when they use onshore power and for how long, and that the government should require cruise ships to plug into onshore power when it was available.

Katherine Barbour, Southampton’s first Green party councillor, said: “If cruise liners aren’t mandated to change, this will continue and our residents will suffer. We need all berths to be able to provide onshore power, and ships need to be adapted to use it.

“Every ship is like a small town, spewing out pollution when they are not using electricity.”

The *New York Times* reported in December 2019 that a single docked cruise ship can emit in a day as much diesel exhaust as 34,400 idling lorries, but that that was almost eliminated with onshore power. The cruise industry says the analysis does not consider advanced technologies on cruise ships used to reduce emissions, the use of alternative fuels, or restrictions on emissions in ports.

While cruising is one of the fastest growing tourism sectors, with 31.5m passengers forecast for 2023, there are concerns about its environmental impact. A study published in the journal *Marine Pollution Bulletin* in December 2021 found a large cruise ship could have a carbon footprint greater than 12,000 cars. An analysis published in June by T&E found that despite the introduction of a new cap of sulphur in marine fuels in 2020, 218 cruise ships operating in Europe in 2022 emitted more sulphur oxides than a billion cars.

In 2021, Venice banned cruise ships from its historic centre. Amsterdam banned cruise ships from its centre earlier this year and Barcelona followed suit from 22 October.

The industry also says it is committed to greener practices, with a target of net zero carbon cruising by 2050. Carnival Corporation, the world's largest leisure travel company, is building new ships powered by LNG, and cruise operators are also conducting trials with biofuels. New LNG engines reduce emissions of sulphur oxides but campaigners say the engines and the fuel production process leak methane, an extremely potent greenhouse gas.

In April 2022, Associated British Ports (ABP), which operates the cruise cruise port at Southampton, announced the launch of an onshore power facility offering "zero emissions at berth". The project cost £9m, supported by £4.4m from the Solent local enterprise partnership, which has significant public funding. But only one ship can plug into that facility at a time.

The 2022 Solent LEP annual report said shore power had saved 1.7m kg of CO_2 in a year; that is only a fifth of the annual savings predicted by ABP in its business case submitted to the LEP to obtain the £4.4m grant. ABP said implementation takes time to "work up".

The Cruise Lines International Association says 46% of its member fleet can connect to shoreside electricity. It said in September that 32 ports had at least one cruise berth with shoreside power, and plugging in could reduce emissions by up to 98%. A spokesperson said: “Connecting to shoreside electricity is a long-term element in the cruise industry’s decarbonisation strategy.”

ABP said: “ABP Southampton is proud to be a UK leader in the provision of shore power. It’s a service to our shipping customers that we want to grow. We see shore power as an integral part of the transition to net zero for both ABP and our customers.

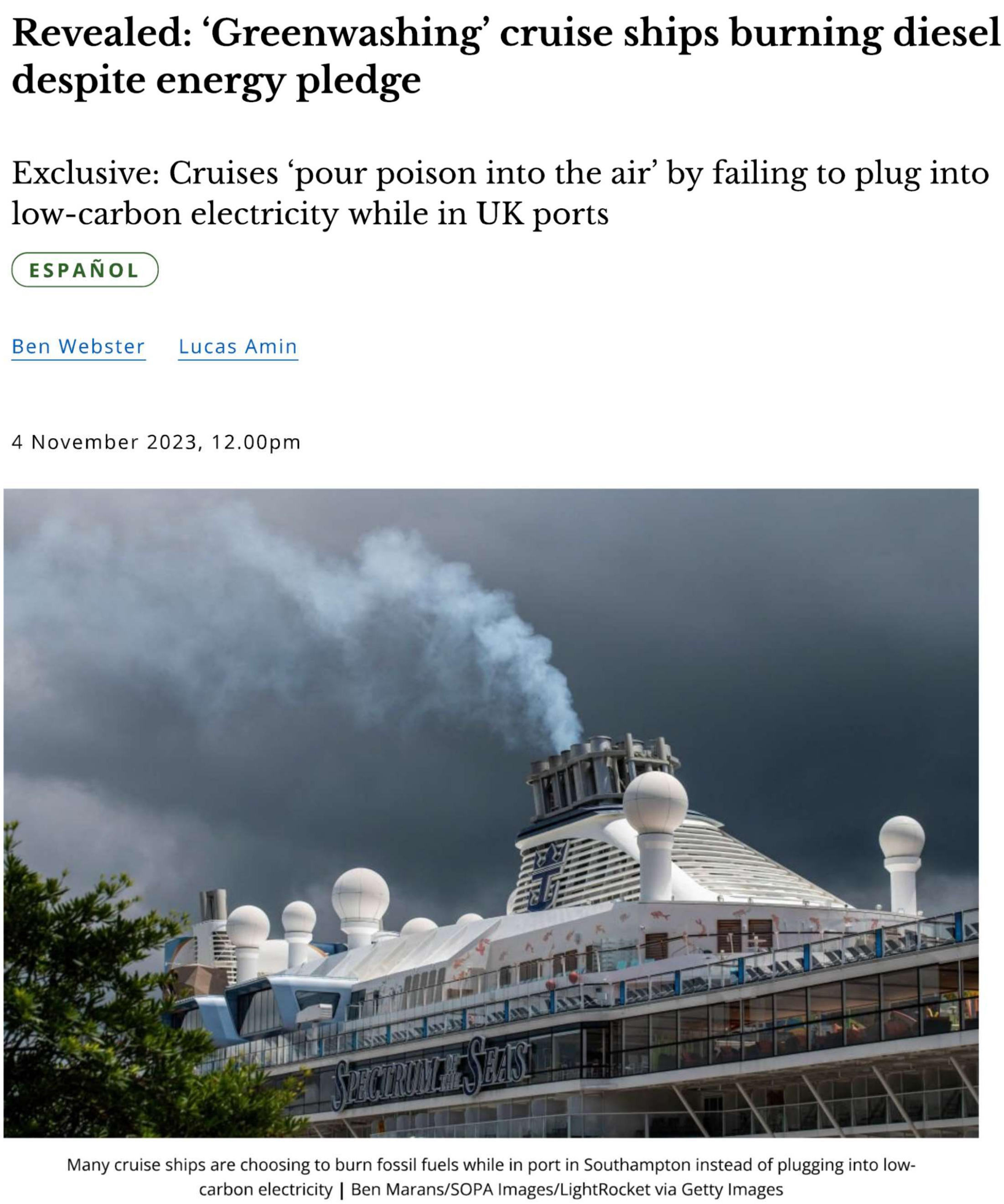
“The port of Southampton has a UK-leading air-quality improvement and emissions reduction strategy, backed by a network of air quality monitors around the port. Real world air-quality monitoring research by Southampton city council demonstrates that air quality levels for port-related emissions are a fraction of other sources such as traffic.”

Port officials say there are various factors involved in the use of the onshore power facility, which may include the fact that UK power costs are some of the highest in Europe. ABP said it planned to publish a 2023 shore-power performance review early next year, with its air quality update.Carnival Corporation said: “We use shore power in ports wherever available and operationally possible. However, despite the benefits, just 2% of the world’s ports have at least one cruise berth equipped with onshore power.”

3. openDemocracy, Revealed: ’Greenwashing’ cruise ships burning diesel despite energy pledge

November 2023

https://www.opendemocracy.net/en/cruise-ships-greenwashing-energy-shore-power-diesel-uk-ports-mislead-tourists/



Revealed: ‘Greenwashing’ cruise ships burning diesel despite energy pledge

Exclusive: Cruises ‘pour poison into the air’ by failing to plug into low-carbon electricity while in UK ports

ESPAÑOL

Ben Webster Lucas Amin

4 November 2023, 12.00pm

Many cruise ships are choosing to burn fossil fuels while in port in Southampton instead of plugging into low-carbon electricity | Ben Marans/SOPA Images/LightRocket via Getty Images

The cruise industry has been accused of misleading tourists with false claims that ships use green energy with “zero emissions” while in port in the UK.

Cruise companies claim the giant vessels – which some experts believe are worse for the climate than flying – are reducing emissions by switching off their engines and plugging into low-carbon electricity while moored.

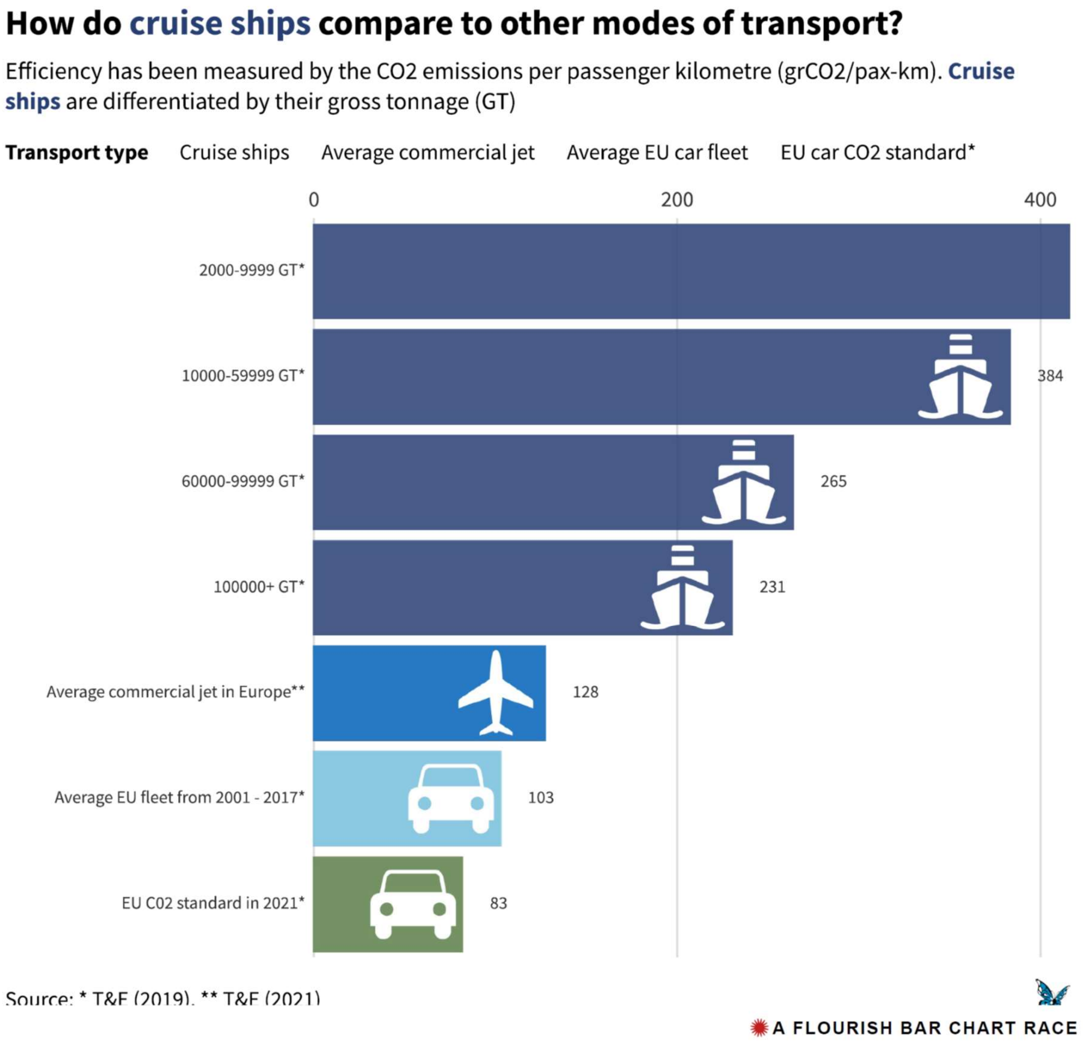
But an investigation by openDemocracy has found that cruise ships regularly fail to use the ‘shore power’ available in port, and instead burn diesel, which is cheaper but has a huge carbon footprint.

Data from the UK’s biggest cruise port in Southampton shows that only around one in ten cruise ships has plugged into shore power since it became available at the port last year.

The data also suggests that the few ships that did use the energy plugged in for only about five hours per visit on average, despite typically spending 12 hours in port.

Cruise ships’ failure to use the shore power appears to be worsening air pollution in Southampton. Just 45 ships visiting the port produced almost ten times more harmful pollutants than the city’s 93,000 cars combined, according to a study published by the Transport & Environment (T&E) think tank in June.

T&E also found that cruise ships emit two to five times more CO_2 per passenger kilometre than the average commercial aeroplane in Europe.



How do cruise ships compare to other modes of transport?

Efficiency has been measured by the CO2 emissions per passenger kilometre (grCO2/pax-km). **Cruise ships** are differentiated by their gross tonnage (GT)

Source: * T&E (2019). ** T&E (2021)

Shore power, which is available at 32 cruise ports across the world, can “reduce emissions by up to 98%, depending on the mix of energy sources, while a ship is in port”, according to Cruise Lines International Association

But companies are choosing not to use it, in part because it costs more than tax-free marine diesel, according to the UK Chamber of Shipping, the industry trade association.

Jon Hood, sustainable shipping manager at T&E, said: “It’s hard to believe in 2023 that cruise ships are still allowed to sit in our busy port towns pouring poison into the air that people breathe.

He continued: “[It’s] harder still to believe they’re allowed to do this even when there’s clean power available right there, but the cruise companies don’t want to pay for it for the sake of their profits.”

‘Plume of smoke’

openDemocracy’s investigation comes as the cruise industry is expanding, with more than 70 new ships – many of which can accommodate up to 7,000 passengers and staff – on order globally. Some 1.7 million people in the UK and Ireland holidayed on a cruise ship last year.

In 2021, the chief executives of six of the world’s biggest cruise lines signed a letter committing to support the development of shore power, which they said was needed “to combat climate change”.

Carnival, the world’s largest cruise company, lists “shore power connection” as a key “environmental feature” of its vessels in its 2022 sustainability report.

But the industry is frequently failing to use shore power when it is available. Southampton port’s owner, Associated British Ports (ABP) announced that shore power was ready for use at two its five terminals where cruise ships can dock in April 2022, saying ships could plug in to achieve “zero emissions at berth”.

Between then and the end of July 2023, there were more than 300 days when at least one cruise ship was berthed at Southampton, according to openDemocracy’s analysis of ABP’s schedule.

This suggests shore power could have been used 300 times over that period – even with local grid constraints that mean only one ship can use shore power at any one time.

But in August, ABP told openDemocracy that shore power had been used on just 71 “occasions” since April 2022, though it refused to say exactly when these occasions were.

> “
>
> **One only has to look at the plume of smoke from the cruise liners to see the pollution being discharged over our city**
>
> **Katherine Barbour, Southampton councillor**

The failure to use shore power can partly be explained by cruise lines delaying the necessary investment to upgrade their ships to be compatible with the energy source.

Only 46% of cruise ships globally can connect to shore power, according to CLIA – despite the first shore power port connection for cruise ships being installed more than 20 years ago. CLIA says 72% of ships will be able to do so by 2028.

Carnival admitted that the Iona, Ventura and Queen Victoria, which visited Southampton 80 times between May 2022 and February 2023, were not capable of taking shore power in that period.

Yet even cruise ships that can use the electricity regularly fail to do so in Southampton.

The cruise company AIDA, which is owned by Carnival, said in 2021 that the use of shore power “is a decisive step for AIDA cruises to reduce local emissions to zero during berthing over time, as a cruise ship typically stays in port around 40% of its operating time”.

AIDA has also claimed to be “campaigning for the development” of shore power infrastructure at other ports.

But the company’s flagship vessel, the AIDAprima, did not connect to shore power in Southampton on 80% of its visits, despite being able to do so, according to ABP data from May 2022 to February 2023 obtained by openDemocracy.

Katherine Barbour, who became Southampton’s first Green councillor in May, said: “One only has to look at the plume of smoke coming up from the cruise liners to see the pollution that is being discharged over our city.”

A spokesperson for Carnival said: “Our ships leverage shore power whenever possible where available at our destinations.”

‘Greenwashing’

Southampton port owner ABP successfully applied in 2020 for a £4.4m public subsidy to install shore power.

In its business case for the grant – which was awarded via the Solent Local Enterprise Partnership (LEP), a voluntary partnership between the local authority and businesses to encourage economic growth in the area – ABP stated that cruise ships were at berth for an average of 12 hours and could plug in for “96% of time in port”.

But figures published in Solent LEP’s annual report suggest that the 55 ships that used shore power in Southampton in the 12 months to the end of March 2023 did so for an average of only five and a half hours, spending the remaining six hours in port burning fossil fuel to generate power. A cruise ship consumes an average of 2,700 litres of diesel an hour in port.

The report stated that the 55 ships used shore power to draw a total of 1.5 million kilowatt hours of electricity. One large cruise ship is likely to use at least this amount of energy in less than two weeks.

> “
>
> **It's hard to believe cruise ships are allowed to pour poison into the air even when there’s clean power available right there**

Peter Aylott, the director of policy at the UK Chamber of Shipping, told openDemocracy: “The current price of electricity is so high that no cruise company is going to use it unless they had to by a mandatory requirement.”

A spokesman for the chamber later clarified Aylott’s comment, saying that the high price of electricity was one reason why cruise ships do not always plug in at Southampton when shore power is available.

The UK is lagging behind the EU in forcing the cruise industry to reduce its emissions via shore power. Cruise ships visiting EU ports will be required to connect to shore power from 2030 under the FuelEU Maritime Regulation. By contrast, the UK government is still considering “options” for expanding shore power use, including “exploring the potential” of requiring vessels to use it when in port.

Jon Hood of T&E said cruise companies that “trumpet their use of shore power in an effort to seem green” but fail to actually use it are guilty of greenwashing.

“The government must require cruise ships to plug into shore power when it’s available,” Hood added. “As a first step, cruise companies should have to publish when their vessels take shore power, and for how long.”

Southampton councillor Katherine Barbour said: “If cruise liners are not mandated to change this will continue and our residents will suffer. We need all berths to be able to provide shore power and ships need to be adapted to use it.

“At the moment every ship is like a small town, spewing out pollution when they are not using electricity.”

Cruise companies have separately been accused of misleading the public with their claims that ships are becoming more environmentally friendly because they can burn liquified natural gas (LNG) instead of diesel.

Environmental group Opportunity Green said research showed that leaks of unburned methane could cancel out the claimed climate benefits of LNG.

A spokesperson for MSC Cruises, whose ships regularly visit Southampton, said it “intends for all ships belonging to MSC Cruises to fully utilise shore power facilities at all other ports they visit once available”. They added that “there exists a variety of reasons for not utilising shore power” but said cost was not one of those reasons.

A spokesperson for ABP said: “ABP Southampton always seeks to maximise the use of its shore power facility subject to asset availability constraints, including grid capacity outside the port, and in response to customer demand.

“The numbers presented to us by [openDemocracy] seem to be taken out of context and to contain important flaws.”

The numbers were either supplied directly by ABP or based on analysis of ABP data.

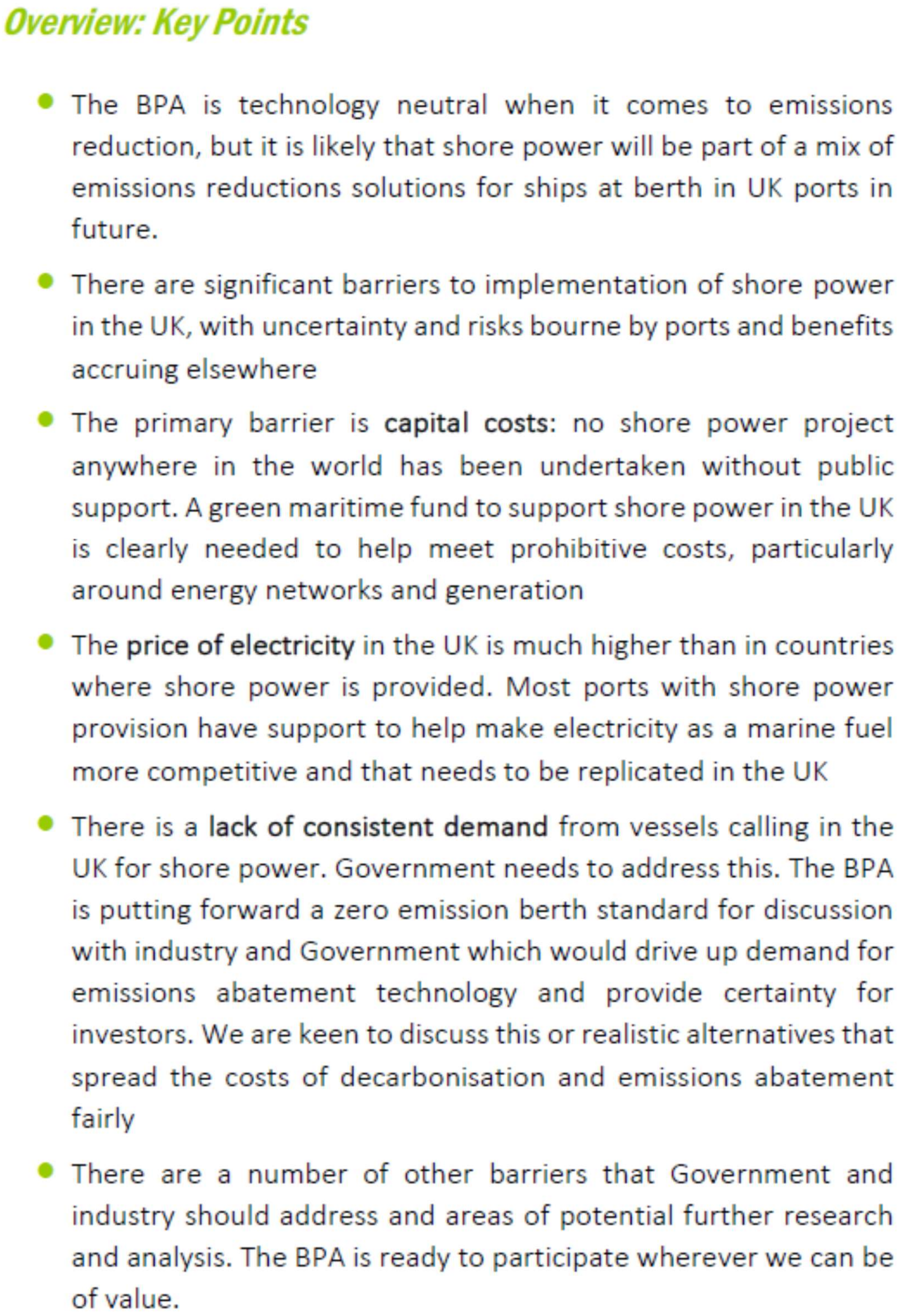
Asked how many times a cruise ship had failed to plug in at Southampton when shore power was available, the spokesperson said: “We don’t collect the data.”

The Solent LEP report said shore power had saved 1.7 million kilograms of CO2 in a year. That is only a fifth of the annual savings predicted by ABP in its business case submitted to the LEP to obtain the £4.4m grant. ABP said: “Implementation always takes a while to work up as both users and providers become familiar with use in practice.”

4. British Ports Association, Examining the Barriers to Shore Power

May 2020

https://www.britishports.org.uk/content/uploads/2021/10/BPA_Shore_Power_Paper_May_2020.pdf



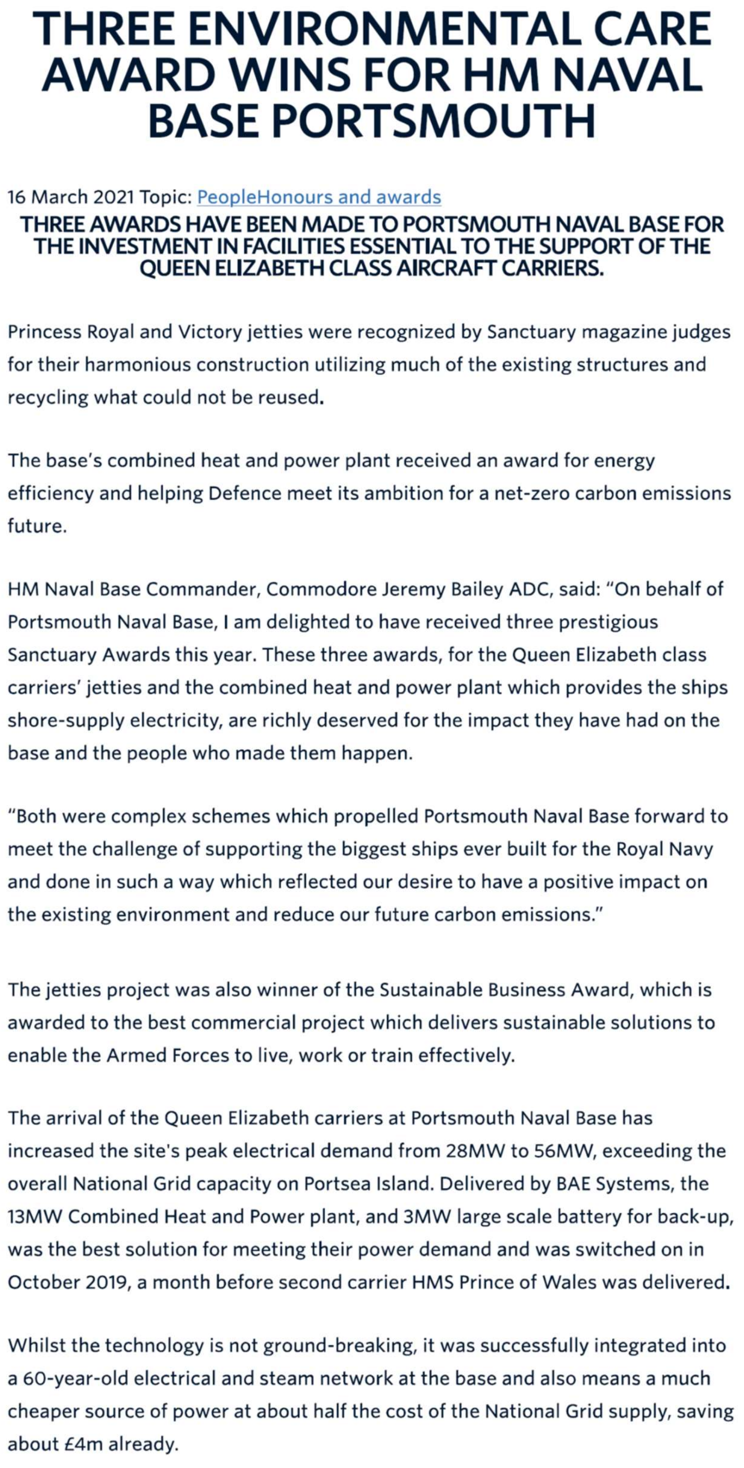
Overview: Key Points

- The BPA is technology neutral when it comes to emissions reduction, but it is likely that shore power will be part of a mix of emissions reductions solutions for ships at berth in UK ports in future.
- There are significant barriers to implementation of shore power in the UK, with uncertainty and risks bourne by ports and benefits accruing elsewhere
- The primary barrier is **capital costs**: no shore power project anywhere in the world has been undertaken without public support. A green maritime fund to support shore power in the UK is clearly needed to help meet prohibitive costs, particularly around energy networks and generation
- The **price of electricity** in the UK is much higher than in countries where shore power is provided. Most ports with shore power provision have support to help make electricity as a marine fuel more competitive and that needs to be replicated in the UK
- There is a **lack of consistent demand** from vessels calling in the UK for shore power. Government needs to address this. The BPA is putting forward a zero emission berth standard for discussion with industry and Government which would drive up demand for emissions abatement technology and provide certainty for investors. We are keen to discuss this or realistic alternatives that spread the costs of decarbonisation and emissions abatement fairly
- There are a number of other barriers that Government and industry should address and areas of potential further research and analysis. The BPA is ready to participate wherever we can be of value.

5. Royal Navy, Three environmental care award wins for HM Naval Base Portsmouth

March 2021

https://www.royalnavy.mod.uk/news-and-latest-activity/news/2021/march/16/210316-three-environmental-care-award-wins-for-hm-naval-base-portsmouth



THREE ENVIRONMENTAL CARE AWARD WINS FOR HM NAVAL BASE PORTSMOUTH

16 March 2021 Topic: PeopleHonours and awards

THREE AWARDS HAVE BEEN MADE TO PORTSMOUTH NAVAL BASE FOR THE INVESTMENT IN FACILITIES ESSENTIAL TO THE SUPPORT OF THE QUEEN ELIZABETH CLASS AIRCRAFT CARRIERS.

Princess Royal and Victory jetties were recognized by Sanctuary magazine judges for their harmonious construction utilizing much of the existing structures and recycling what could not be reused.

The base's combined heat and power plant received an award for energy efficiency and helping Defence meet its ambition for a net-zero carbon emissions future.

HM Naval Base Commander, Commodore Jeremy Bailey ADC, said: "On behalf of Portsmouth Naval Base, I am delighted to have received three prestigious Sanctuary Awards this year. These three awards, for the Queen Elizabeth class carriers' jetties and the combined heat and power plant which provides the ships shore-supply electricity, are richly deserved for the impact they have had on the base and the people who made them happen.

"Both were complex schemes which propelled Portsmouth Naval Base forward to meet the challenge of supporting the biggest ships ever built for the Royal Navy and done in such a way which reflected our desire to have a positive impact on the existing environment and reduce our future carbon emissions."

The jetties project was also winner of the Sustainable Business Award, which is awarded to the best commercial project which delivers sustainable solutions to enable the Armed Forces to live, work or train effectively.

The arrival of the Queen Elizabeth carriers at Portsmouth Naval Base has increased the site's peak electrical demand from 28MW to 56MW, exceeding the overall National Grid capacity on Portsea Island. Delivered by BAE Systems, the 13MW Combined Heat and Power plant, and 3MW large scale battery for back-up, was the best solution for meeting their power demand and was switched on in October 2019, a month before second carrier HMS Prince of Wales was delivered.

Whilst the technology is not ground-breaking, it was successfully integrated into a 60-year-old electrical and steam network at the base and also means a much cheaper source of power at about half the cost of the National Grid supply, saving about £4m already.

Sanctuary Magazine is produced by the Defence Infrastructure Organisation and its awards for 2020 were delayed until today (Tuesday). They were co-hosted in a virtual ceremony by Lt Gen Richard Nugee who is leading the review into the way the MOD meets the challenge of conducting all activities in a more sustainable way.

The award judges were also impressed by the construction of the jetties the carriers occupy when they are in Portsmouth. The existing moorings were not capable of supporting two ships of more than 65,000 tonnes, but there was considerable history and perfectly usable material already built into the structure. Parts of it were 90 years old and it also covers a Stuart-era basin.

The design used by the naval base and project partners DIO and Volker Stevin retained 97% of Victory Jetty and 50% of Princess Royal Jetty, with the removed concrete and steel crushed and set for recycling on future projects.

Care was taken to protect the seabed and seawall, and the wider project included networks to deliver the power created halfway across the base in the CHP, 14 solar-powered navigation towers in the harbour, and converters to transform the 50Hz electrical current to the 60Hz which ships operate on.

> **Both were complex schemes which propelled Portsmouth Naval Base forward to meet the challenge of supporting the biggest ships ever built for the Royal Navy and done in such a way which reflected our desire to have a positive impact on the existing environment and reduce our future carbon emissions.**

HM NAVAL BASE COMMANDER, COMMODORE JEREMY BAILEY ADC

6. SSE, Batteries arrival at SSE Renewables storage project at Salisbury marks key milestone for net zero ambitions

October 2023

www.sserenewables.com/news-and-views/2023/10/batteries-arrival-at-sse-renewables-storage-project-at-salisbury-marks-key-milestone-for-net-zero-ambitions/

Batteries arrival at SSE Renewables storage project at Salisbury marks key milestone for net zero ambitions

18 Oct 2023

SSE Renewables' first battery energy storage system (BESS) project has reached a significant milestone, with all 26 battery units successfully installed at the site in Salisbury, Wiltshire.

The 50MW project is being delivered in conjunction with Wartsila. The site is scheduled to be fully operational in early 2024.

Installation took place over a three-week period and was carried out by King Lifting. The battery units were carefully lowered down onto the concrete foundations in four modular sections via crane.

It follows the recent news that SSE Renewables has started construction of its second battery storage site – a 150MW project in Ferrybridge, West Yorkshire – with more projects set to be rolled out as part of the company's significant solar and battery pipeline.

"It's fantastic to have completed the installation of the battery units at Salisbury as we edge ever closer to energisation of our first battery storage project.

The team have worked incredibly hard to get to this point and we are looking forward to the site going live so that we can start to provide flexible, renewable energy to the Grid."

Richard Cave-Bigley SSE Renewables Solar & Battery Director

"All 26 batteries have been successfully installed on site and it's great to reach this milestone on the project.

Our next step is to reach energisation which should later this year, with the site due to be fully operational at the beginning of next year.

It's exciting to be involved on our first battery storage project and we are now very close to delivering SSE Renewables' first live battery energy storage system project."

Chris Lloyd SSE Renewables Senior Project Manager at Salisbury

SSE Renewables is progressing a 1.2GW secured pipeline of solar and battery projects across the UK and Ireland; with a further 1.3GW of other prospective sites under development.

These assets complement SSE's existing portfolio of other low carbon infrastructure such as wind and hydro.

The project at Salisbury will be SSE Renewables' first operational battery storage project, with a 150MW BESS site at Ferrybridge now also under construction and due for completion in 2024. The business has also received planning consent for battery storage projects at Fiddler's Ferry (150MW) and Monk Fryston (320MW).

SSE recently set out plans that could see the group invest up to £40bn in low carbon technology across the decade to 2031/32, with a fully funded £18bn five-year investment plan to 2027. In doing so SSE expects to create 1,000 new green jobs a year.

7. SEE, Solar and Battery Projects, Ferrybridge

www.sserenewables.com/solar-and-battery/projects/

Solar and Battery Projects

Our Solar and Battery projects provide grid scale solar and battery storage to support delivering the UK's net zero ambitions.

We currently have a secured pipeline of 1.2GW of solar and battery sites with a further 1.3GW of future projects under assessment and development.

You can find out some more details on our current projects below.

Ferrybridge Battery Project

Ferrybridge

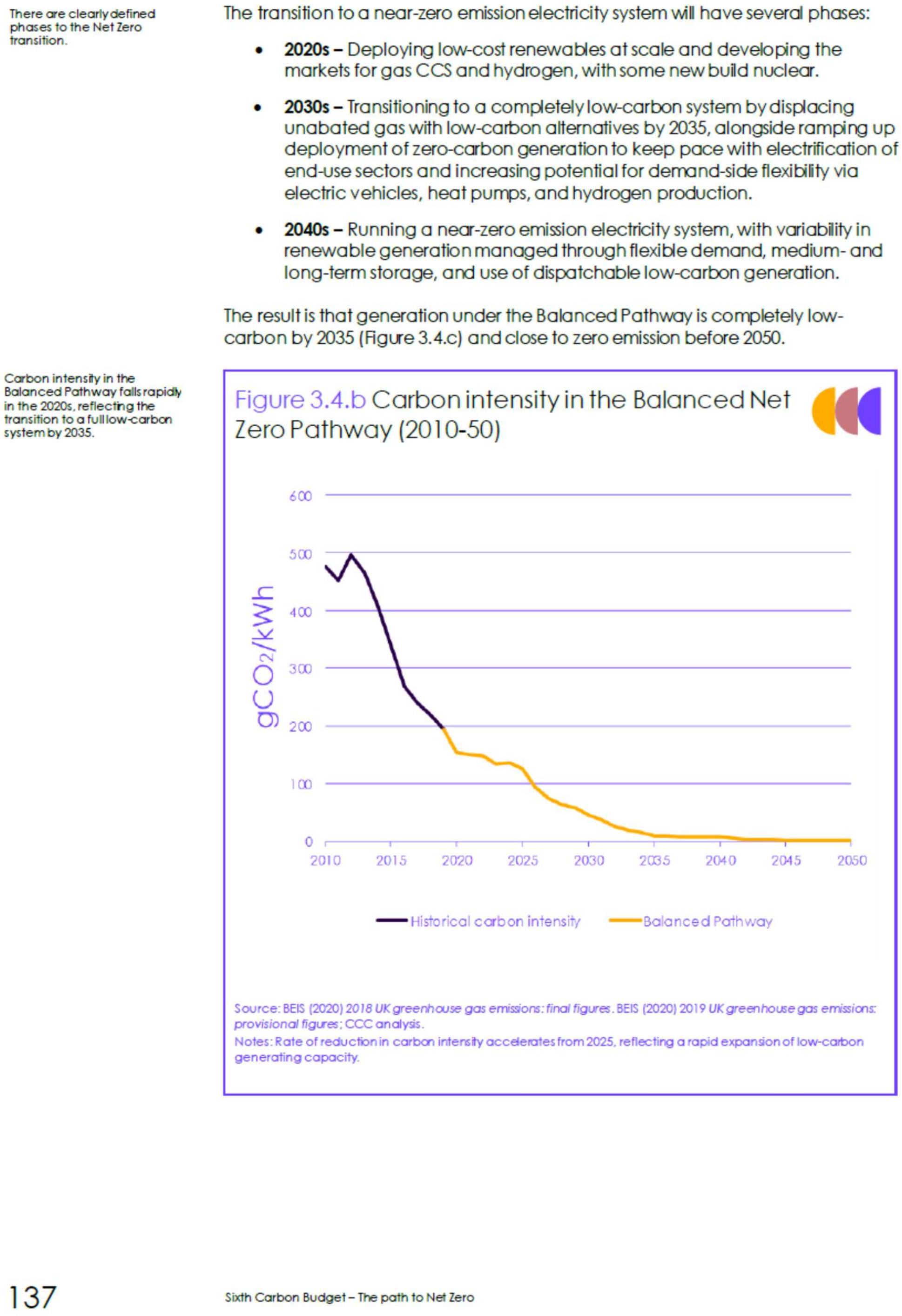
Ferrybridge is a legacy SSE coal power station which was closed in 2016 and SSE Solar and Battery are developing a 150MW / 300MWh battery energy storage system (BESS) site on the land in West Yorkshire.

Project construction is scheduled to begin this year.

8. CCC, Sixth Carbon Budget

December 2020

https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf



There are clearly defined phases to the Net Zero transition.

The transition to a near-zero emission electricity system will have several phases:

- **2020s –** Deploying low-cost renewables at scale and developing the markets for gas CCS and hydrogen, with some new build nuclear.
- **2030s –** Transitioning to a completely low-carbon system by displacing unabated gas with low-carbon alternatives by 2035, alongside ramping up deployment of zero-carbon generation to keep pace with electrification of end-use sectors and increasing potential for demand-side flexibility via electric vehicles, heat pumps, and hydrogen production.
- **2040s –** Running a near-zero emission electricity system, with variability in renewable generation managed through flexible demand, medium- and long-term storage, and use of dispatchable low-carbon generation.

The result is that generation under the Balanced Pathway is completely low-carbon by 2035 (Figure 3.4.c) and close to zero emission before 2050.

Carbon intensity in the Balanced Pathway falls rapidly in the 2020s, reflecting the transition to a full low-carbon system by 2035.

Figure 3.4.b Carbon intensity in the Balanced Net Zero Pathway (2010-50)

Source: BEIS (2020) *2018 UK greenhouse gas emissions: final figures*. BEIS (2020) 2019 *UK greenhouse gas emissions: provisional figures*; CCC analysis.

Notes: Rate of reduction in carbon intensity accelerates from 2025, reflecting a rapid expansion of low-carbon generating capacity.

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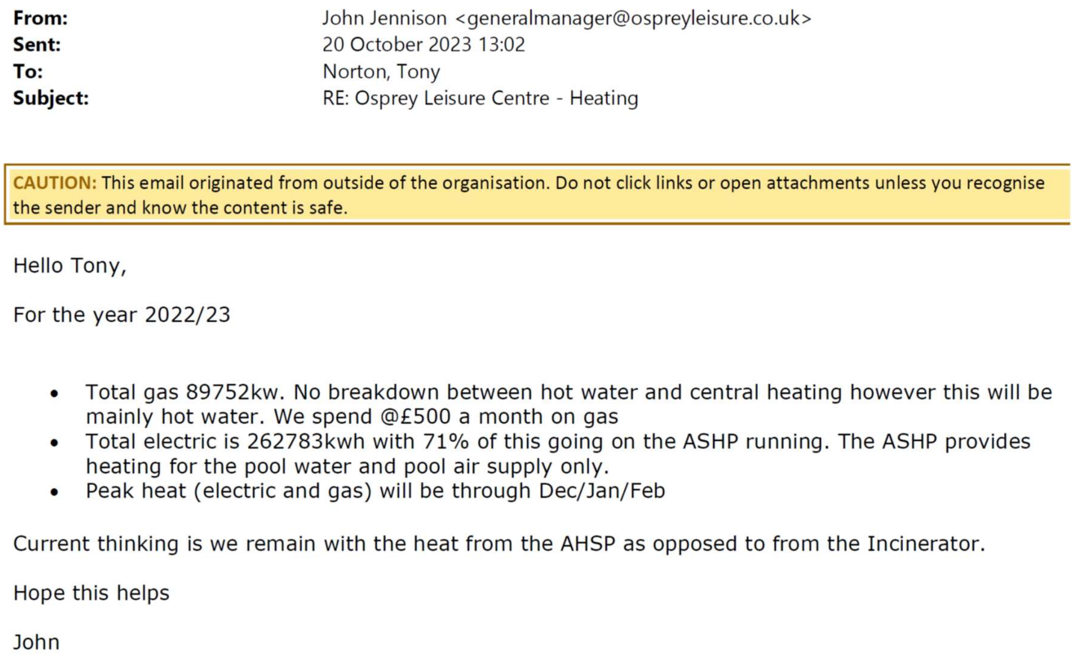
Sixth Carbon Budget – The path to Net Zero

9. Osprey Leisure Centre - email correspondence



From:	John Jennison <generalmanager@ospreyleisure.co.uk>
Sent:	20 October 2023 13:02
To:	Norton, Tony
Subject:	RE: Osprey Leisure Centre - Heating

CAUTION: This email originated from outside of the organisation. Do not click links or open attachments unless you recognise the sender and know the content is safe.

Hello Tony,

For the year 2022/23

- Total gas 89752kw. No breakdown between hot water and central heating however this will be mainly hot water. We spend @£500 a month on gas
- Total electric is 262783kwh with 71% of this going on the ASHP running. The ASHP provides heating for the pool water and pool air supply only.
- Peak heat (electric and gas) will be through Dec/Jan/Feb

Current thinking is we remain with the heat from the AHSP as opposed to from the Incinerator.

Hope this helps

John

10. BuroHappold Engineering, Connecting Existing Buildings to District Heating Networks

December 2016

https://www.usdn.org/uploads/cms/documents/161214_-_connecting_existing_buildings_to_dhns_-_technical_report_00.pdf

Note: Cover page below – full report included at the end of this Appendix 3

BUROHAPPOLD
ENGINEERING

Connecting Existing Buildings to District Heating Networks

Technical Report

035317

14 December 2016

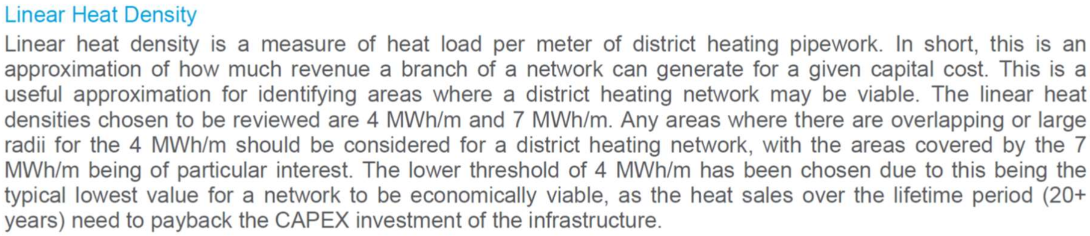
Revision 00

11. Scottish Government, Local Heat and Energy Efficiency Strategies

September 2019

https://www.gov.scot/binaries/content/documents/govscot/publications/research-and-analysis/2019/09/local-heat-energy-efficiency-strategies-phase-1-pilots-technical-evaluation-report/documents/local-heat-energy-efficiency-strategies-phase-1-pilots-technical-evaluation-report/local-heat-energy-efficiency-strategies-phase-1-pilots-technical-evaluation-report/govscot%3Adocument/local-heat-energy-efficiency-strategies-phase-1-pilots-technical-evaluation-report.pdf

Page 20



Linear Heat Density

Linear heat density is a measure of heat load per meter of district heating pipework. In short, this is an approximation of how much revenue a branch of a network can generate for a given capital cost. This is a useful approximation for identifying areas where a district heating network may be viable. The linear heat densities chosen to be reviewed are 4 MWh/m and 7 MWh/m. Any areas where there are overlapping or large radii for the 4 MWh/m should be considered for a district heating network, with the areas covered by the 7 MWh/m being of particular interest. The lower threshold of 4 MWh/m has been chosen due to this being the typical lowest value for a network to be economically viable, as the heat sales over the lifetime period (20+ years) need to payback the CAPEX investment of the infrastructure.

12.WSP, Enter Energy Network Detailed Feasibility Study Refresh

May 2017

Figure 2-20 HM Prison Heat Demand Profile

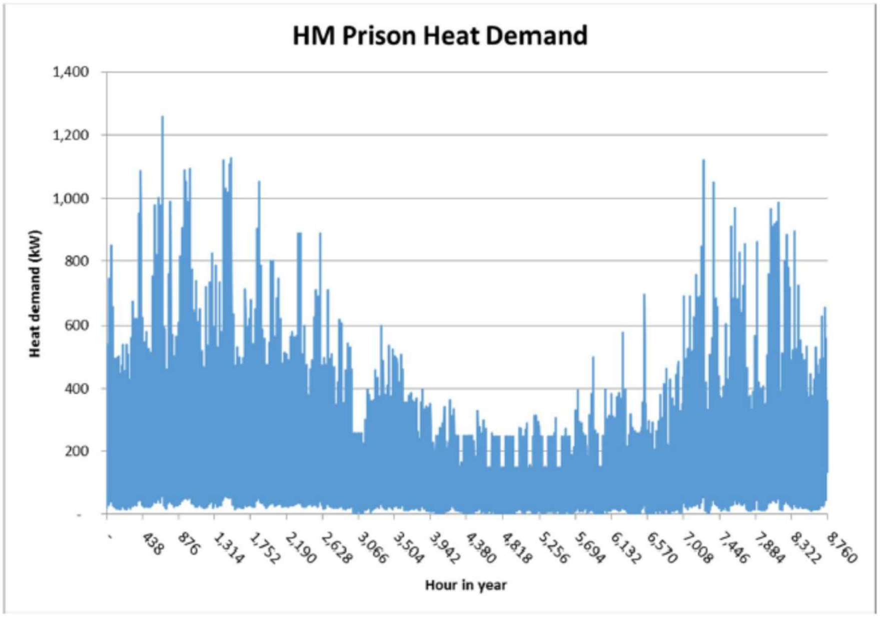
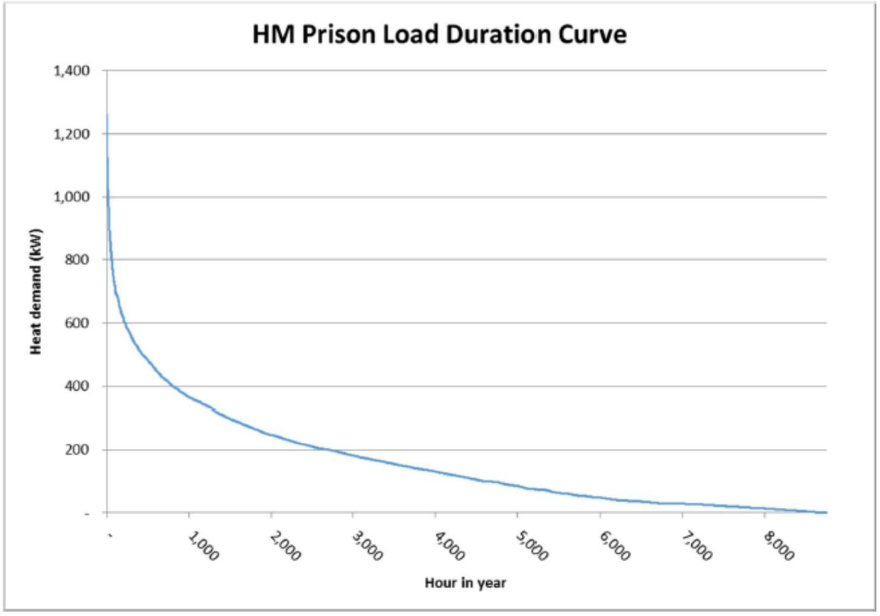


Figure 2-21 Load duration curve for HM Prison



13. DESNZ, Prices of fuels purchased by non-domestic consumers in the UK

September 2023

https://www.gov.uk/government/statistical-data-sets/gas-and-electricity-prices-in-the-non-domestic-sector

Table 3.4.2 Prices of fuels purchased by non-domestic consumers in the United Kingdom (including the Climate Change Levy) (Annual)

For notes see notes page

Blank cells represent years where data was not collected.

In the table r indicates revised data. An r in the date column indicates all data in the row has been revised.

Source: Department for Energy Security and Net Zero

Year	Electricity: Very Small (Pence per kWh)	Electricity: Small (Pence per kWh)	Electricity: Small/Medium (Pence per kWh)	Electricity: Medium (Pence per kWh)	Electricity: Large (Pence per kWh)	Electricity: Very Large (Pence per kWh)	Electricity: Extra Large (Pence per kWh)	Electricity: Average (Pence per kWh)	Gas: Very Small (Pence per kWh)	Gas: Small (Pence per kWh)	Gas: Medium (Pence per kWh)	Gas: Large (Pence per kWh)	Gas: Very Large (Pence per kWh)	Gas: Average (Pence per kWh)
2004	6.27	5.34	4.27	3.82	3.62	3.20		4.16	1.553	1.396	1.245	1.057	0.994	1.254
2005	6.97	6.18	5.62	4.92	4.53	4.18		5.15	1.920	1.864	1.733	1.515	1.471	1.694
2006	8.45	7.37	7.23	6.49	6.18	5.46		6.69	2.453	2.374	2.183	1.989	1.608	2.112
2007	9.80	8.18	7.50	6.72	6.24	6.09	5.26	7.10	2.803	2.437	1.959	1.628	1.273	1.954
2008	10.68	9.13	8.32	7.64	7.33	7.55	6.51	8.20	3.269	2.677	2.358	2.225	2.068	2.468
2009	12.19	10.44	9.49	8.54	8.29	8.23	7.18	9.36	3.641	2.666	2.321	2.056	1.532	2.417
2010	12.30	10.11	8.51	7.51	6.88	6.73	6.69	8.53	3.259	2.411	1.949	1.781	1.576	2.124
2011	12.10	10.20	8.79	7.91	7.39	7.17	7.05	8.55	3.434	2.602	2.254	2.137	2.044	2.394
2012	12.58	10.74	9.47	8.59	8.38	7.94	8.10	9.25	4.066	3.020	2.680	2.433	2.150	2.847
2013	12.99	11.28	10.03	9.17	9.14	8.93	8.54	9.78	4.229	3.246	3.007	2.654	2.304	3.073
2014	13.82	11.85	10.59	9.62	9.56	9.29	9.04	10.28	4.470	3.270	2.908	2.411	2.086	3.025
2015	13.38	12.22	10.92	10.04	9.78	9.54	9.24	10.53	4.304	2.893	2.573	2.080	1.791	2.752
2016	12.75	12.08	10.86	10.01	9.83	9.66	9.35	10.54	4.051	2.462	2.207	1.719	1.416	2.373
2017	14.00	12.60	11.00	10.49	10.44	10.24	9.21	10.92	3.962	2.236	2.083	1.628	1.526	2.168
2018	15.48	13.72	12.19	11.53	10.85	10.37	9.88	11.73	4.037	2.443	2.371	1.893	1.886	2.406
2019	16.71	14.89	13.51	12.56	11.86	11.34	11.39	12.90	4.515	2.698	2.425	1.913	1.678	2.484
2020	17.16	15.43	14.33	13.22	12.92	11.82	11.77	13.48	4.873	2.709	2.322	1.834	1.503	2.470
2021	17.99	16.25	15.75	14.30	14.08	13.84	14.18	15.08	4.842	3.012	3.048	2.486	2.592	3.073
2022	23.84	20.09	23.85	20.21	19.30	20.10	19.81	20.86	7.417	4.612	4.825	4.809	5.195	5.302

14. Cruisemapper - Portland web page

https://www.cruisemapper.com/ports/isle-of-portland-port-8996?month=2023-10#schedule accessed 14th October 2023. Note: The functionality of this web site has changed since accessed

Isle of Portland (Weymouth, Dorset England)

CRUISE PORT SCHEDULE, LIVE MAP, TERMINALS, NEWS

Rating: **4 of 5 stars**

Region

Ireland - UK - British Isles

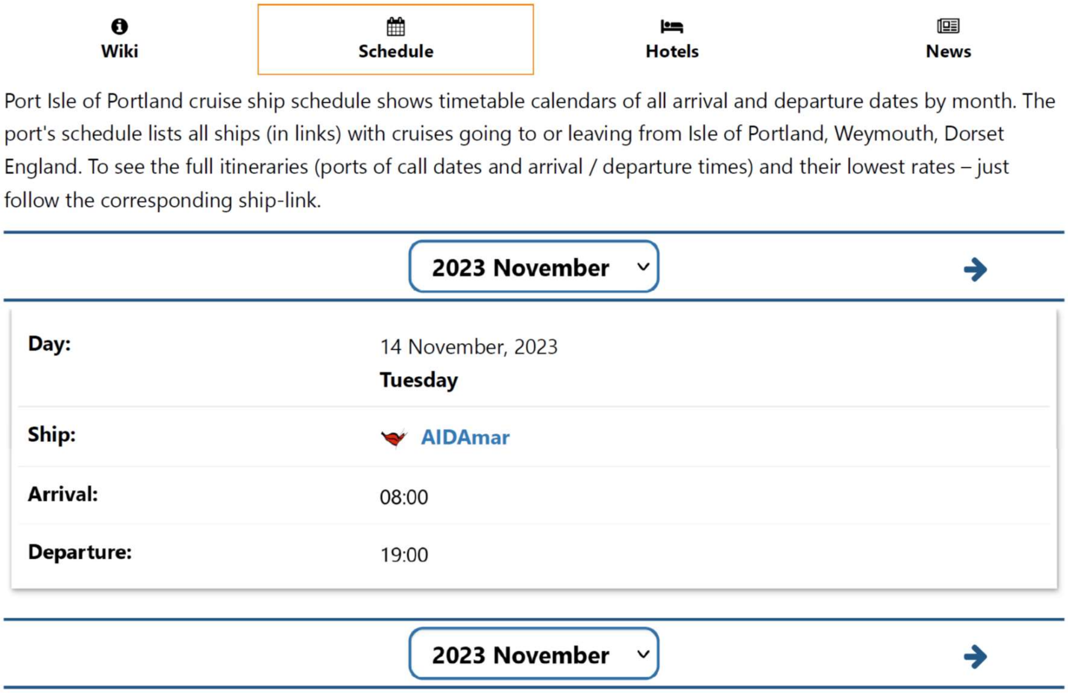
Local Time

2023-11-14 07:55

54°F 12.4°C

Strong breeze 12.2 m/s

56 °F / 14 °C
49 °F / 10 °C



Port Isle of Portland cruise ship schedule shows timetable calendars of all arrival and departure dates by month. The port's schedule lists all ships (in links) with cruises going to or leaving from Isle of Portland, Weymouth, Dorset England. To see the full itineraries (ports of call dates and arrival / departure times) and their lowest rates – just follow the corresponding ship-link.

Day:	14 November, 2023 **Tuesday**
Ship:	**AIDAmar**
Arrival:	08:00
Departure:	19:00

BUROHAPPOLD
ENGINEERING

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Technical Report

035317

14 December 2016

Revision 00

Revision	Description	Issued by	Date	Checked
00	Technical Report – Approved by GLA	MD	14-Dec-2016	AY, SW

This report has been prepared for the sole benefit, use and information of Greater London Authority for the purposes set out in the report or instructions commissioning it. The liability of Buro Happold Limited in respect of the information contained in the report will not extend to any third party.

author	**Dr Mark Dowson**
date	**14 Dec 2016**
approved	**Alasdair Young**
signature	
date	**14 Dec 2016**

Contents

Appendix A – CNCA Replicability Study

Appendix B – DHW and secondary network design guidance

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Glossary

ACH	Air change per hour
AHU	Air handling unit
BH	BuroHappold
BSRIA	Building Services Research and Information Association
Capex	Capital expenditure
CERT	Carbon Emissions Reduction Target
CIBSE	Chartered Institute of Building Services Engineers
CIGA	Cavity Insulation Guarantee Agency
CNCA	Carbon Neutral Cities Alliance
DECC	Department of Energy and Climate Change
DEMaP	Decentralised Energy Master Planning programme
DG	Double glazing
DH	District heating
DHN	District heating network
DHW	Domestic hot water
ECO	Energy Company Obligation
EEC	Energy Efficiency Commitment
EPC	Energy Performance Certificate
ESP-r	Environmental Systems Performance research
EST	Energy Saving Trust
FCU	Fan coil unit
FENSA	Fenestration Self-Assessment Scheme
GIS	Geographic information system
GLA	Greater London Authority
HEED	Homes Energy Efficiency Database
HIU	Heat interface unit
HVAC	Heating, ventilation and air conditioning
LSOA	Lower layer super output area
LTHW	Low temperature hot water
MSOA	Middle layer super output area
ONS	UK Office of National Statistics
OS	Ordnance Survey
rdSAP	Reduced Standard Assessment Procedure
SAP	Standard Assessment Procedure
TRV	Thermostatic radiator valves
TRY	Test reference year
VAT	Value Added Tax
VOA	Valuation Office Agency
VRF	Variable refrigerant flow
WP	Work Package

Executive Summary

Overview

This Greater London Authority (GLA) project has been funded by the Carbon Neutral Cities Alliance (CNCA); a collaboration of international cities committed to achieving aggressive long-term carbon reduction goals, cutting greenhouse gas emissions by at least 80% by 2050.

The study investigates the opportunity, technical requirements and cost effectiveness of connecting existing non-communally heated buildings in London to district heating networks. It then goes on to investigate what further retrofit measures are required to buildings to enable heat networks to operate at supply temperatures of 70 °C and below, also termed fourth generation district heating networks. This reduction in temperature enables the cost-effective integration of renewable and secondary (environmental and waste) heat sources into heat networks in order to decarbonise their heat supply.

Typology assessment and spatial mapping

The London building stock has been represented by 32 typologies, covering houses, low rise flats, high rise flats, offices and retail buildings. The study captures 92.5% of all properties in London. These properties cover 95.4% of domestic properties (i.e. all buildings except those already with communal heating, or those with details not recorded in the property database) and 72.1% of all non-domestic buildings, excluding district heating ‘anchor loads’, which are already suitable for connection to district heating networks. Due to the inherent diversity of non-domestic buildings it was decided that the typologies in the study should cover office and retail uses only.

Indicative connection strategies were developed for retrofitting the chosen typologies so that they could be connected to district heating networks. The typologies included houses, low-rise flats (purpose built and converted) and high rise flats, as well as small and large office and retail buildings on the high street.

The cost to connect existing gas centrally heated domestic buildings was found to vary from £66/m^2 to £87/m^2 equating to between £4,600 and £6,800 per unit, based on the architectures assessed. For commercial buildings this varied from £15/m^2 to £82/m^2. The cost to connect existing electrically heated buildings was higher, ranging from £112/m^2 to £141/m^2 for domestic buildings, equating to between £7,700 and £11,000 per unit. For commercial buildings this varied from £30/m^2 to £191/m^2. By comparison, the cost to undertake an energy efficiency retrofit to a low efficiency solid walled dwelling was estimated to be £106/m^2 to £159/m^2. This works would involve meeting Part L1B insulation standards for improved U-values, new windows and halving air infiltration on hard-to-treat dwellings. Going deeper, a retrofit with Passivhaus U-values, halved infiltration and triple glazing was found to be up to £354/m^2.

Cost effectiveness study

The assessment of medium or high cost effectiveness for connection to district heating was determined based upon whether a 30 or 15 year payback, respectively, could be achieved across a wide range of indicative heat retail prices (£25/MWh to £115/MWh) compared to a counterfactual case (e.g. gas boiler or electric heating). This allowed the costs of retrofitting the various typologies to be compared against each other to determine their relative cost effectiveness, helping to inform district heating pre-feasibility studies around the cost and opportunity for retrofitting existing buildings for connection to local heat networks as part of a strategic decarbonisation plan.

The properties found to be the most cost effective in relation to connecting to district heating networks were low and medium efficiency electrically heated high-rise flats, low-rise flats and houses, as well as large offices which are electrically heated. These types of buildings represent 8.7% (330,000) of existing buildings in London. The LSOAs with the highest densities of these properties can be found in Tower Hamlets, Westminster, Hammersmith & Fulham and Southwark. These boroughs are relatively central suggesting that the greatest opportunities for retrofitting these types of buildings for connection to district heating are in the denser, more central London boroughs.

Properties found to be of medium cost effectiveness for district heating include low and medium efficiency gas heated high and low rise flats, houses and large retail buildings. Collectively the properties falling into the high and medium cost effective categories represent up to 81.7% of the stock (3,100,000 buildings). Areas with the highest density of medium cost effective buildings include Tower Hamlets, Westminster, Hounslow, Southwark, Islington and Wandsworth. Most of these boroughs are relatively central, with Wandsworth and Hounslow also featuring a relatively high proportion of flats in their stock.

In terms of whole life costs compared to the counterfactual case, for gas heated flats it was found that high cost effectiveness can only be achieved up to district heating retail prices of £35/MWh, with medium cost effectiveness achieved up to £60/MWh. If gas prices increased by 20%, high cost effectiveness can be achieved at district heating retail prices of £50/MWh, with medium cost effectiveness up to £70/MWh. If gas prices increased by 50%, high cost effectiveness can be achieved at district heating retail prices of £65/MWh, with medium cost effectiveness up to £85/MWh. Further scenarios to improve cost effectiveness include reductions in capital cost driven from the market, or policy driven e.g. supported by additional funding leveraged through Carbon offset payments, ECO or other grants.

In terms of subsidies for district heating retrofit, at a fixed district heating heat retail of £60/MWh, it was shown that with capital funding set at a level of 20% to 40% all low and medium efficiency electric domestic properties can achieve high cost effectiveness at £60/MWh. With capital funding reaching 60% low and high rise gas heated flats can achieve high cost effectiveness. At this level of funding, low and medium efficiency houses can also achieve medium levels of cost effectiveness too.

What this analysis therefore conveys is that with relatively small grant subsidies the overall cost effectiveness of district heating retrofit in electric heated properties increases, and with relatively larger grant subsidies there is potential to unlock a greater proportion of the gas heated building stock. To provide the greatest benefit, these grant subsidies (e.g. leveraged through Carbon offset taxes or other policy measures) should be available for district heating retrofit in areas with a high likelihood for developing district heating networks as a cost effective way to catalyse the decarbonisation of buildings, then in areas where district heating networks are not as likely to be developed then whole house energy efficiency and building level decarbonisation of heating supply solutions should be considered.

The choice of criteria to determine cost effectiveness was based upon guidance for the economic evaluation of heat supply from the London Plan's Sustainable Design and Construction SPG and the Energy Planning Guidance. This approach was selected to identify the most promising building typologies for retrofit, their relative abundance and cost compared to other typologies, as well as their spatial spread across London, but does not look to predict uptake. Understanding the likely level of uptake is complex and requires more detailed study across a range of factors, including consumer preferences and proposition for heat customers, and not just the whole life cost of heat. Other issues such as affordability, carbon emissions, compatibility with local energy system, finance sources, alternative investments, comfort, space take, disruption, tenure and opportunities for installing district heating alongside other works (e.g. kitchen replacement, home extension) would be just some of the factors to be considered.

Pilot study

In a pilot study, a methodology was developed to determine the relative cost effectiveness of district heating retrofit across the 32 typologies at a higher resolution of detail for LSOAs in Islington, Enfield, Sutton and Camden. The analysis of the pilot study areas found that Islington and Enfield had the highest densities of high cost effective buildings, e.g. electrically heated properties, whereas Sutton and Camden consisted primarily of gas heated properties of medium cost effectiveness.

The proof of concept model showed good potential for identifying architectures of high cost effectiveness, e.g. high rise flats and offices provided data at individual property level could be acquired. More data on the thermal efficiency of properties should be gathered at Census output area to develop the pilot study mapping method further into a tool for energy masterplanning capable of inputting into feasibility studies. The type of data to be gathered includes wall construction e.g. at local authority level, load/energy consumption data and/or on-site survey observations of heating system type.

4th Generation district heating

To assess the implications of third and fourth generation district heating, load modelling for each typology demonstrated that as district heating supply temperature reduces, so does the percentage of annual energy demand capable of being met through the heat network. In a district heating network with a supply temperature of 70 °C approximately 99% of annual energy demand can be met. At 60 °C this drops to between 96%-99%, and at 50 °C this drops further to between 86%-98%. At a supply temperature of 40 °C this can be as low as 50%-92% depending on the efficiency of the existing property to be supplied. District heating systems can operate with variable supply temperatures and during cold weather periods this strategy is often employed.

Using low temperature, low carbon heat sources, such as waste or environmental heat with heat pumps, for the majority of the year, with peak loads met by gaseous or liquid fuels, would be a possible strategy to maintain comfort levels for consumers while minimising the overall carbon intensity of heat supplied. It was identified that through the use of larger radiators it was possible to meet 100% of heating demand in a domestic property at supply temperatures from 70 to 50 °C with minimal impact on internal space due to the larger radiators. Often a larger surface area radiator can be fitted in the same wall area as the existing radiator. By comparison, with 40 °C supply temperatures larger radiators alone would be an impractical solution, because of the number and size of additional radiators required.

For a district heating network with a 40 °C supply temperature, low cost measures to improve air tightness alone were estimated to only increase the percentage of annual energy demand from approximately 60% to 70%, meaning that an impractical number of additional radiators would be needed to provide the level of thermal comfort required. By comparison, an energy efficiency upgrade with insulation, equivalent to Building Regulations Part L1B standards for improved U-values, new windows and air tightness improvements, were shown to increase this to 95%. These energy efficiency works add further costs of £71/m^2 to £161/m^2 to the district heating retrofit, but they allow larger emitters (or variations in heat network temperature) to meet the remaining energy demand for the building.

It was estimated that several typologies were still cost effective, at the lower end of the indicative heat retail price range, even after taking account of the additional costs for building fabric upgrades, larger radiators and DHW systems. Principally, these typologies were the large electrically heated offices, as well as low efficiency, electrically heated domestic properties. Regarding domestic hot water, it may be possible to install point-of-use heaters or an electric coil in the calorifier or hot water tank, if present, to provide additional heat as necessary. For high-rise flats DHW can also be provided through a centralised approach.

Conclusions

In terms of the wider roll out of district heating in London, it is likely that start-up network locations would still be dictated by new-build developments and existing district heating anchor loads. This study serves to identify an additional layer of existing buildings that can be connected to local networks as they expand and grow in their later phases and contribute to the decarbonisation of building stock at a neighbourhood or district level.

The LSOA mapping has allowed areas containing the most cost effective typologies to be located across London. The methodology for pilot study mapping then allows a view with greater resolution to be developed for area-by-area strategies to be investigated and inform future district heating network feasibility studies. It is likely that local authority housing estates would be the most straight-forward to retrofit due to simpler ownership and control; albeit subject to consumer preferences and maintenance considerations. Conservation areas may also prove to be suitable for retrofitting for district heating as they offer a potentially low carbon solution in low efficiency dwellings where building fabric upgrade measures are restricted and/or expensive (e.g. external/internal solid wall insulation).

Where there are existing or planned district heating networks, retrofitting existing buildings to them offers a cost effective solution to decarbonise their heat supply and create low and zero carbon neighbourhoods. From a consumer point of view, owners of electrically heated properties may be more receptive to a district heating retrofit than those in properties heated by natural gas, due to the high costs of electricity compared to gas and the potential for improved comfort and convenience e.g. on-demand high pressure hot water for showering and free space in former hot water tank cupboards. In locations where district heating networks are not expected to be built, energy efficiency measures together with alternative building level low carbon heat supply systems, such as heat pumps or green gas, will be required to decarbonise their heat supply. The most optimal strategy for decarbonising heat supply will vary depending on the part of the city that is considered; it is likely to require a combination of heat network connections, energy efficiency measures and a mix of heat generation systems. Factors affecting the choice will depend on the nature of the building stock, the mix of property types and their heat demand density and what the local infrastructure can sustain, e.g. available electrical network capacity and heat network capacity.

1 Introduction

1.1 Context

This Greater London Authority (GLA) project has been funded by the Carbon Neutral Cities Alliance[1] (CNCA) Innovation Fund. The CNCA is a collaboration of international cities committed to achieving aggressive long-term carbon reduction goals, cutting greenhouse gas emissions by at least 80% by 2050.

The CNCA aim to address what it will take for leading international cities to achieve these ambitious levels of emission reductions and how they can work together to meet their respective goals more efficiently and effectively. The long-term objective of the CNCA Innovation Fund is to support projects that will build a portfolio of tested tools, for cities to use to achieve their deep carbon reduction goals.

1.2 Background

The previous Mayor's Climate Change Mitigation and Energy Strategy[2], published in 2011, sets a target to reduce London's CO_2 emissions by 60% of 1990 levels by 2025 and by 80% by 2050. It also includes a target to supply 25% of London's energy demand from local decentralised and existing sources by 2025. The present Mayor has set a new more ambitious target for London to actually be a zero carbon city by 2050.

To support the achievement of these targets, accommodate projected levels of population growth and understand how London's energy systems need to evolve and grow, the Greater London Authority (GLA) has developed the Scenarios to 2050: London Energy Plan[3] - a spatial plan of London's energy demand, supply and distribution infrastructure requirements through to 2050. The Plan aims to identify the most cost effective integration of heat and electricity infrastructure to accommodate London's growing population whilst ensuring energy supply is capable of being low and ultimately zero carbon, secure, resilient and affordable.

As the Mayor identifies the most cost effective ways to decarbonise neighbourhoods and districts, integrated programmes will look to reduce demand through retrofitting the fabric of existing buildings whilst simultaneously decarbonising their heat supply. One option for decarbonising heat supply is the use of district heating networks. Many heat networks use low carbon sources such as natural gas fired combined heat and power (CHP) or energy from waste. In time in order to meet the Mayor's zero carbon ambitions these networks will need to transition to zero carbon heat sources.

To efficiently use renewable and secondary heat sources, previous research[4] has shown that network supply temperatures will need to drop from the traditional 90 °C - 95 °C down to around 70 °C. This reduction in temperature is part of a move towards so called Fourth Generation District Heating Networks which is emerging in other European countries where district heating has a high market share[5]. Network temperatures as low as 40 °C could be possible with supplementary heating for domestic hot water supply.

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[1] Carbon Neutral Cities Alliance website: http://usdn.org/public/page/13/CNCA

[2] Delivering London's Energy Future https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/Energy-future-oct11.pdf

[3] Scenarios to 2050: LEP: https://www.london.gov.uk/what-we-do/environment/energy/scenarios-2050-london-energy-plan

[4] London's zero carbon energy resource – secondary heat, Greater London Authority 2013 https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/031250%20GLA%20Secondary%20Heat%20-%20Summary%20Report_0.pdf

[5] Henrik Lund et al. 4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems. Energy 2014; 68:1-11

These lower temperature heat networks are necessary to enable transition away from fossil fuels (e.g. natural gas fired combined heat and power (CHP) units) to renewable and secondary heat (environmental and waste heat) sources.

The project will look at two fundamental aspects in this transition, covering:

- The technical feasibility and cost effectiveness of connecting existing buildings to district heating; and,
- To what extent the existing building stock and its secondary heating systems need to be retrofitted to accommodate lower supply temperatures. The focus is to look at the technical feasibility and cost effectiveness of retrofitting district heating across a range of existing building typologies in London so that the opportunity for future growth of district heating networks beyond already communally heated buildings can be assessed.

1.3 Objectives and outcomes

The project is intended to complement the GLA's existing heat mapping work and support the development of future work streams within the Energy for Londoners[6] programme emerging from the London Energy Plan, and specifically the heat element of this.

The objectives of this project, as defined by the GLA are to:

- Understand the spatial opportunity as well as the technical and financial issues and barriers associated with retrofitting London's existing building typologies that are currently not communally heated so that they could be supplied by a district heating network.
- Understand the optimum level of building energy performance and secondary heating system design that is required in existing buildings to allow lower temperature, and ultimately 4th Generation, district heating networks to supply their space and domestic hot water heat demand whilst maintaining the required levels of thermal comfort for their inhabitants.
- Develop a generic methodology and approach, by working with four partner CNCA cities in North America: Minneapolis, Seattle, Vancouver and Washington DC; that can then be used by other cities in the CNCA Network to ensure the learning and solutions generated by this project are as replicable as possible for CNCA member cities, including North American and European ones.

Expected outcomes of the project are:

- London will have an assessment of how best to retrofit existing residential and non-residential building typologies that are not currently communally heated, so that they can be supplied by district heating networks. This will include a cost effectiveness study, created from the breakdown of the associated costs and technical challenges, for each of the identified building typologies.
- London will have a graphical representation of the cost effective opportunities for retrofitting its existing building typologies so that they can be connected to district heating networks. In addition, up to four areas/neighbourhoods will be identified as potential pilot areas, due to their existing building typologies and proximity to existing or planned heat networks, and more detailed plans for their potential retrofit for connection to district heating will be developed.

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[6] Energy for London 2016-2019, https://www.london.gov.uk/md1542-energy-london-2016-2019

- London will understand the issues and the optimum level of building retrofit, including design of secondary heating system, required to improve a building's energy performance so that it can be supplied by lower temperature, and ultimately Fourth Generation District Heating Networks (4G-DHNs), without negatively affecting the thermal comfort of its inhabitants.
- London, the Carbon Neutral Cities Alliance and its member cities will have a methodology for making informed and evidence based decisions on the cost effectiveness of retrofitting existing buildings that are not communally heated so that they could be supplied by a district heating network.
- The Carbon Neutral Cities Alliance and member cities will have a comprehensive understanding of the levels of building energy efficiency and associated secondary heating system design required to allow building typologies connection to lower temperature and ultimately 4G-DHNs.

1.4 University partners

Alongside BuroHappold, the GLA and the CNCA partner cities, the project team also included input from Strathclyde University's Energy Systems Research Unit (ESRU) on energy modelling aspects (predominantly feeding into Chapters 6,7 and 9) and University College London's (UCL) as an independent reviewer.

Input from Strathclyde University was led by Professor Joseph Clark, Dr Nicolas Kelly, Dr Jon Hand and Andrew Cowie. Collectively they have expertise on modelling and monitoring of building energy performance, renewable energy technologies, human well-being and new approaches to mitigate adverse environmental impacts. A major aspect of their current work involves the development and dissemination of software tools for energy systems simulation, and support for the application of these tools in design, research, teaching and policy-making contexts.

The energy modelling approach adopted for this project was the Strathclyde University ESP-r (Environmental Systems Performance research) building energy modelling tool, developed through the ESRU research unit. ESP-r explicitly calculates all of the energy and mass transfer processes underpinning building performance and was used to simulate the environmental performance of domestic and non-domestic building typologies developed throughout this study.

The independent review was conducted by Dr Francis Li, appointed through UCL Consultants Ltd. Dr Li is a Research Associate at the UCL Energy Institute, focusing on energy economic modelling and energy policy. His portfolio of projects includes both academic research for the Research Councils UK energy programme and strategic analysis for major industry stakeholders (including UK Energy Technologies Institute and National Grid). He has worked with BuroHappold as peer reviewer on other recent projects and brings a critical but collaborative approach.

2 Methodology

2.1 Deliverables

In the project brief, a number of deliverables were defined by the GLA, as summarised below:

- **Output 1a**: Generic list of existing residential and non-residential building typologies and assessment of issues and requirements for how each of these building typologies could be retrofitted to have their heat supplied by a district heating network. In the context of this project, existing buildings are properties that currently do not have their heat supplied by communal or district heating networks.
- **Output 1b**: Spatial representations, using a mapping system compatible with GLA software such as GIS, of where each of these identified building typologies are mainly represented across London.
- **Output 2**: A generic list of building typologies, influenced by the project's partner cities from the CNCA network: Minneapolis, Seattle, Vancouver and Washington DC; that allows an initial high-level assessment of what the opportunity is for retrofitting a city, town, district or neighbourhood's existing building stock so that its heat could be supplied by a district heating network.
- **Output 3**: A detailed cost effectiveness study looking at the technical requirements and issues as well as the financial costs associated with cost effectively retrofitting each of London's commonest building typologies for connection to a district heating network.
- **Output 4a & 4b**: A map illustrating the prioritised areas in London for district heating networks and the opportunity for retrofitting the existing building typologies in each of these prioritised areas for cost effective connection to district heating systems. Further mapping of four neighbourhoods as potential pilot projects.
- **Output 5**: An assessment that establishes the cost optimum level of energy performance that a building retrofit needs to achieve to allow the supply temperature in district heating networks to be reduced to between 40 °C and 70 °C along with a recommended operating regime for the building's secondary heating system and its domestic hot water options.
- **Output 6**: A short report, including context and methodology that can be used by CNCA cities to undertake a high-level assessment of the opportunity that exists in their city for retrofitting existing buildings for connection to district heating networks.
- **Output 7**: A Final Report that explains what has been done, compiles the outputs, how to use it and summarises the opportunities that this represents for cities.

2.2 Work Packages

In order to meet the deliverables, the research was split across five core work packages. Figure 2-1 illustrates the how the activities associated within each work package feeds into the deliverables for the project. As shown, the order of the work packages broadly follows that of the deliverables, with a period of inception and data gathering at the start of the project. During the project, a combined progress report was issued to the GLA covering work packages 1 and 2. A second interim report was issued covering work packages 3 and 4. Regular progress meetings were held with the GLA to agree assumptions and review findings. Teleconference calls were also held with a work group of CNCA cities with leaders from Minneapolis, Seattle, Vancouver and Washington DC.

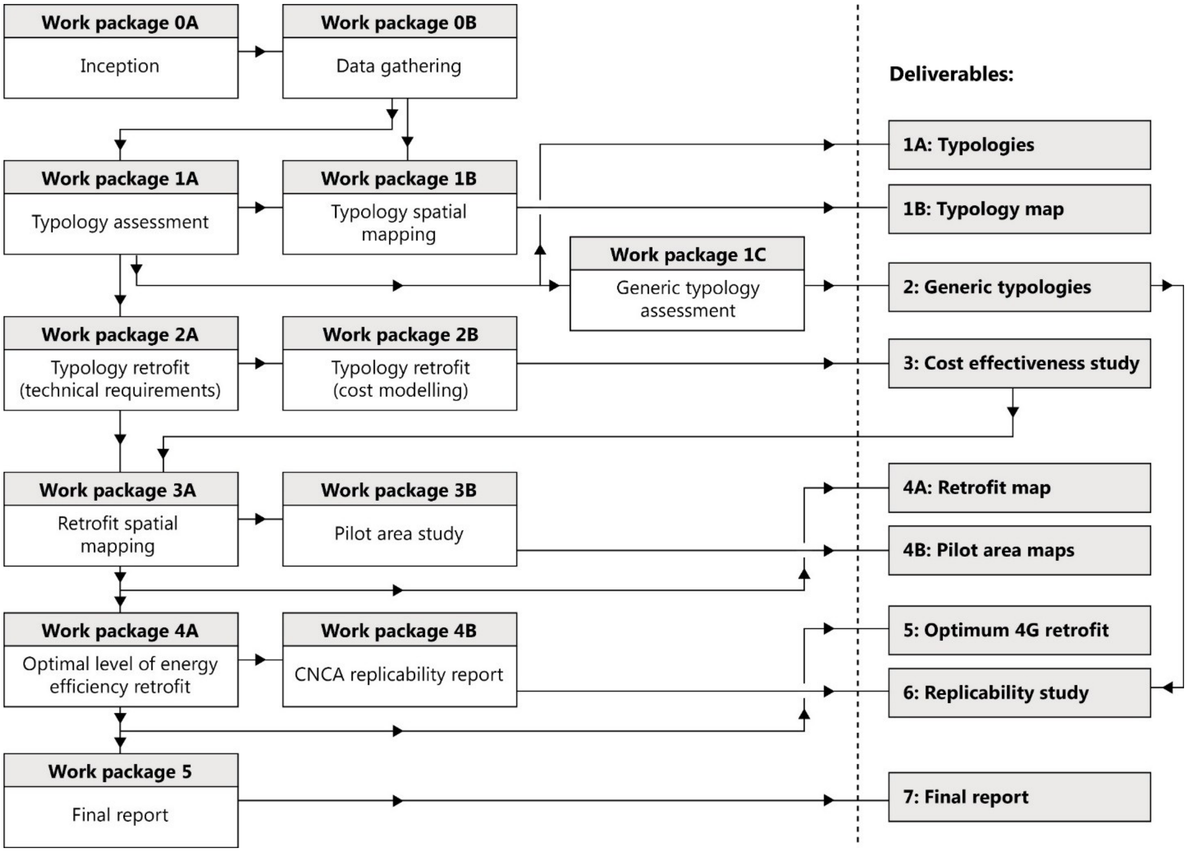


Figure 2-1 Overview of work packages and associated deliverables.

2.3 Report structure

An overview of technical report chapters with reference to the Work Package (WP) they cover is as follows:

- **Chapter 3: Building typology assessment (WP1A).** This is the first stage of the project and is about developing a representative set of building typologies for existing domestic and non-domestic building stock in London. Following review and agreement with the GLA, the London building stock has been represented by 18 domestic and 14 non-domestic typologies, based on a simplified balance between representing the range of thermal properties and architectural characteristics and having a manageable number of typologies within a defined budget. Datasets were then analysed to determine the number of buildings which fall within each typology at lower layer super output area (LSOA) level.

- **Chapter 4: Building typology spatial mapping (WP1B).** The next chapter presents the typology assessment data in spatial maps for London that illustrate geographically how the identified building typologies are represented across London's existing building stock. For the GLA, this would allow the data to be compared with maps showing London's prioritised areas for district heating networks and so enable the identification of areas where retrofitting of existing building stock for connection to district heating networks would support the development and growth of networks in those prioritised areas.

- **Chapter 5: Building typology retrofit - technical requirements (WP2A).** With the typologies defined, this chapter provides a high-level assessment of how each of these typologies could be retrofitted so that they can be connected to a district heating network, either immediately or sometime in the future. These retrofit assessments consider the various types of heating systems that there could be in each of these existing building typologies, including wet and electric systems, and assess how these may be retrofitted to enable them to have their heat supplied by a district heating network. Illustrative connection diagrams are provided with discussion regarding challenges and further considerations such as domestic hot water production.

- **Chapter 6: Building typology retrofit - cost modelling (WP2B).** This chapter provides an estimation of the financial cost for retrofitting each building typology for connection to a district heating network. It should be noted that the scope of the costing exercise only includes costs from the property boundary and excludes the capital costs associated with extending the wider district heating network infrastructure to the property boundary. All assumptions and cost reference figures are set out. To provide conservative capital cost figures, opportunities for shared districting heating connections for adjacent single properties are not considered.

- **Chapter 7: Cost effectiveness study and retrofit spatial mapping (WP3A).** In this chapter, load modelling results are presented illustrating the proportion of heat demand for each typology that can be met through a district heating connection, at heat supply scenarios of 70 °C, 60 °C, 50 °C and 40 °C. Cost effectiveness is then assessed, based upon payback calculations baselined against a counterfactual operating cost scenario (e.g. as boiler), allowing the cost effectiveness of the 32 identified typologies to be compared. Findings from the cost effectiveness study are visualised geographically on maps for London at LSOA level, with results overlaid against the London Energy Plan district heating opportunity areas.

- **Chapter 8: Pilot study (WP3B).** Based upon the outcomes of the cost effectiveness study, further more detailed cost effectiveness studies have been carried out for four pilot areas in London. The four pilot areas, each consist of two adjacent LSOAs in Islington, Sutton, Enfield and Camden. These were selected in discussions with the GLA following a review of the spatial retrofit assessment and a knowledge of, existing and potential heat networks in London. Results are presented at Census output area, with existing and proposed networks from the London Energy Plan overlaid, to better understand where existing non-communally heated buildings could be cost effectively retrofitted.

- **Chapter 9: Optimum level of energy efficiency retrofit (WP4A):** The final study for London in this report is a review of the cost optimum level of energy efficiency retrofit to support the implementation of 4th generation district heating networks with supply temperatures from 70 °C to 40 °C. The study sets out how the proportion of annual energy demand met through district heating can be increased through a fabric energy retrofit to Building Regulations standard and beyond. Cost modelling covering all typologies is undertaken for the associated retrofit measures and recommendations for operating regimes of the building's secondary heating system and its domestic hot water options are discussed.

- **Appendix 1: CNCA replicability study (WP1C & WP4B):** Using the knowledge gathered, a short report, has been produced to increase the replicability of this London based study for the CNCA partner cities. A generic typology assessment is carried out based on initial datasets provided for Minneapolis, Seattle, Vancouver and Washington DC and an initial assessment of the opportunity for retrofitting each of the generic building typologies, from a technical perspective is discussed. The intention is that this will allow other cities to understand the approach taken in London and use this to undertake an initial high-level review of its building stock so that they are able to make an initial high-level assessment of the opportunity for connecting its existing building stock to district heating networks.

3 Building Typology Assessment (WP1A)

3.1 Overview

This section of the report outlines the methodology followed to develop a set of simplified building typologies to represent the existing domestic and non-domestic building stock in London. Typologies have been developed based upon a balance between representing the widest range of buildings and the largest coverage of London. All assumptions and typologies were agreed through consultation with the GLA.

The methodology developed for generating the domestic typologies is presented first, followed by the non-domestic approach. The underlying datasets are based on a bottom up spatial assessment using the LSOA (Lower Super Output Area) geographic areas. LSOAs are sized to be equivalent to population areas of approximately 1,000 - 3,000 households, giving a high level of granularity in data across the city.

In total, the selected typologies are considered to represent:

- 3,297,485 domestic addresses: 95.4% of the stock (i.e. all buildings except those already with communal heating, or those with details not recorded in the ONS property database).
- 206,193 non-domestic addresses: Offices and retail uses assessed only, representing 62.0% of the total non-domestic building stock, or 72.1% of the stock when district heating anchor loads are removed.

The full extent of possible typologies in the non-domestic sector is more extensive than the domestic sector by virtue of the number of different sector activities. To limit the number of model iterations, the non-domestic assessment has focussed on office and retail buildings as these uses make up the majority of the non-building uses across the city.

Key non-domestic district heating 'anchor' loads (see Section 3.3) and communally heated domestic properties have been removed from the study, because they can be easily connected to district heating networks, allowing the study to focus on buildings which would require more significant levels of retrofit..

3.2 Domestic building typology assessment

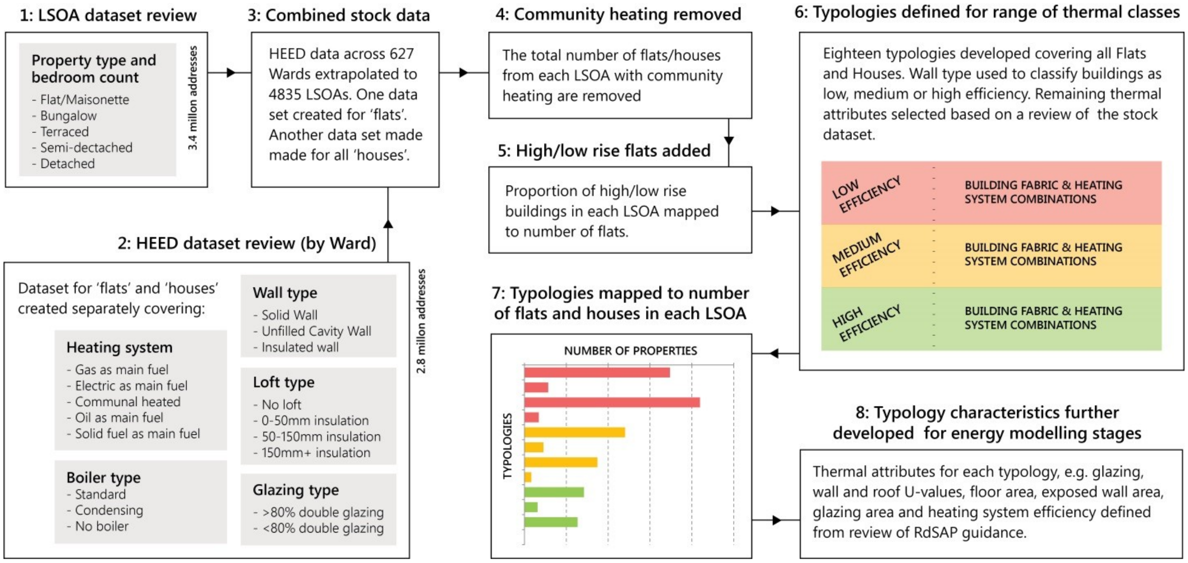
Working with the limitations of available data for spatial mapping across London, the following datasets have been used to develop a representative list of London's domestic building stock covering 95.4% of known addresses.

Table 3-1 Domestic typology model inputs.

Input	Dataset	Details Used
LSOA level characteristics	Office for National Statistics (ONS) neighbourhood statistics, 2014	Property type and bedroom count.
	Ordnance Survey (OS) Master map, 2011	Building count by property height to determine number of low and high rise buildings.
Ward level characteristics	Homes Energy Efficiency Database (HEED), Energy saving trust (EST) home analytics data report for Greater London, 2012	Wall type, loft insulation, glazing type, main heating fuel for approximately 2.8 million homes in London, taken from loft installation records, English Housing Survey data and Energy Saving Trust proprietary research.
Addressing	London Datastore, 2011 Boundaries, Office for National Statistics and London-wards-2014	Ward and LSOA GIS shape files.

Domestic methodology

Figure 3-1 gives a summary of the methodology used to define the domestic typologies for Work Package 1. As shown, an eight step process was followed. At the start of the method, two main datasets have been brought together to produce a combined domestic stock dataset for the analysis. All steps are described below.



1: LSOA dataset review

Property type and bedroom count
- Flat/Maisonette
- Bungalow
- Terraced
- Semi-dectached
- Detached

3: Combined stock data

HEED data across 627 Wards extrapolated to 4835 LSOAs. One data set created for 'flats'. Another data set made made for all 'houses'.

4: Community heating removed

The total number of flats/houses from each LSOA with community heating are removed

5: High/low rise flats added

Proportion of high/low rise buildings in each LSOA mapped to number of flats.

6: Typologies defined for range of thermal classes

Eighteen typologies developed covering all Flats and Houses. Wall type used to classify buildings as low, medium or high efficiency. Remaining thermal attributes selected based on a review of the stock dataset.

2: HEED dataset review (by Ward)

Dataset for 'flats' and 'houses' created separately covering:

Heating system
- Gas as main fuel
- Electric as main fuel
- Communal heated
- Oil as main fuel
- Solid fuel as main fuel

Boiler type
- Standard
- Condensing
- No boiler

Wall type
- Solid Wall
- Unfilled Cavity Wall
- Insulated wall

Loft type
- No loft
- 0-50mm insulation
- 50-150mm insulation
- 150mm+ insulation

Glazing type
- >80% double glazing
- <80% double glazing

7: Typologies mapped to number of flats and houses in each LSOA

8: Typology characteristics further developed for energy modelling stages

Thermal attributes for each typology, e.g. glazing, wall and roof U-values, floor area, exposed wall area, glazing area and heating system efficiency defined from review of RdSAP guidance.

Figure 3-1 Overview of methodology used to define domestic typologies for Work Package 1.

Step 1: LSOA dataset review

The baseline figures used are an LSOA dataset from the Office of National Statistics for dwelling type and bedroom count, illustrated in Figure 3-2. This was used to determine the total number of "flats" and "houses" in London. Here, houses have been classified as all bungalows, terraces, semi-detached and detached dwellings. Flats have been classified as all flats/maisonettes. This data covers 3.4 million homes in London, with the majority (81%) of flats having 1-2 bedrooms, and houses (60%) having 3 bedrooms.

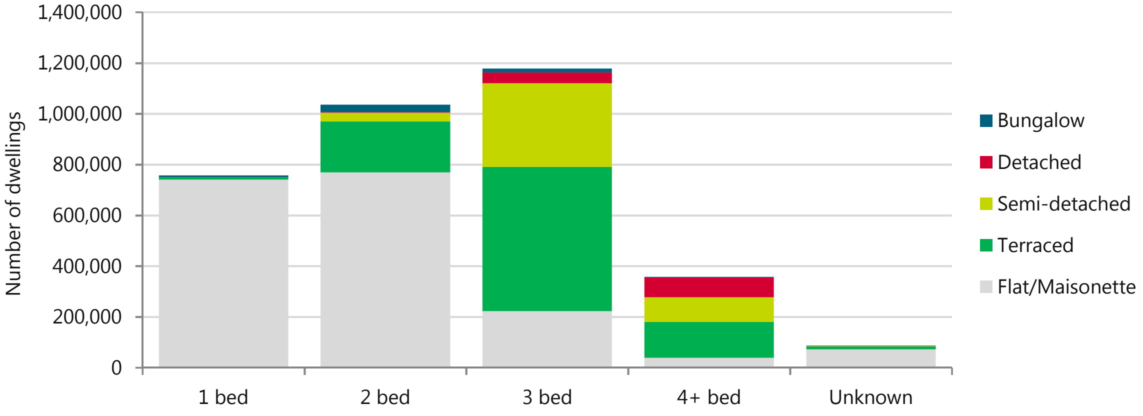


Figure 3-2 LSOA dataset for dwelling type and bedroom count (ONS neighbourhood statistics, 2014).

Step 2: HEED dataset review

The second dataset used was the HEED Home Energy Efficiency Database "EST Home Analytics data report" for Greater London, 2012. This dataset contains figures for approximately 2.8 million homes in London. The database was selected as it contained data for key variables such wall type, level of loft insulation, glazing type and main heating fuel (similarly to the LSOA data). However, unlike the LSOA datasets, this information was linked to particular property type e.g. flats, and all houses allowing a more direct approach to distribution of data.

Figures not used from the HEED database include 'property age' and 'tenure type'. Through discussion with the GLA it was agreed that wall type was a more suitable measure for a domestic property's thermal efficiency. Tenure type was not mapped to the typologies as this would have tripled the number of typologies (i.e. private rented, local authority or owner occupied), which through discussion with the GLA was agreed not to be the aim of this exercise.

For information, Table 3-2 and Table 3-3 respectively, give a summary of the underlying datasets for each variable and its predicted accuracy, as per the Energy Saving Trust's description in the covering sheet of the database.

Table 3-2 Underlying datasets for each variable used in the HEED database (as per the EST description).

	Underlying datasets for each variable
Wall type	Cavity wall installation records (Approx 4.8 million from CIGA, EEC, CERT & Warm Front), English Housing Survey data 2006 - 2011, Scottish House Condition Survey data 2007 - 2009, living in Wales Survey data, Experian Property age, type, tenure and bedroom number data, National Statistics Index of Multiple Deprivation, National Statistics Rural/Urban classification, Energy Saving Trust proprietary research
Loft insulation	Loft installation records (Approx 4.2 million from EEC, CERT & Warm Front), English Housing Survey data 2006 - 2011, Scottish House Condition Survey data 2007 - 2009, living in Wales Survey data, Experian Property age, type, tenure and bedroom number data, National Statistics Index of Multiple Deprivation, National Statistics Rural/Urban classification, Energy Saving Trust proprietary research
Glazing type	Glazing installation records (Approx 7.3 million from FENSA, EEC, CERT, Warm Front and EST), English Housing Survey data 2006 - 2011, Scottish House Condition Survey data 2007 - 2009, living in Wales Survey data, Experian Property age, type, tenure and bedroom number data, National Statistics Index of Multiple Deprivation, National Statistics Rural/Urban classification, Energy Saving Trust proprietary research
Main heating fuel	Experian gas mains present data, Boiler installation and fuel switching records (Approx 2.6 million from CORGI, EEC, CERT & Warm Front), English Housing Survey data 2006 - 2011, Scottish House Condition Survey data 2007 - 2009, living in Wales Survey data, Experian Property age, type, tenure and bedroom number data, National Statistics Index of Multiple Deprivation, National Statistics Rural/Urban classification, Energy Saving Trust proprietary research

Table 3-3 Data variable predicted accuracy from the HEED database (as per the EST description).

	Data variable predicted accuracy
Wall type	Modelled estimates are accurate to the combined UK housing survey within a margin of 5% error when aggregated to the Regional level. A test of the modelled data against a visual survey of the properties within three test LSOAs showed data accuracy varied between 69% and 93%. Aggregated across the three LSOAs the data accuracy was 100%. It is highlighted that the small sample size used in this test does not represent a statistically robust test.
Loft insulation	Modelled estimates are accurate to the combined UK housing survey within a margin of 5% error. No test of the loft insulation data against real data has been carried out to date.
Glazing type	Modelled estimates are accurate to the combined UK housing survey within a margin of 5% error. No test of the glazing type data against real data has been carried out to date.
Main heating fuel	The base dataset is real data on the presence of gas meter. Accuracy will depend on the level of properties without a gas meter in the area covered. Modelled estimates for non-gas grid properties are accurate to the combined UK housing survey within a margin of 5% error.

Step 3: Combined stock data

In order to produce a combined dataset for the LSOA figures and HEED database, a key factor requiring data processing was a conversion from Ward level to LSOA, because the HEED database was given at Ward level. Figure 3-3 illustrates the relationship between Ward and LSOA. In total, the HEED dataset contained figures for 627 Wards. This would need to be extrapolated to the 4,835 LSOAs.

Figure 3-3 Illustration showing relationship between Ward area and LSOA.

The extrapolation from Ward to LSOA took place by identifying which Ward takes up the largest area in each LSOA. A spatial dataset supporting this analysis was available as a GIS shape file from the London Datastore[7].

Ward level data was expressed as a percentage then scaled to the actual number of dwellings in each LSOA. Some minor data cleansing occurred (on 299 of 4,835 LSOAs, or 6% of the data) where the HEED database did not contain any data for the particular Ward identified as being the largest in that LSOA. In these instances, Ward data from an adjacent LSOA with a consecutive reference was taken. Values were then scaled to the actual number of dwellings in each LSOA for the final distribution, with validation carried out to quality check the final extrapolated scaling.

From the resulting combined dataset, Figure 3-4 to Figure 3-7 shows the trends observed across London for domestic wall construction, loft insulation, double glazing and heating fuel.

In Figure 3-4 below, it can be seen that solid walls are the most common wall type for both houses (circa 900,000 properties) and flats (circa 850,000 properties), followed by un-insulated cavity walls and insulated walls.

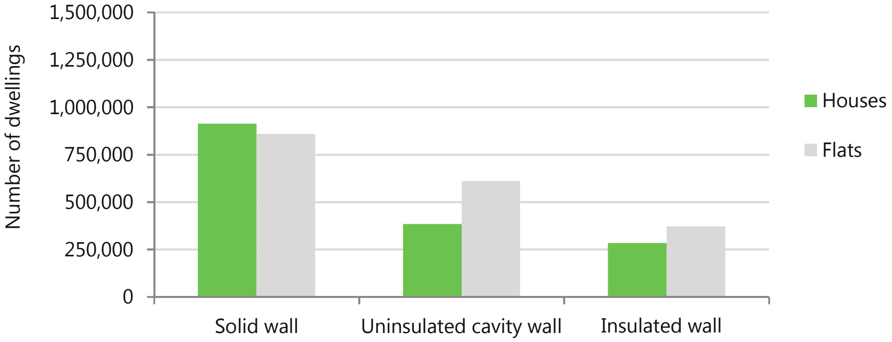


Figure 3-4 Domestic wall construction for flats and houses in London from combined stock dataset.

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[7] London Datastore, Greater London Authority, https://data.london.gov.uk/

Figure 3-5 shows the distribution of loft insulation. As shown in the data, flats typically have no loft, or 50-150mm insulation. The majority of houses have 50-150mm insulation, or over 150mm insulation.

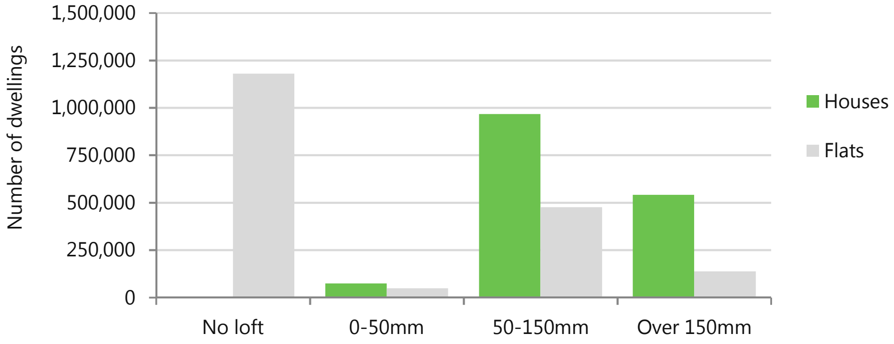

Figure 3-5 Domestic loft insulation for flats and houses in London from combined stock dataset.

Figure 3-6 shows the proportion of double glazing amongst the stock. Approximately 65% of flats and 74% of houses typically have the majority of windows double glazed.

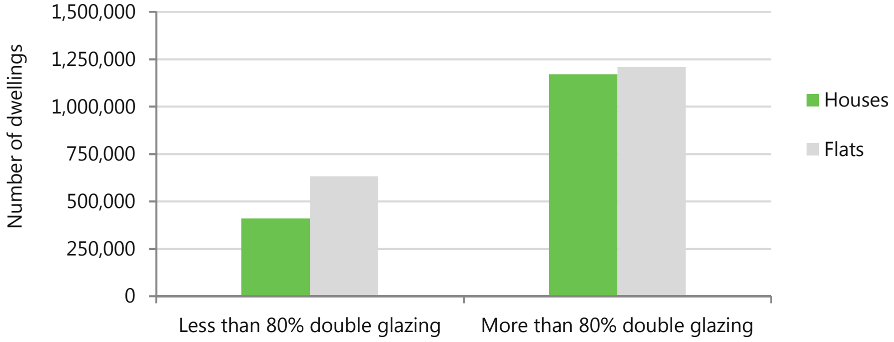

Figure 3-6 Domestic double glazing percentage for flats and houses in London from combined stock dataset.

Figure 3-7 shows the range of heating fuels. As shown, gas heating is slightly more common in houses than flats. Approximately 260,000 flats are shown to be electrically heated, compared to circa 85,000 houses.

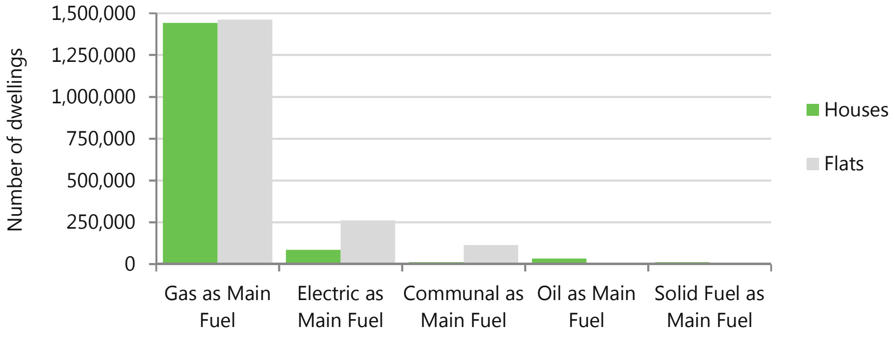

Figure 3-7 Domestic heating fuel for flats and houses in London from combined stock dataset.

Step 4: Community heating removed

As was shown in Figure 3-7, the communally heated homes, predominantly flats, has been removed from the building stock assessment as these were outside the scope of the study because they were already capable of being connected to a heat network.

Step 5: High / low rise flats added

For flats, the denotation between 'low rise' and 'high rise' was determined from an Ordnance Survey (OS) master map dataset, which included figures for property count by building height covering flats only. This data is illustrated below in Figure 3-8. Properties above 16m (i.e. above 5 floors) were considered to be high rise flats, with the remaining properties allocated as low rise flats.

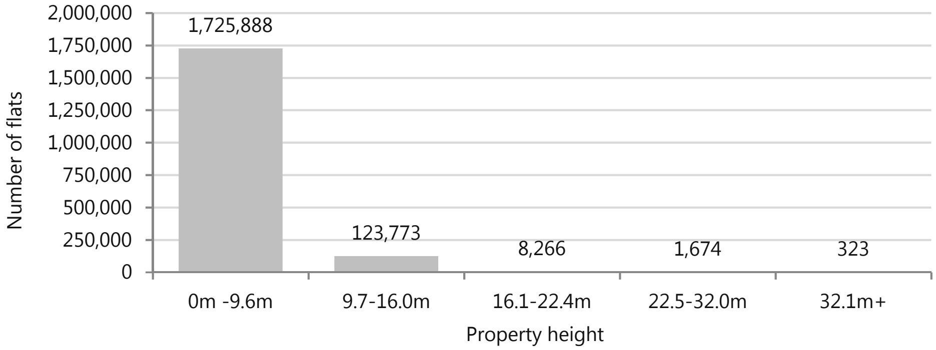

Figure 3-8 Number of flats by property height (Ordnance Survey, 2011) used to denote low and high rise flats.

Step 6: Thermal classes defined

To generate a list of domestic typologies that could be mapped to the largest number of buildings possible, a general spread of typologies for flats and houses was developed covering three fabric efficiency classes, representing low, medium and higher efficiency properties, all of which are either heated by gas, or not. With this general approach 18 typologies were developed, as shown in Table 3-4.

Table 3-4 Preliminary domestic building typologies.

	Dwelling type	Efficiency	Wall type	Heating fuel
d-1	Flat - low rise	Low	Solid wall	Gas
d-2	Flat - low rise	Low	Solid wall	Not gas
d-3	Flat - high rise	Low	Solid wall	Gas
d-4	Flat - high rise	Low	Solid wall	Not gas
d-5	House	Low	Solid wall	Gas
d-6	House	Low	Solid wall	Not gas
d-7	Flat - low rise	Medium	Un-insulated cavity wall	Gas
d-8	Flat - low rise	Medium	Un-insulated cavity wall	Not gas
d-9	Flat - high rise	Medium	Un-insulated cavity wall	Gas
d-10	Flat - high rise	Medium	Un-insulated cavity wall	Not gas
d-11	House	Medium	Un-insulated cavity wall	Gas
d-12	House	Medium	Un-insulated cavity wall	Not gas
d-13	Flat - low rise	High	Insulated wall	Gas
d-14	Flat - low rise	High	Insulated wall	Not gas
d-15	Flat - high rise	High	Insulated wall	Gas
d-16	Flat - high rise	High	Insulated wall	Not gas
d-17	House	High	Insulated wall	Gas
d-18	House	High	Insulated wall	Not gas

For the purpose of mapping low, medium and high efficiency properties to the London domestic stock, the base data used for this was the wall type, i.e. solid walled properties were considered low efficiency, un-insulated cavity walls were medium efficiency and insulated walls were high efficiency.

According to the Rd-SAP 2012 (the government's Standard Assessment Procedure for existing dwellings), for housing energy efficiency, a U-value for solid walls is approximately 2.1 W/m^2.K, compared to 1.6 W/m^2.K for un-insulated cavity walls. Whilst this difference is not as significant an improvement compared to an insulated wall (generally 0.45 W/m^2.K or lower), it should be noted that for future work packages where the cost of energy efficient retrofit is considered, the cost difference between insulating a solid wall and an un-insulated cavity wall will be a significant factor impacting on overall cost effectiveness and consequently this typology split was deemed an important factor.

Step 7: Thermal classes mapped to the number of houses and flats in each LSOA

With the broad typology list defined, the properties within each LSOA could be mapped against the 18 typologies. It was then possible to investigate how the London domestic stock is distributed against the typologies and also geographically represent this information using GIS mapping. The output of this mapping study then forms Work Package 1B, which is given in Chapter 4.

Step 8: Typology characteristics further developed for energy modelling stages

Further to the typology list presented in Table 3-4, the selection of remaining thermal attributes was undertaken based upon a review of the dataset and manual selection based upon the number of dwellings meeting each criteria. This process for both houses and flats is summarised in Table 3-5 and Table 3-6. Through this exercise, the loft insulation level for the 'low efficiency' house typology (i.e. with solid walls) was selected to be 50-150mm. Similarly, all flats were defined as having 'no lofts'. Solid walled properties were taken to have single glazing, with properties with insulated and cavity walls having full double glazing.

Table 3-5 Summary of fabric assumptions selected for each efficiency level in the housing typologies.

		Base typology attributes			**Selected modelling attributes (loft and glazing)**					
		Solid wall	Uninsulated cavity wall	Insulated wall	No loft	Loft insulation between 0-50mm	Loft insulation between 50-150mm	Loft insulation more than 150mm	Less than 80% double glazing	More than 80% double glazing
All houses	**1,580,320**	**912,673**	**383,830**	**284,338**	**0**	**74,132**	**965,934**	**540,682**	**410,099**	**1,170,681**
Low efficiency house	912,938	BASE	-	-	-	-	SELECTION	-	SELECTION	-
Medium efficiency house	383,461	-	BASE		-	-	SELECTION	-	-	SELECTION
High efficiency house	283,921	-	-	BASE	-	-	-	SELECTION	-	SELECTION

Table 3-6 Summary of fabric assumptions selected for each efficiency level in the flat typologies.

		Base typology attributes			**Selected modelling attributes (loft and glazing)**					
		Solid wall	Uninsulated cavity wall	Insulated wall	No loft	Loft insulation between 0-50mm	Loft insulation between 50-150mm	Loft insulation more than 150mm	Less than 80% double glazing	More than 80% double glazing
All flats	**1,841,594**	**858,748**	**610,948**	**371,901**	**1,179,801**	**49,117**	**475,045**	**137,569**	**632,399**	**1,209,181**
Low efficiency flat	858,811	BASE	-	-	SELECTION	-	-	-	SELECTION	-
Medium efficiency flat	610,915	-	BASE		SELECTION	-	-	-	-	SELECTION
High efficiency flat	371,868	-	-	BASE	SELECTION	-	-	-	-	SELECTION

Table 3-7 gives the finalised typology list with the wider thermal characteristics included. During the exercise undertaken above, electricity was identified as the most common heating fuel after gas, so this is used as the default but there are small numbers of other heating fuels such as oil etc. In Chapter 5, the technical requirements for retrofitting these properties to connect to district heating are considered. Here, the wider baseline property characteristics are given including U-values, floor areas, glazing areas and assumed heating system efficiency can be found, together with details of representative property architectures.

Table 3-7 Domestic building typologies.

	Dwelling type	**Efficiency**	**Wall type**	**Glazing type**	**Loft insulation**	**Heating fuel**
d-1	Flat - low rise	Low	Solid wall	Less than 80% double glazed	No loft	Gas
d-2	Flat - low rise	Low	Solid wall	Less than 80% double glazed	No loft	Electricity
d-3	Flat - high rise	Low	Solid wall	Less than 80% double glazed	No loft	Gas
d-4	Flat - high rise	Low	Solid wall	Less than 80% double glazed	No loft	Electricity
d-5	House	Low	Solid wall	Less than 80% double glazed	50-150mm	Gas
d-6	House	Low	Solid wall	Less than 80% double glazed	50-150mm	Electricity
d-7	Flat - low rise	Medium	Un-insulated cav. wall	More than 80% double glazed	No loft	Gas
d-8	Flat - low rise	Medium	Un-insulated cav. wall	More than 80% double glazed	No loft	Electricity
d-9	Flat - high rise	Medium	Un-insulated cav. wall	More than 80% double glazed	No loft	Gas
d-10	Flat - high rise	Medium	Un-insulated cav. wall	More than 80% double glazed	No loft	Electricity
d-11	House	Medium	Un-insulated cav. wall	More than 80% double glazed	50-150mm	Gas
d-12	House	Medium	Un-insulated cav. wall	More than 80% double glazed	50-150mm	Electricity
d-13	Flat - low rise	High	Insulated wall	More than 80% double glazed	No loft	Gas
d-14	Flat - low rise	High	Insulated wall	More than 80% double glazed	No loft	Electricity
d-15	Flat - high rise	High	Insulated wall	More than 80% double glazed	No loft	Gas
d-16	Flat - high rise	High	Insulated wall	More than 80% double glazed	No loft	Electricity
d-17	House	High	Insulated wall	More than 80% double glazed	150mm+	Gas
d-18	House	High	Insulated wall	More than 80% double glazed	150mm+	Electricity

3.3 Non-domestic building typology assessment

The following datasets were used to develop a combined office and retail dataset representing 62.0% of all known non-domestic buildings. The diversity of uses, sizes, building fabric and heating systems means that within the scope of this study a range of simplifications and caveats has had to be applied to generate a manageable number of non-domestic typologies. With greater budget and a longer programme more typologies could have been assessed.

Table 3-8 Non-domestic building typology model inputs.

Input	Dataset	Details Used
Address level characteristics	Ordnance Survey Address-Base-Plus, Nov 2015 and 2011 Census Lower Super Output Areas.	Building location and use
	Energy Performance Certificate (EPC) register	Building type, floor area, EPC rating and heating fuel for 61,300 buildings across London
	Valuation Office Agency (VOA) register	Building type and floor area for all office and retail
MSOA level characteristics	VOA register	Building type and floor area for all office and retail
	ONS Inter-Departmental Business Register	UK Business: Activity, Size and Location
Addressing	London Datastore Statistical GIS Boundary Files	LSOA GIS shapefiles
Initial heat demand benchmarks	CIBSE Guide F and TM46	Primary annual fuel benchmarks by floor space and building type
	BSRIA Rules of Thumb: Guidelines for building services (5th edition)	Primary peak demand benchmarks by floor space and building type

Non-domestic methodology

Figure 3-9 gives a summary of the methodology used to produce the non-domestic typologies for Work Package 1. As shown, four main steps were carried out, involving a review of available data, removal of district heating anchor loads, high level assessment of heat demand to shortlist typologies and the development of thermal typologies using Energy Performance Certificate (EPC) data.

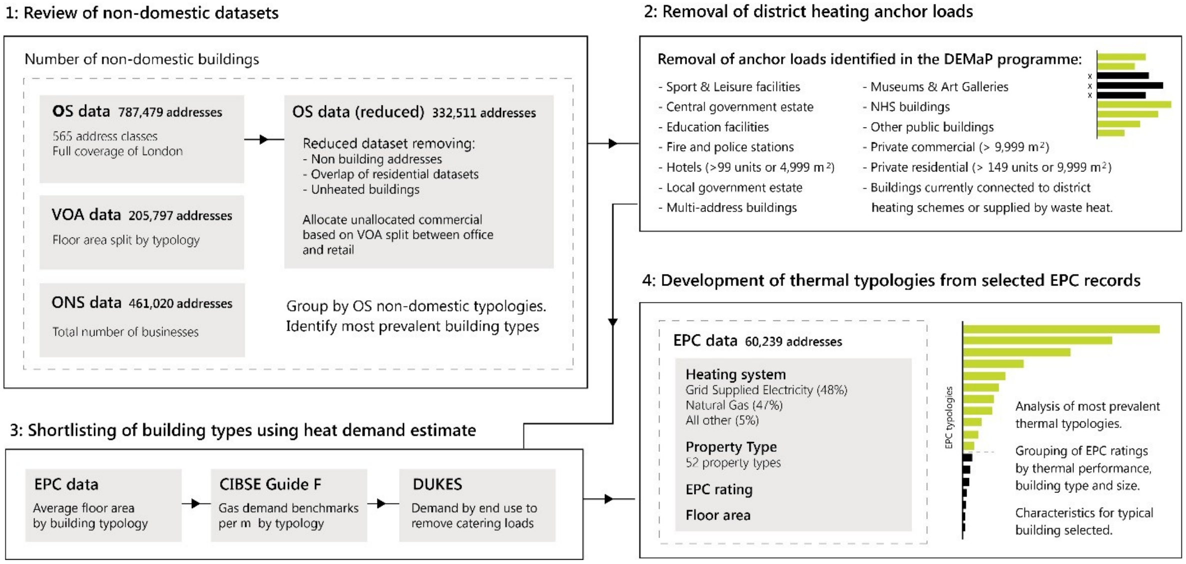

Figure 3-9 Overview of methodology used to define non-domestic typologies for Work Package 1.

Step 1: Review of non-domestic datasets

The first step in generating the non-domestic typologies involved a review of the available non-domestic datasets to determine the total number of non-domestic buildings in London. Table 3-9 summarises the number of non-domestic records within the main datasets assessed. Figures shown for the Ordnance Survey data are based on a reduced dataset, which has been processed to remove non-building addresses, residential data and unheated buildings.

Table 3-9 Number of non-domestic property records.

	EPC (Energy efficiency rating for 52 property types)	**VOA** (Covers property type by floor area)	**Ordnance Survey** (565 address classes. Full coverage of London)	**ONS** (Total number of businesses in London)
Offices	20,073	82,420	118,101	-
Retail	21,698	97,513	88,092	-
Other	18,468	25,864	116,318 *	-
Total	60,239	205,797	332,511	461,020

*Subject to validation of address level Ordnance Survey data

The number of records will vary depending on the extent of data collected and the methodology behind each dataset. In an architectural sense, defining the number of non-domestic buildings can be a complex issue, as one record may comprise several separate buildings sharing one site, a single building, one or more floors in a building, or part of a floor, for example. The classification of building use also varies, such as the split of wholesale space between retail and storage classifications.

The following observations were noted from the datasets compared:

- **EPC** records are only required when a building is constructed or sold. Whilst there are a large number of properties listed on this database it does not represent the whole of London's non-domestic building stock, it represents about 20% of it (using OS data as the baseline). EPCs can be spatially located at an address level.
- **VOA** data reports on all properties which are required to pay business rates. A number of property types are exempt from business rates such as agricultural buildings, churches and Crown properties and so are not included in this dataset. The size of this 'other' building category is not actually known. Ordnance Survey data suggests that this dataset may underestimate the number of non-domestic buildings.
- **Ordnance Survey** data incudes records for all architectural features mapped across the UK. This data has been manually sorted to remove non-building records to provide a more accurate representation of total building numbers. Further verification at an address level was required to validate the building classification of Ordnance Survey data.
- **Office for National Statistics (ONS)** data shows the total number of businesses in London, including locally registered businesses belonging to larger enterprises. It is not linked to property records, as such businesses may occupy multiple buildings or only parts of buildings. For this reason it was included for reference and validation only.

Although there was no clear total number of non-domestic buildings, an absolute number is useful when comparing records against a total. The Ordnance Survey total of 332,511 has been used for this purpose through this document to represent the total number of non-domestic buildings in London. The dataset contains information for the full coverage of London across over 500 address classes.

Step 2: Removal of district heating anchor loads

As all district heating anchor loads that could connect to district heating with minimal retrofit requirements are considered exempt from this study, they were removed from the typology assignment process. A list of exempt buildings is given below, based on the building typologies prioritised for primary district heating connection in the Mayor's decentralised energy mapping (DEMaP) programme, completed in October 2010.

- Sport & Leisure facilities
- Central government estate
- Education facilities
- Fire and police stations
- Hotels (>99 units or 4,999 m^2)
- Local government estate
- Multi-address buildings
- Museums & Art Galleries
- NHS buildings
- Other public buildings
- Private commercial (> 9,999 m^2)[8]
- Private residential institution (> 149 units or 9,999 m^2)
- Buildings currently connected to district heating schemes or supplied by waste heat

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[8] * Private commercial is accounted for in Step 4 of the non-domestic methodology, where EPC data above 10,000m^2 was excluded from the prioritisation of EPC ratings used to inform typology selection.

An overview of the non-domestic building types in London, based on the grouping and number of buildings from the Ordnance Survey data is given in Figure 3-10, with a more detailed breakdown by OS typology shown in Figure 3-11. Those properties coloured black represent the district heating anchor loads. Upon review of the data it was estimated that offices and retail represent 62.0% of all non-domestic buildings in London. Once the district heating anchor loads have been removed from the dataset, offices and retail account for 72.1% of all remaining non-domestic buildings.

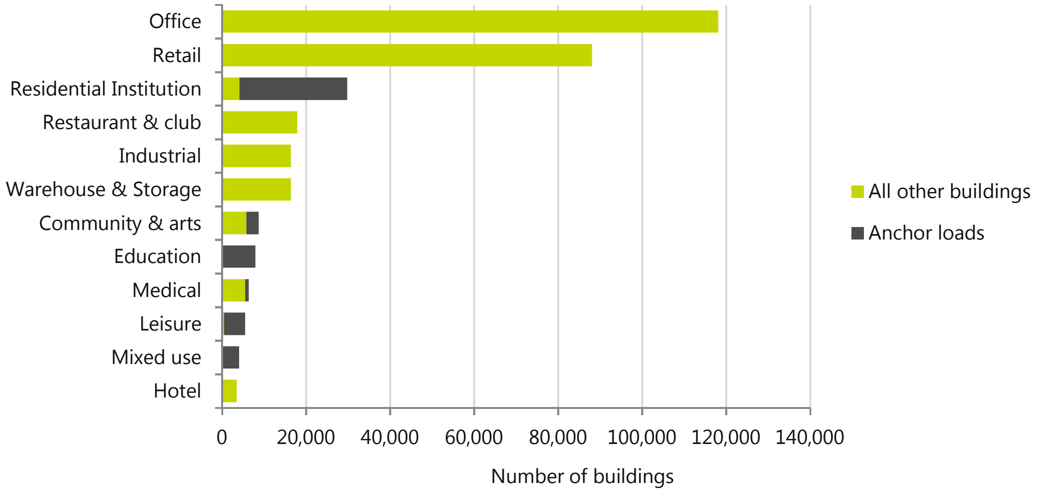

Figure 3-10 Summary of the number of non-domestic buildings in London (Ordnance Survey data). Those results shown in black represent district heating anchor loads outside the scope of the study.

Step 3: Shortlisting of building types using heat demand estimate

As part of the process to better generate a representative sample of buildings, a high level estimate of heat demand for each non-domestic building type was also undertaken. In this assessment, EPC data was used to determine the average floor area by building typology and heat demand benchmarks per m^2 by building typology were used from CIBSE Guide F, together with benchmarks from DUKES to remove catering loads for gas benchmarks.

The finding of this calculation was that offices and retail were estimated to account for 71% of total heat demand, once anchor loads were removed, further justifying their selection for the study. As this was of a similar magnitude to the total number of buildings (72.1%), following review with the GLA, it was agreed that offices and retail were the predominant non-domestic building types and were sufficient to focus upon for the generation of thermal typologies for this study.

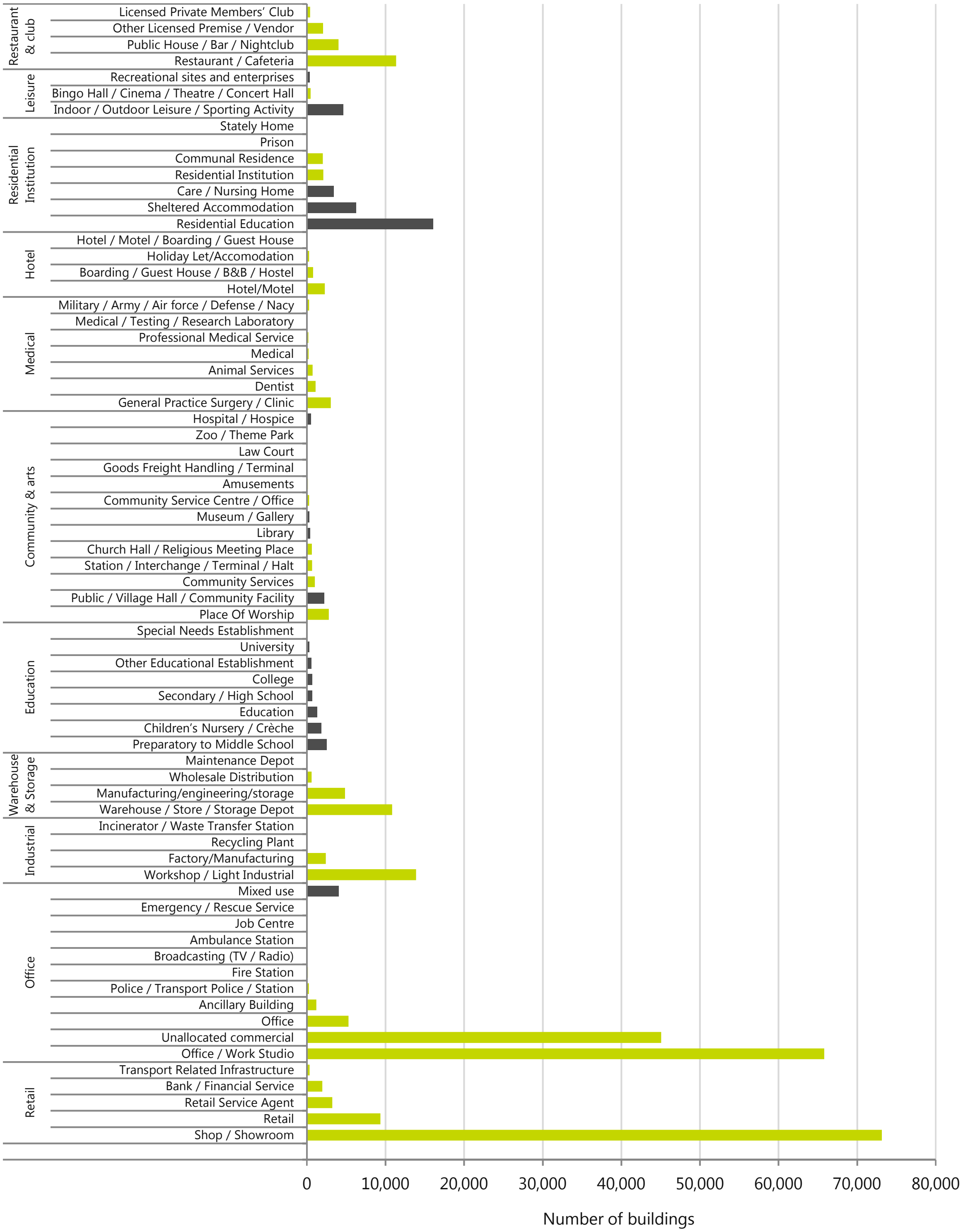

Figure 3-11 Number of non-domestic buildings in London (Ordnance Survey, reduced data set). Those results shown in black represent district heating anchor loads outside the scope of the study. As shown, the retail “shop/showroom”, “office/work studio” and “unallocated commercial” are the three most common non-domestic building types.

Step 4: Prioritisation of office and retail typologies using EPC data

To define the thermal characteristics, the office and retail typologies, EPC records were consolidated for London. Figure 3-12 illustrates the top 25 EPC classes for office and retail buildings. Figures grouped by EPC bands A-B (high efficiency), C-D (medium efficiency) and E-G (low efficiency), taking the first quartile of all data points for small buildings and the third quartile for large buildings. The data shows that large and then small, medium efficiency gas heated office buildings are the most common typologies, followed by small and large, low efficiency gas heated offices. The most common retail typology was a small, medium efficiency electrically heated building.

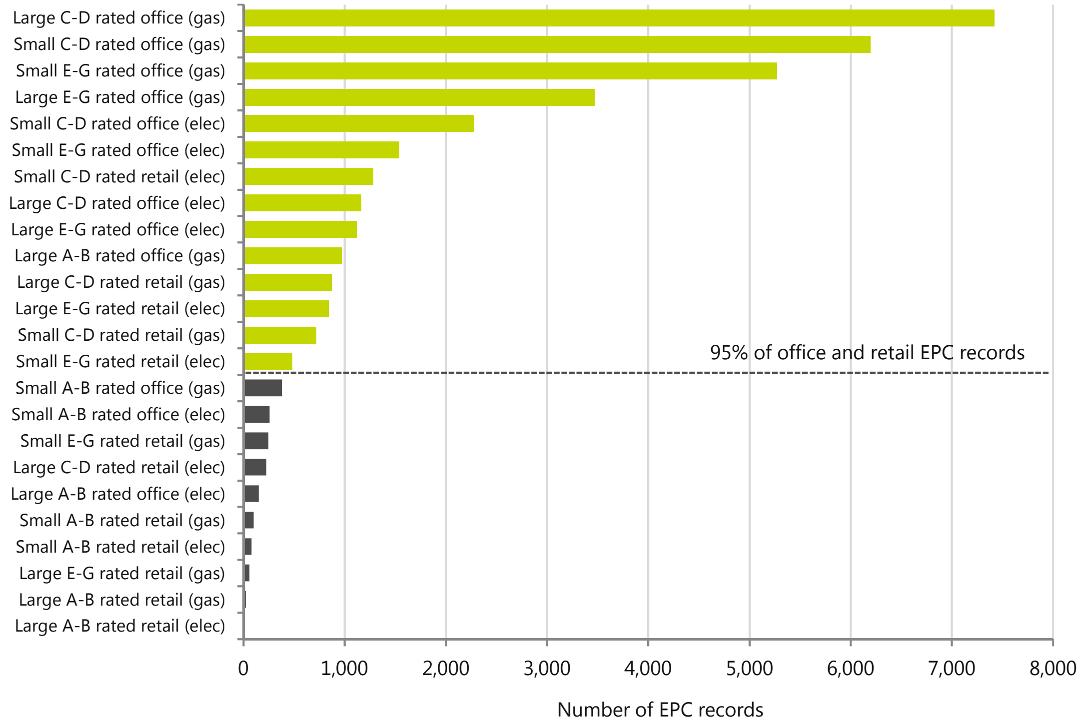

Figure 3-12 Frequency of office and retail EPC data (based on review and consolidation of London EPC records).

Further detail on the spatial mapping of the EPC data to all non-domestic buildings is given in Chapter 4. Upon review of the EPC data, it was found that the top 14 EPC records accounted for 95% of the total office and retail records and these EPC records were therefore used as the basis of the non-domestic typologies.

3.4 Summary

The 32 identified building typologies are made up of an even mix of low, medium and high efficiency domestic typologies used for mapping London's domestic properties along with a good coverage of mainly low and medium efficiency non-domestic buildings that have been identified through the EPC analysis. The typologies cover the vast majority of London's estimated building stock, 95.4% of domestic and 72.1% of applicable non-domestic, and these have been mapped at an LSOA level across London to provide a comprehensive understanding of how London's building stock is spatially and proportionally represented by the chosen typologies across London.

Table 3-10 and Table 3-11 summarise the domestic and non-domestic typologies, respectively, forming the core output of Work Package 1A. In total, 32 typologies have been produced.

Table 3-10 Summary of the 18 domestic typologies for district heating retrofit assessment. Figures cover 3,297,485 domestic addresses, equivalent to 95.4% of the stock (only existing communally heated blocks have been removed). Total stock is 3,455,750 addresses.

#	Dwelling type	Efficiency	Wall type	Glazing type	Loft insulation	Heating fuel
d-1	Flat - low rise	Low	Solid wall	Less than 80% double glazed	No loft	Gas
d-2	Flat - low rise	Low	Solid wall	Less than 80% double glazed	No loft	Electricity
d-3	Flat - high rise	Low	Solid wall	Less than 80% double glazed	No loft	Gas
d-4	Flat - high rise	Low	Solid wall	Less than 80% double glazed	No loft	Electricity
d-5	House	Low	Solid wall	Less than 80% double glazed	50-150mm	Gas
d-6	House	Low	Solid wall	Less than 80% double glazed	50-150mm	Electricity
d-7	Flat - low rise	Medium	Un-insulated wall	More than 80% double glazed	No loft	Gas
d-8	Flat - low rise	Medium	Un-insulated wall	More than 80% double glazed	No loft	Electricity
d-9	Flat - high rise	Medium	Un-insulated wall	More than 80% double glazed	No loft	Gas
d-10	Flat - high rise	Medium	Un-insulated wall	More than 80% double glazed	No loft	Electricity
d-11	House	Medium	Un-insulated wall	More than 80% double glazed	50-150mm	Gas
d-12	House	Medium	Un-insulated wall	More than 80% double glazed	50-150mm	Electricity
d-13	Flat - low rise	High	Insulated wall	More than 80% double glazed	No loft	Gas
d-14	Flat - low rise	High	Insulated wall	More than 80% double glazed	No loft	Electricity
d-15	Flat - high rise	High	Insulated wall	More than 80% double glazed	No loft	Gas
d-16	Flat - high rise	High	Insulated wall	More than 80% double glazed	No loft	Electricity
d-17	House	High	Insulated wall	More than 80% double glazed	150mm+	Gas
d-18	House	High	Insulated wall	More than 80% double glazed	150mm+	Electricity

Table 3-11 Summary of the 14 non-domestic typologies. Figures cover 206,193 non-domestic addresses, equivalent to 62.0% of non-domestic stock, or 72.1% once anchor loads have been removed (representing 46,348 addresses). Total stock is 332,511 addresses.

#	Building type	Efficiency	EPC rating	Heating fuel
nd-1	Office - small	Low	Typical of building with E-G rated EPC	Gas
nd-2	Office - small	Low	Typical of building with E-G rated EPC	Electricity
nd-3	Retail - small	Low	Typical of building with E-G rated EPC	Electricity
nd-4	Office - large	Low	Typical of building with E-G rated EPC	Gas
nd-5	Office - large	Low	Typical of building with E-G rated EPC	Electricity
nd-6	Retail - large	Low	Typical of building with E-G rated EPC	Electricity
nd-7	Office - small	Medium	Typical of building with C-D rated EPC	Gas
nd-8	Retail - small	Medium	Typical of building with C-D rated EPC	Gas
nd-9	Office - small	Medium	Typical of building with C-D rated EPC	Electricity
nd-10	Retail - small	Medium	Typical of building with C-D rated EPC	Electricity
nd-11	Office - large	Medium	Typical of building with C-D rated EPC	Gas
nd-12	Retail - large	Medium	Typical of building with C-D rated EPC	Gas
nd-13	Office - large	Medium	Typical of building with C-D rated EPC	Electricity
nd-14	Office - large	High	Typical of building with A-B rated EPC	Gas

4 Building Typology Spatial Mapping (WP1B)

4.1 Overview

In this chapter the domestic and non-domestic typologies generated in Work Package 1A are matched to the London building stock by total number of buildings and also spatially using GIS (Geographic information system) mapping.

The spatial allocation of building typologies was dependent on the type and quality of the existing data available. For the domestic building stock, the assessment was based on a combination of Census data aggregated at an LSOA level and individual records collated for London's domestic stock and consequently all of the generated typologies can be mapped at an LSOA level.

For the non-domestic stock, the type of buildings could only be identified with a high degree of accuracy at the LSOA level due to the type and quality of the data that was available for non-domestic buildings as defined in the Work Package 1A report. The understanding of heating fuel, overall energy efficiency and floor area was based on available EPC data for offices and retail and this makes up an estimated 20% of the total office and retail building stock. The remainder of the office and retail building stock has been modelled by extrapolation of floor area data and inclusion of an additional 2% of EPC records, based on a review of wider non-domestic EPC records with similar characteristics

4.2 Domestic building typology spatial mapping

Figure 4-1 illustrates the proportion of London's domestic building stock that falls into each of the 18 domestic typologies. It illustrates that low efficiency (i.e. solid walled), gas heated houses are the most common typology, followed by low efficiency, gas heated low rise flats. These are followed by medium efficiency (i.e. un-insulated cavity walled), gas heated houses and low rise flats.

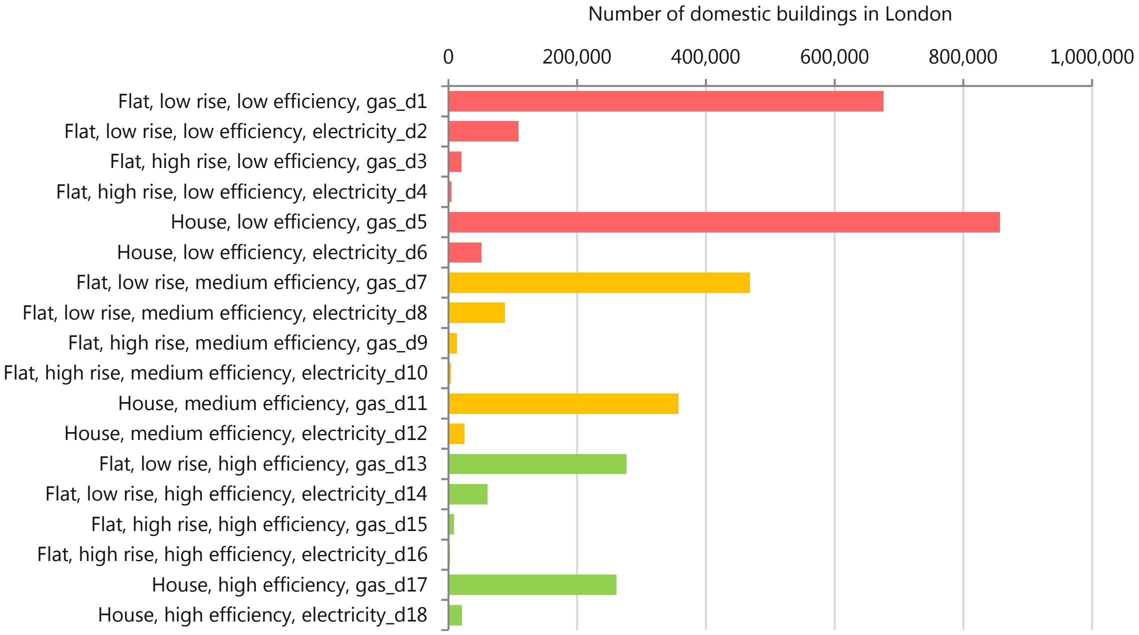

Figure 4-1 The number of London's domestic properties that fall into each of the 18 domestic typology categories. Figures represent the sum of all 4835 LSOAs, covering circa 3,298,000 domestic properties. Colouring represent low, medium and high efficiency.

The datasets allow the identified domestic typologies to be numerically allocated at LSOA level. Figure 4-2 and Figure 4-3 illustrate the distribution of domestic typologies in all Islington and Westminster LSOAs, respectively. The graph for Islington illustrated that there is a predominance of low rise flats and within these typologies low efficiency is best represented followed by medium and then high efficiency. In Westminster there is a predominance of low rise flats, followed by houses and high rise flats along with a greater level of electrically heated properties.

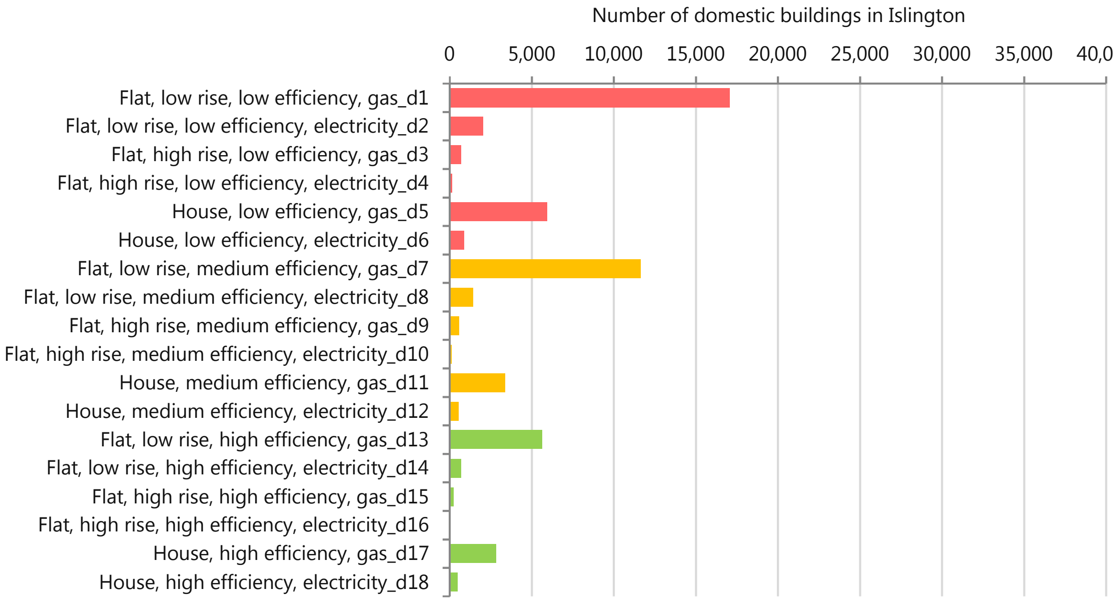

Figure 4-2 Allocation of domestic typologies to all LSOAs for Islington. Data covers 114 LSOAs and circa 55,000 properties.

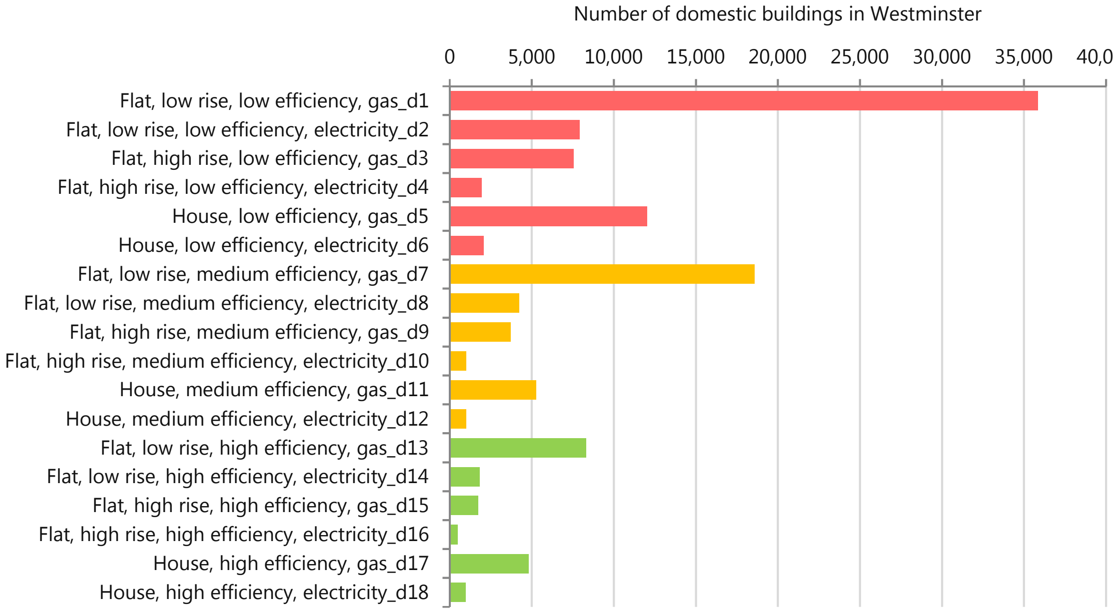

Figure 4-3 Allocation of domestic typologies to all LSOAs for Westminster. Data covers 128 LSOAs and circa 120,000 properties.

A summary of the allocation of the domestic typologies across London, as a function of their density is shown spatially in Figure 4-4. Here, LSOAs with a high density of buildings are shaded darker, with the colour displaying the predominant typology in that LSOA (e.g. brown for low efficiency, blue for medium and green for high efficiency).

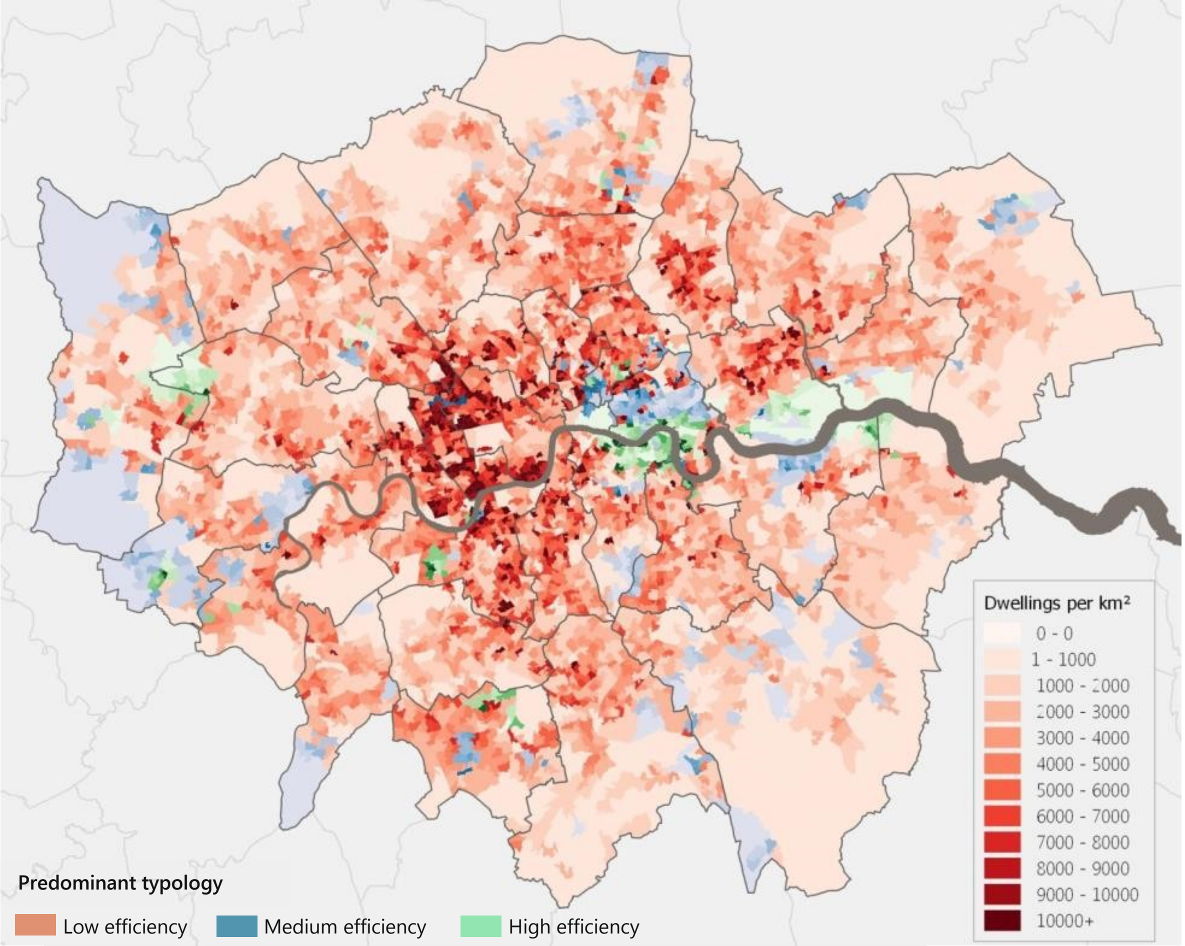

Figure 4-4 Spatial mapping of low, medium and high efficiency domestic properties

A summary of the LSOAs with the highest numbers of low, medium and high efficiency properties is given below. The LSOAs for Westminster 011E, Newham 013G and Hammersmith & Fulham 021C have the highest numbers of low efficiency dwellings, whereas Sutton 001D and Tower Hamlets 033C and 032D have the most high efficiency dwellings.

Table 4-1 LSOAs with the highest number of low, medium and high efficiency domestic properties.

	Low efficiency	**#**	**Medium efficiency**	**#**	**High efficiency**	**#**
1	Westminster 011E	1580	Newham 013G	909	Sutton 001D	946
2	Newham 013G	1244	Sutton 001D	791	Tower Hamlets 033C	754
3	Hammersmith & Fulham 021C	1224	Sutton 022B	669	Tower Hamlets 032D	725
4	Waltham Forest 018B	1194	Hillingdon 027E	666	City of London 001F	691
5	Hillingdon 027E	1126	Croydon 030C	650	Greenwich 002B	665

4.3 Non-domestic spatial mapping

Figure 4-5 gives the EPC data for Central and East London, illustrating how these records can be spatially allocated at address level, but demonstrating that coverage is limited, particularly outside of Central London.

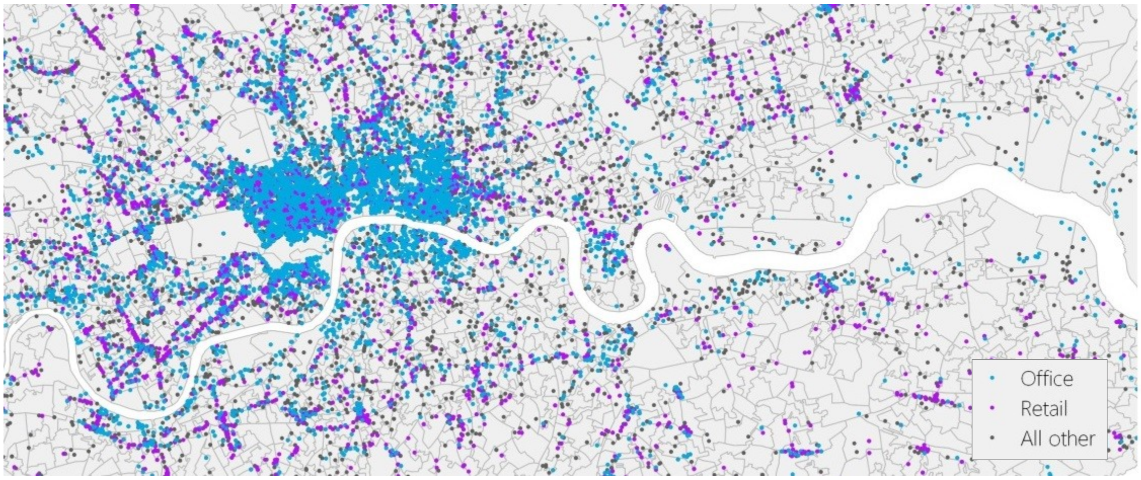

Figure 4-5 Distribution of EPC certificates across Central and East London.

The EPC data for office and retail covers approximately 20% of the office and retail stock. To this data, a further 2% of EPC records have been allocated to typologies, based on a review of wider non-domestic EPC records with similar floor areas, ages and heating fuels. The remaining 78% of retail and office units were allocated to the relevant typology based on the average split (by floor area) of building typologies across London. The resulting distribution is shown below.

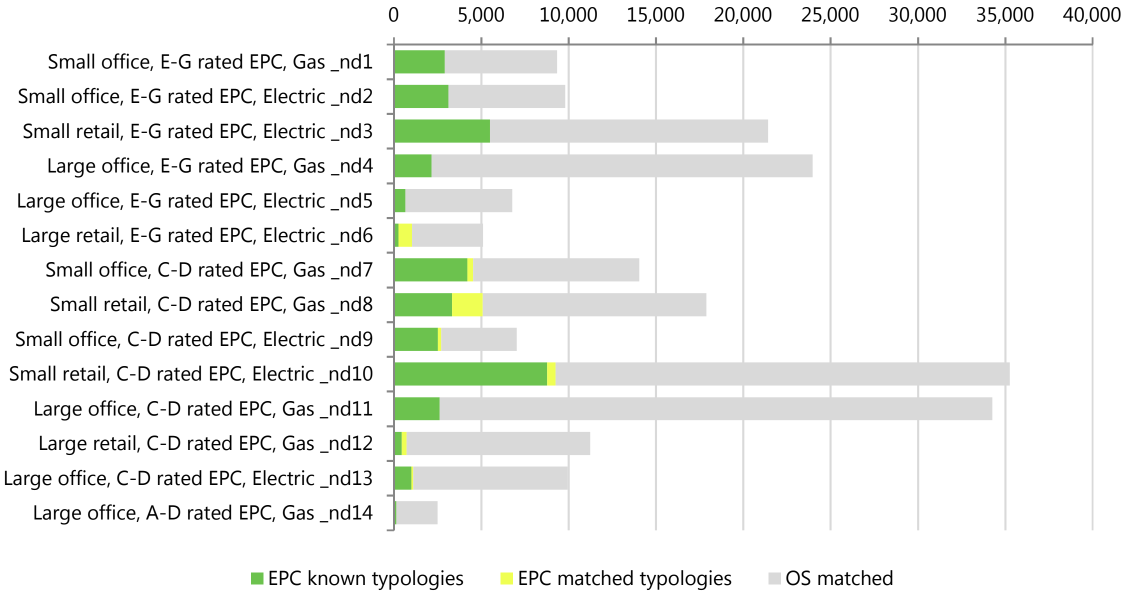

Figure 4-6 The number of London's non-domestic properties that fall into each of the 14 non-domestic typology categories, covering circa 206,000 non-domestic properties.

It was noted that the interpolation of non-domestic data across the typologies relied on a level of assumption, as such the sources of data are noted in the key on Figure 4-6. Within the data, 39% of LSOAs contained offices but had no EPC data available. Similarly, for retail, 25% of LSOAs contained retail buildings but had no EPC data available. In these cases, figures were allocated from the OS floor area data only. This methodology was therefore a practical limitation of the modelling due to the current lack of EPC data available (expected to increase in future).

Although approximately 80% of addresses have been interpolated across London, this was not evenly distributed amongst all LSOAs because the number of EPCs in each LSOA varied. This effect can be seen in the two figures below (note that scales vary on the two charts), where for Islington 26% of the typology allocation was based on EPC data and for Westminster 22% of the typology allocation was based on the EPC data.

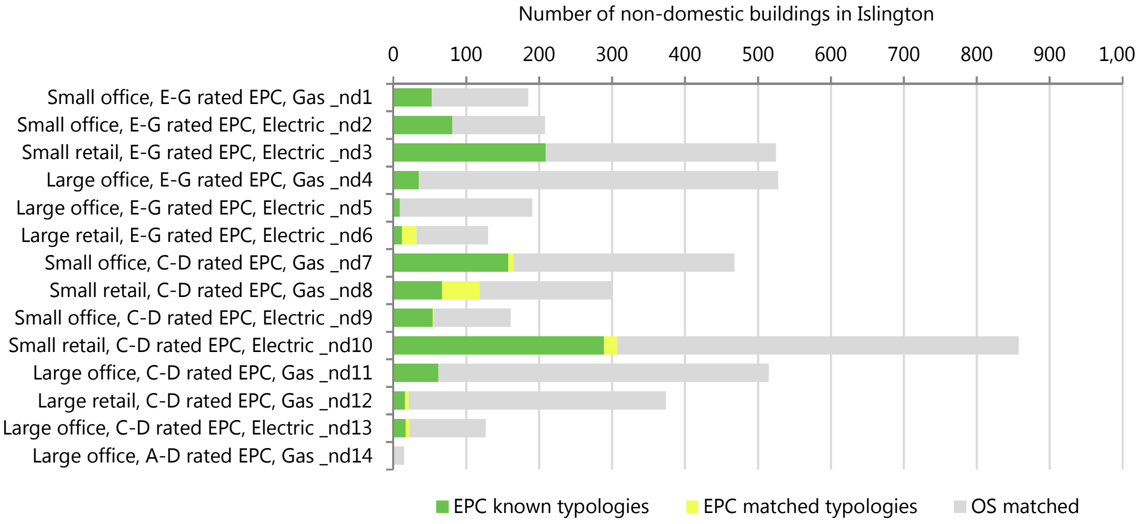

Figure 4-7 Allocation of non-domestic typologies to all LSOAs for Islington. Data covers 114 LSOAs and circa 4,500 properties.

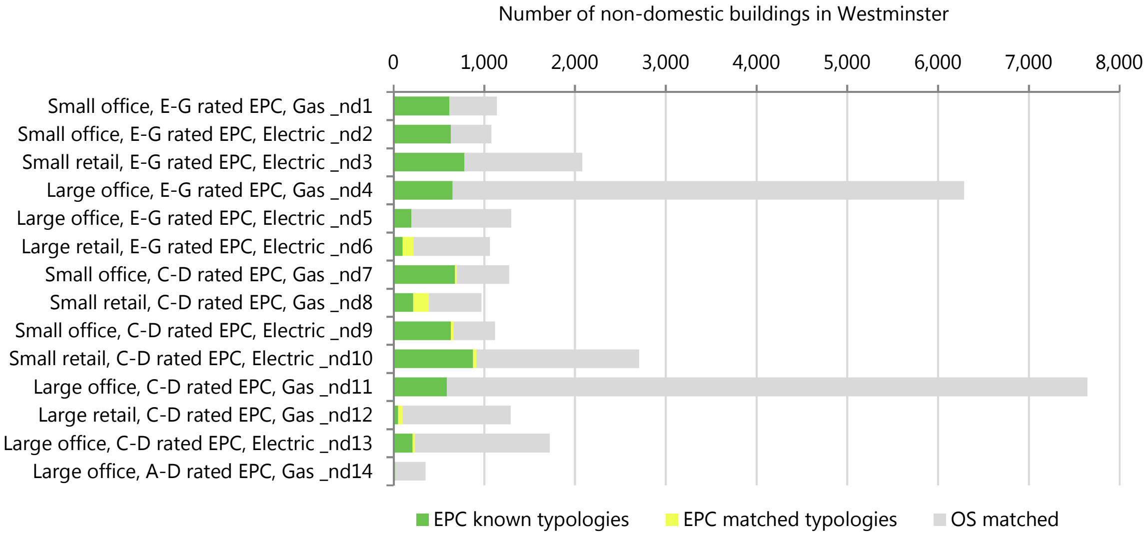

Figure 4-8 Allocation of non-domestic typologies to all LSOAs for Westminster. Data covers 114 LSOAs and circa 30,000 properties.

Spatial allocation of office buildings

Figure 4-9 gives the corresponding spatial allocation of office density by LSOA, with the 10 LSOAs with the largest number of low, medium and high efficiency offices given in Table 4-2. As shown, Westminster has the highest number of low and medium efficiency offices, while Hillingdon and Bromley have the largest numbers of high efficiency offices.

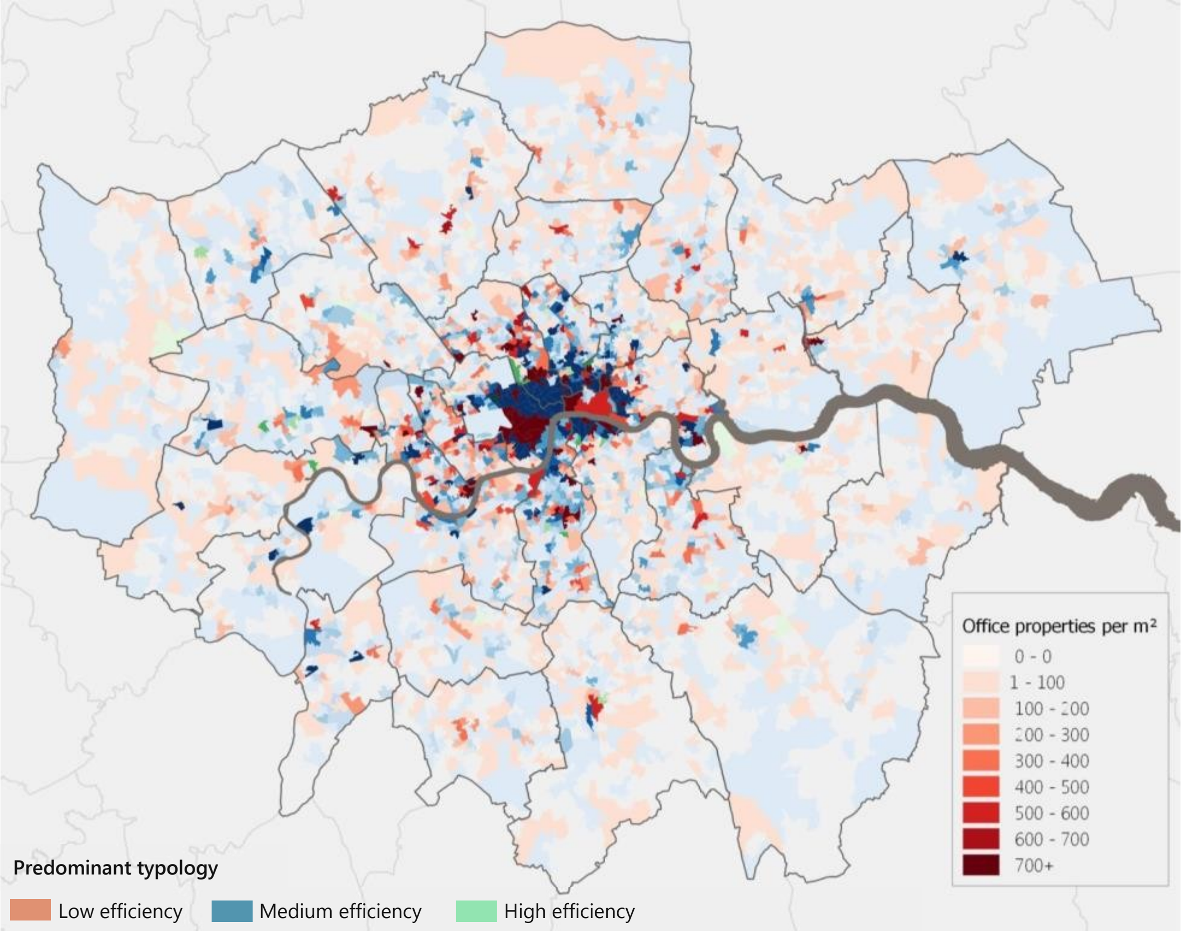

Figure 4-9 Spatial mapping of low, medium and high efficiency office buildings.

Table 4-2 LSOAs with the highest number of low, medium and high efficiency office buildings.

	Low efficiency	**#**	**Medium efficiency**	**#**	**High efficiency**	**#**
1	Westminster 013E	1734	Westminster 013E	1915	Hillingdon 001E	137
2	Westminster 018D	1203	Westminster 018C	918	Bromley 007A	131
3	Westminster 018C	1068	Westminster 018D	884	Westminster 011E	92
4	Westminster 013B	671	Westminster 013D	882	Bromley 011B	83
5	Hackney 027G	645	Brent 022D	882	Wandsworth 027C	81
6	Westminster 020A	556	Brent 024B	877	Croydon 030E	77
7	Westminster 018A	528	Westminster 013B	841	Hackney 029D	76
8	City of London 001F	489	Westminster 011B	676	Havering 021D	70
9	Westminster 018B	486	Westminster 018A	636	Hillingdon 030B	65
10	Brent 024B	466	Hackney 027G	607	Brent 028E	63

Spatial allocation of retail buildings

Figure 4-11 gives the corresponding spatial allocation of retail building density, with the most prevalent LSOAs given in Table 4-4. As shown, Westminster has the highest number of low efficiency retail buildings and whilst medium efficiency buildings are scattered more widely across London the highest number are also in Westminster.

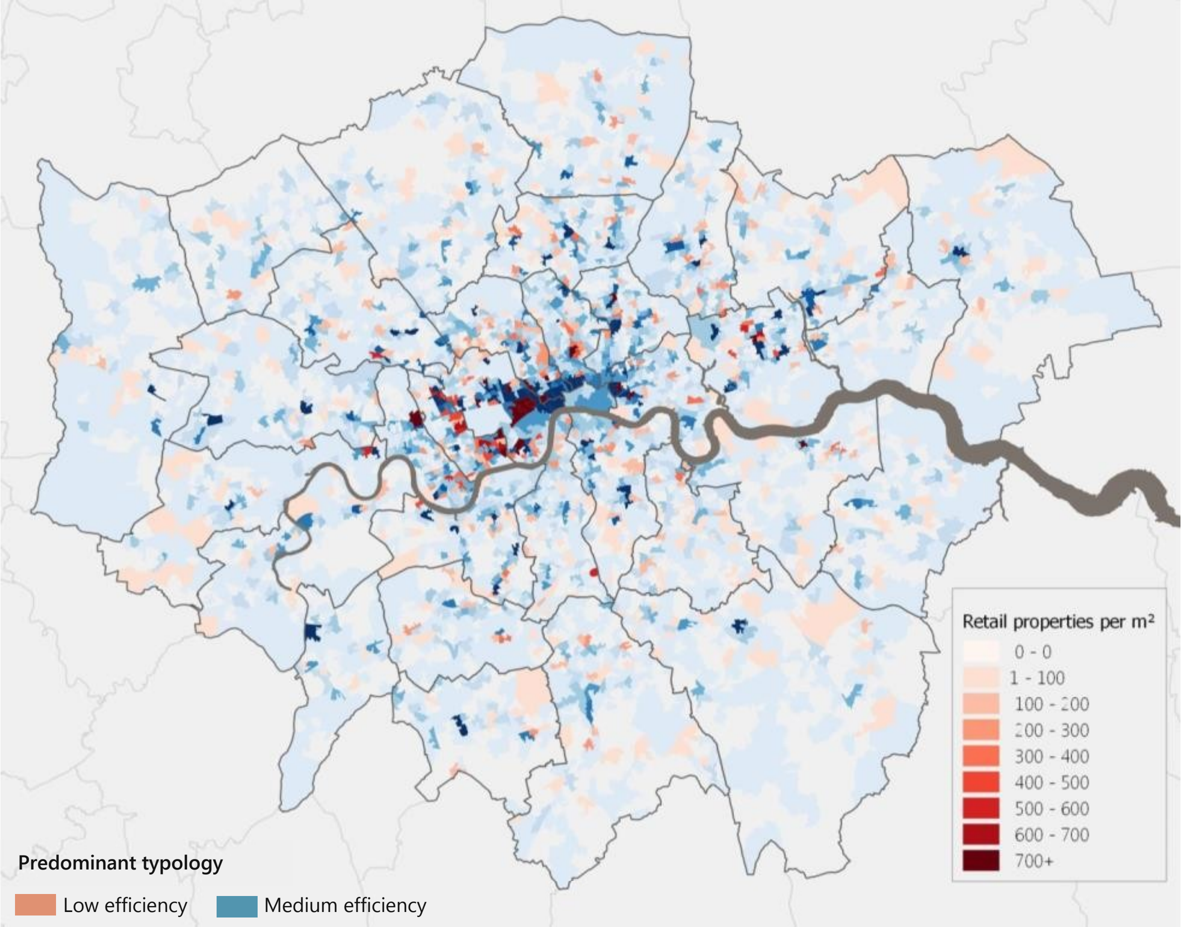

Figure 4-10 Spatial mapping of low and medium retail buildings (high efficiency retail was not a shortlisted typology).

Table 4-3 LSOAs with the highest number of low and medium retail buildings. (High efficiency retail was not a shortlisted typology).

	Low efficiency	#	Medium efficiency	#
1	Westminster 013E	694	City of London 001F	538
2	Enfield 033C	277	Newham 013G	406
3	Westminster 018D	250	Westminster 013E	375
4	Westminster 018C	221	Islington 014F	369
5	Westminster 013D	177	Brent 024B	346
6	City of London 001F	172	Westminster 018A	336
7	Westminster 018A	169	Westminster 013B	328
8	Westminster 013F	150	Westminster 011B	288
9	Bromley 007A	140	Westminster 013D	281
10	Westminster 011B	140	Harrow 033F	272

Spatial allocation of office and retail buildings together

Lastly, Figure 4-11 gives the spatial allocation of office and retail buildings together, with the most prevalent LSOAs given in Table 4-4. As shown, central London, particularly Westminster LSOAs have the highest numbers overall.

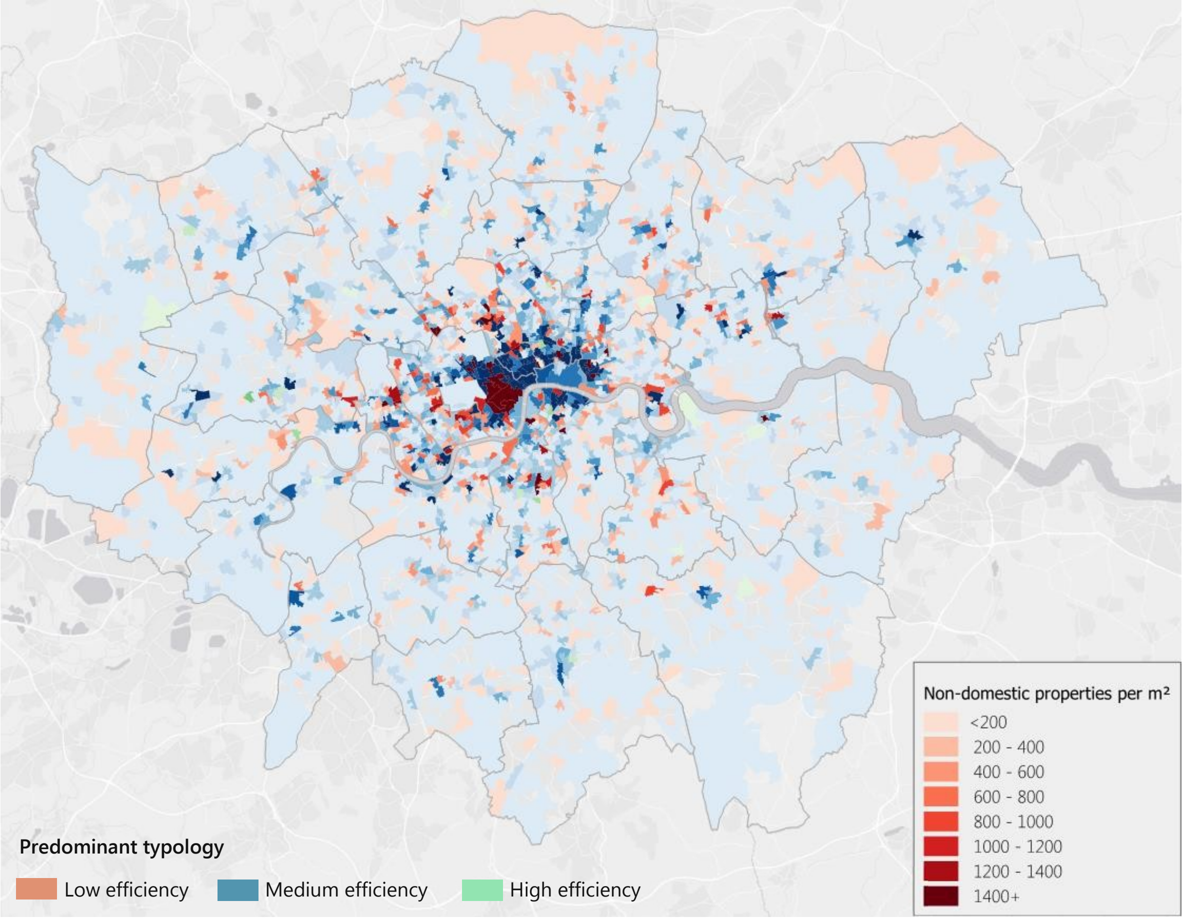

Figure 4-11 Spatial mapping of low, medium and high efficiency office and retail buildings.

Table 4-4 LSOAs with the highest number of low, medium and high efficiency office and retail buildings.

	Low efficiency	**#**	**Medium efficiency**	**#**	**High efficiency**	**#**
1	Westminster 013E	2428	Westminster 013E	2290	Hillingdon 001E	137
2	Westminster 018D	1453	Brent 024B	1223	Bromley 007A	131
3	Westminster 018C	1289	Westminster 018C	1181	Westminster 011E	92
4	Westminster 013B	785	Westminster 013B	1169	Bromley 011B	83
5	Hackney 027G	710	Westminster 013D	1163	Wandsworth 027C	81
6	Westminster 018A	697	Westminster 018D	1096	Croydon 030E	77
7	City of London 001F	661	Brent 022D	1084	Hackney 029D	76
8	Westminster 018B	621	City of London 001F	1023	Havering 021D	70
9	Westminster 020A	603	Westminster 018A	972	Hillingdon 030B	65
10	Westminster 013D	598	Westminster 011B	964	Brent 028E	63

5 Building Typology Retrofit Technical Requirements (WP2A)

5.1 Overview

The study has identified 32 representative building typologies and allocated London's existing domestic building stock along with the office and retail elements of its non-domestic building stock to these typologies. It has also spatially mapped the numerical representation of each typology across London at an LSOA level. This chapter now provides a high level assessment for how each of the identified building typologies could be retrofitted so that they could be connected to a district heating network, either immediately or sometime in the future.

This Work Package provides an illustrative connection strategy for each typology (see Section 5.5) along with a discussion regarding the challenges and considerations that need to be thought about when assessing the opportunity for connecting these typologies to district heating networks. To provide context for this assessment, the typologies have been matched against representative buildings from London's existing building stock to define a geometry to each building. Characteristics such as the baseline heating system are then based upon a review of typical system types. Broader building properties such as floor area, glazing area and building fabric have also been set out at this stage for typology load modelling.

5.2 Building stock review

The following section gives an overview of the representative buildings that have been selected to illustrate a typical geometry for the domestic and non-domestic typologies considered in this study. Understandably, the variation of construction and building types in London is huge and the scope of this study did not include a full building stock survey. As such, an evidence based approach was taken for identifying typical geometries where possible, and where not, the resulting assumptions were agreed with GLA.

Houses

For houses, a three bedroom mid-terrace was selected as the representative geometry as it was the most common typology in the LSOA domestic stock data for houses (illustrated earlier in Figure 3-2). Figure 5-1 therefore shows typical terrace houses illustrating the low, medium and high efficiency house typologies.

Low efficiency, mid terrace
(Solid walls, single glazing)

Medium efficiency, mid terrace
(Un-filled cavity, old double glazing)

High efficiency, mid terrace
(Insulated wall, double glazing)

Figure 5-1 Examples of London houses for the low/medium/high efficiency properties.

Low rise flats

The three architectures selected for low rise flats are shown in Figure 5-2. The first is a low rise converted flat, typically converted from pre-war multi-level terrace houses. The medium and high efficiency properties are low rise purpose built flats. Whilst alternative purpose built options were reviewed for the low rise low efficiency flat, the connection strategy to district heating would be similar to that of the medium efficiency property, thus the converted property provided a different architecture to represent in the costing exercise. Furthermore, according to a study by the Centre for Sustainable Energy[9], 72% of converted flats have solid walls, compared to 17% of purpose built flats.

Low efficiency, converted
(Solid walls, single glazing)

Medium efficiency, purpose built
(Un-filled cavity, old double glazing)

High efficiency, purpose built
(Insulated wall, double glazing)

Figure 5-2 Examples of low rise flats for the low/medium/high efficiency properties.

High rise flats

Low efficiency solid walled properties were assumed to be pre-cast concrete high rise blocks with single glazing. The medium efficiency typology has un-insulated cavity walls and old double glazing (installed over 20 years ago). High efficiency high rise flats were taken as new build or insulated existing build with newer double glazing.

Low efficiency, high rise
(solid walls, single glazing)

Medium efficiency, high rise
(un-filled cavity, old double glazing)

High efficiency, high rise
(insulated wall, double glazing)

Figure 5-3 Examples of high rise flats for the low/medium/high efficiency properties.

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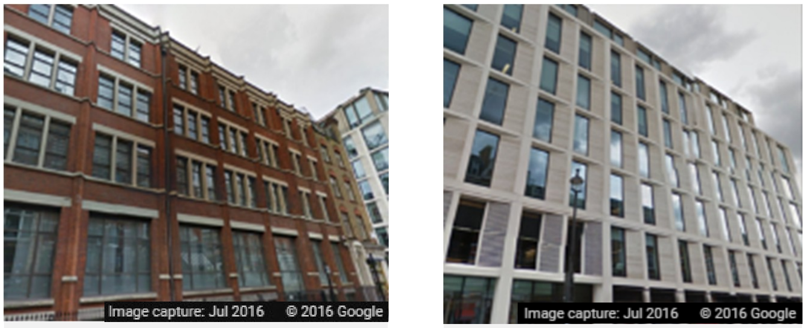
[9] Centre for Sustainable Energy, *Analysis of hard-to-treat housing in England*, 2011. https://www.cse.org.uk/downloads/reports-and-publications/insulation-and-heating/building-performance/analysis_of_hard-to-treat_housing_in_england.pdf

Offices

Similarly to the domestic stock, there are a large number of office types in London that could be matched to the selected typologies. The main architectural differences have therefore been split into two typical office types: pre-1960s buildings with load bearing facades and glazing ratios below 50% and more modern office buildings with non-load bearing facades and glazing ratios above 50%. Figure 5-4 shows examples of these two building types.



Pre 1960 office
(solid walls, single glazing)

Modern office
(insulated wall, double glazing)

Figure 5-4 Examples of typical office buildings in London.

Retail

Similarly, there are a number of different ways to categorise the architecture of retail units. Both the small and large retail typologies have been considered to be units on the high street (as opposed to retail parks etc) as these are the most likely to be located close to district heating networks. Furthermore, they are less likely to have already been considered as a district heating anchor load.

Images of typical small and large retail buildings are given in Figure 5-5. Generally high street retail units have large expanses of glazing and are part of a terraced row, or larger block. The shop floor may cover the ground floor or be multilevel. As well as the main shop floor itself, high street retail units may have a number of other usage areas, including storage, staff welfare and/or offices. Residential areas may also be adjacent.

Large retail, high street
(Solid walls, double glazing full at front)

Small retail, high street
(Solid wall, single glazing full at front)

Figure 5-5 Examples of typical high street retail buildings in London.

5.3 Baseline typology characteristics

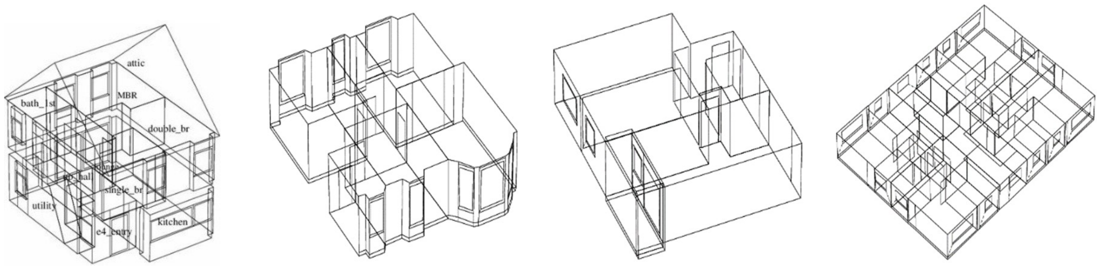
This section cross references the selected geometry for each typology with the assumed building fabric and the baseline heating system efficiencies. The three-dimensional energy models created by Strathclyde University are shown for reference and to illustrate the chosen geometries.

Domestic typologies

Table 5-1 summarises the main characteristics selected for each of the domestic typologies and images of the 3D model architectures are shown in Figure 5-6. Where the same geometry was used for low, medium and high efficiency typologies, the construction and leakage characteristics were adjusted. Properties with lower fabric efficiency were assumed to have an infiltration rate of 1 air change per hour (ACH), medium efficiency properties assume 0.8 ACH and newer properties 0.7 ACH. All U-values and solar g-values were derived from RdSAP[10].

Table 5-1 Selected geometry and building fabric parameters domestic typologies The units for U-values are in W/m^2.K. SG stands for single glazing. DG stands for double glazing.

#	Geometry	Walls	Windows	Roof
d-1	2 bed converted flat, (4 stories)	Solid brick walls, U=2.1	SG, U=4.8, g=0.85	No loft (dwelling above)
d-2	2 bed converted flat, (4 stories)	Solid brick walls, U=2.1	SG, U=4.8, g=0.85	No loft (dwelling above)
d-3	2 bed high rise built flat, (10 stories)	System built, U=2.0	SG, U=4.8, g=0.85	No loft (dwelling above)
d-4	2 bed high rise built flat, (10 stories)	System built, U=2.0	SG, U=4.8, g=0.85	No loft (dwelling above)
d-5	3 bed mid terrace house	Solid brick walls, U=2.1	SG, U=4.8, g=0.85	50-150mm ins. U=0.4
d-6	3 bed mid terrace house	Solid brick walls, U=2.1	SG, U=4.8, g=0.85	50-150mm ins. U=0.4
d-7	2 bed purpose built flat, (4 stories)	Un-insulated cavity, U=1.6	Old DG, U=2.8, g=0.76	No loft (dwelling above)
d-8	2 bed purpose built flat, (4 stories)	Un-insulated cavity, U=1.6	Old DG, U=2.8, g=0.76	No loft (dwelling above)
d-9	2 bed high rise built flat, (10 stories)	Un-insulated cavity, U=1.6	Old DG, U=2.8, g=0.76	No loft (dwelling above)
d-10	2 bed high rise built flat, (10 stories)	Un-insulated cavity, U=1.6	Old DG, U=2.8, g=0.76	No loft (dwelling above)
d-11	3 bed mid terrace house	Un-insulated cavity, U=1.6	Old DG, U=2.8, g=0.76	50-150mm ins. U=0.4
d-12	3 bed mid terrace house	Un-insulated cavity, U=1.6	Old DG, U=2.8, g=0.76	50-150mm ins. U=0.4
d-13	2 bed purpose built flat, (4 stories)	Filled cavity, U=0.35	DG, U=2.0, g=0.72	No loft (dwelling above)
d-14	2 bed purpose built flat, (4 stories)	Filled cavity, U=0.35	DG, U=2.0, g=0.72	No loft (dwelling above)
d-15	2 bed high rise built flat, (10 stories)	Filled cavity, U=0.35	DG, U=2.0, g=0.72	No loft (dwelling above)
d-16	2 bed high rise built flat, (10 stories)	Filled cavity, U=0.35	DG, U=2.0, g=0.72	No loft (dwelling above)
d-17	3 bed mid terrace	Filled cavity, U=0.35	DG, U=2.0, g=0.72	270mm ins. U=0.2
d-18	3 bed mid terrace	Filled cavity, U=0.35	DG, U=2.0, g=0.72	270mm ins. U=0.2



3 bed mid-terrace (78.7m^2) **2 bed converted flat (103.2m^2)** **2 bed purpose built flat (60.3m^2)** **2 bed high rise flat (60.3m^2)**

Figure 5-6 Domestic building simulation models. Areas shown are for reference only, as results per m^2 are generated through this study. Note that high rise image shows the entire floor plate, covering four flats. Also, for the low efficiency house, window size is increased slightly.

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[10] SAP 2012 - The Government's Standard Assessment Procedure for Energy Rating of Dwellings, 2012 edition, BRE- Building Research Establishment. https://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf

In terms of the baseline heating system, low and medium efficiency gas heated properties are set to have a standard gas boiler with efficiency of 74%, and high efficiency properties have a condensing gas boiler with efficiency of 84%. All electric properties are assumed to have electric storage heaters (100% efficient). All efficiencies were set in line with RdSAP figures for typical domestic properties.

It was assumed that the space heating delivery method for district heating for all gas heated building typologies would be via a wet radiator system. In terms of pressure, radiators are typically built to 6 bar, with some even less, especially the older radiators. For electric properties, a new wet heating system would be installed.

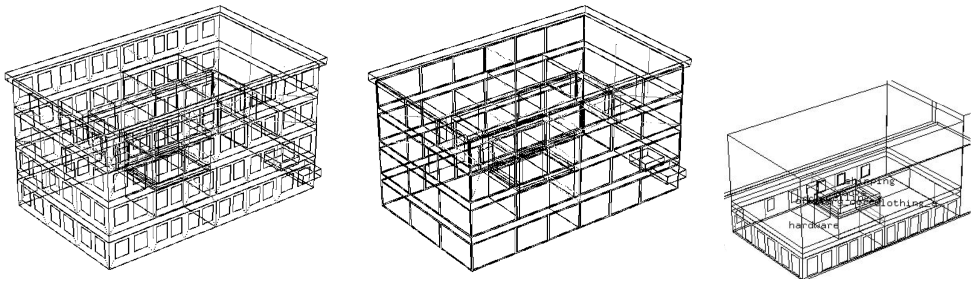
Regarding control, a minimum of two temperature zones are assumed in each property with temperature set-points corresponding to rdSAP assumptions (18°C in bedrooms, 20 °C in living areas and night set back to 15°C). Occupancy patterns are set to include diversity between zones as well as weekday / weekends activity.

Non-domestic typologies

Building fabric parameters for the office and retail models are given in Table 5-2, with example architectures shown in Figure 5-7. For walls, solid brick construction with a typical U-value of 2.1 W/m^2.K was used in older premises, with insulated wall U-values of 0.6 W/m^2.K for more modern properties and properties with more efficient EPC ratings. Assumptions on glazing type and coverage are based upon probable assumptions, considering the properties EPC rating (whilst also considering the efficiency of the HVAC strategy). To reflect the urban context of the models, solar access has been reduced appropriately.

Table 5-2 Selected geometry and building fabric parameters office typologies.

#	Geometry	Size	EPC	Glazing	Glazing coverage	Wall type & U-value
nd-1	Pre 1960 office	Small	E-G	Single	Partially (50% glazed)	Solid, 2.1
nd-2	Modern office	Small	E-G	Double	Fully (80% glazed)	Insulated 0.6
nd-3	Retail, High street	Small	E-G	Single	Full at front (100% at front, 50% at back)	Solid, 2.1
nd-4	Pre 1960 office	Large	E-G	Single	Partially (50% glazed)	Solid, 2.1
nd-5	Modern office	Large	E-G	Double	Fully (80% glazed)	Insulated 0.6
nd-6	Retail, large	Large	E-G	Double	Full at front (100% at front, 50% at back)	Solid, 2.1
nd-7	Modern office	Small	C-D	Double	Fully (80% glazed)	Insulated 0.6
nd-8	Retail, High street	Small	C-D	Single	Full at front (100% at front, 50% at back)	Solid, 2.1
nd-9	Modern office	Small	C-D	Double	Partially (50% glazed)	Insulated 0.6
nd-10	Retail, High street	Small	C-D	Single	Full at front (100% at front, 50% at back)	Solid, 2.1
nd-11	Pre 1960 office	Large	C-D	Double	Partially (50% glazed)	Insulated 0.6
nd-12	Retail, large	Large	C-D	Double	Full at front (100% at front, 50% at back)	Solid, 2.1
nd-13	Modern office	Large	C-D	Double	Partially (50% glazed)	Insulated 0.6
nd-14	Pre 1960 office	Large	A-B	Double	Partially (50% glazed)	Insulated 0.6


Pre-1960 office and large retail

Modern office

Small retail high street

Figure 5-7 Non-domestic building simulation models. Note that further iterations of the models were also created, to account for the glazing coverage requirements. Results are expressed in m^2 figures then scaled to 100m^2 and 1,000m^2 respectively to represent small / large premises.

Similar to the façade parameters, the HVAC strategy for each non-domestic typology was based on probable assumptions, including consideration of the property's EPC as well as its size.

The HVAC strategy selected for offices is shown in Table 5-3. Offices heated with gas have been assumed to have a boiler providing heat to perimeter heaters (radiators or trench heaters) and, where present air handling units (AHUs) and ceiling heaters, i.e. fan coil units (FCUs). Buildings without a central cooling system may have ad-hoc installation of variable refrigerant flow (VRF) or split systems. Although installed to provide cooling these can also provide heating and allow a tenant to better manage their own energy consumption. Buildings heated with electrical systems may have a central heat pump supplying hot and chilled water or they may operate a VRF system, or in some cases they may use direct electric or storage radiators.

Table 5-3 Office typologies - Selected probable HVAC strategies. VRF seasonal efficiency was based upon the Non-Domestic Building Services Compliance Guide[11]. All other efficiencies are based upon BH experience. Domestic hot water (DHW) efficiencies are based on a BH assumption that half of DHW served by heat pump or VRF, with the remainder from electric element.

#	Size	EPC	Heating fuel	HVAC strategy	Heating emitters	Heating efficiency	DHW efficiency
nd-1	Small	E-G	Gas	Gas boilers + ad-hoc cooling	Radiators	80%	80%
nd-2	Small	E-G	Electric	Heat pump	Radiator + AHU	220%	160%
nd-4	Large	E-G	Gas	Gas	Gas boilers + ad hoc cooling	80%	80%
nd-5	Large	E-G	Electric	Heat pump	Radiator + AHU	220%	160%
nd-7	Small	C-D	Gas	Gas	Gas, AHU, FCU + perimeter heating	80%	80%
nd-9	Small	C-D	Electric	VRF	Radiator + AHU	260%	180%
nd-11	Large	C-D	Gas	Gas	Gas, AHU, FCU + perimeter heating	80%	80%
nd-13	Large	C-D	Electric	VRF	Radiator + AHU	260%	180%
nd-14	Large	A-B	Gas	Gas, AHU, FCU	Radiator + AHU	90%	90%

The HVAC strategy selected for retail is given in Table 5-4. Retail units tend to have very little heat demand except where there is hot water required for catering. They also typically lack radiators because wall and window space is prioritised for display purposes. Because of this they tend towards all electric systems. Larger stores with catering and higher heat demands are more likely to have a wet heating system. VRF systems are very popular in retail because they can be used to balance simultaneous heating and cooling. Retail with catering has even more extensive cooling requirements and most of their heating can be done through heat recovery from cooling heat rejection, though this is typically most common in newer stores.

Table 5-4 Retail typologies - Selected probable HVAC strategies.

#	Size	EPC	Heating fuel	Catering	HVAC strategy	Heating emitters	Heating efficiency	DHW efficiency
nd-3	Small	E-G	Electric	No catering	Heat pump	Overhead	220%	160%
nd-6	Large	E-G	Electric	No catering	VRF	Overhead	260%	180%
nd-8	Small	C-D	Gas	No catering	Gas boiler, no cooling	Overhead	80%	80%
nd-10	Small	C-D	Electric	No catering	VRF	Overhead	260%	180%
nd-12	Large	C-D	Gas	On site	Gas boilers, AHU, FCU	Overhead + AHU	80%	80%

In terms of occupancy, the offices are assumed to maintain traditional hours with a few people in on Saturdays and closed on Sunday. Retail premises are assumed to be open all days but with trading reduced hours on Sunday, reflecting UK norms. Regarding systems and control, heating temperature set points are 20 °C during operating hours with night setbacks to 15°C and on holidays. It was assumed that TRVs are used to control temperatures.

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[11] Non-domestic building services compliance guide, 2013, HM government
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/453973/non_domestic_building_services_compliance_guide.pdf

5.4 Load modelling

Load modelling results for simulation models capable of representing all 32 domestic and non-domestic building typologies are given in Table 5-5 and Table 5-6 respectively. For the domestic typology cases, figures for total kW and W/m² are presented. For the non-domestic models, W/m² figures are given, which are scaled to give total kW figures for small (100m²) and large (1,000m²) buildings for the purpose of this study.

Results were simulated in the Strathclyde University ESP-r (Environmental Systems Performance research) software model using the 'CIBSE TRY 2011' London climate file, after which a verification exercise was then conducted. ESP-r explicitly calculates all of the energy and mass transfer processes underpinning building performance. These include conduction and thermal storage in materials, all convective and radiant heat exchanges (including solar processes), air flows, interaction with plant and control systems. The calculation takes into account real time series climate data which is coupled with control and occupancy-related boundary conditions that then produces the dynamic temperatures, energy exchanges (heat and electrical) and fluid flows within the building and its supporting systems.

Table 5-5 Peak space heating load and hot water loads from domestic load modelling.

	Low rise flats			High rise flats			Houses		
	Low Efficiency	Medium Efficiency	High Efficiency	Low Efficiency	Medium Efficiency	High Efficiency	Low Efficiency	Medium Efficiency	High Efficiency
Floor area (m²)	103.2	60.3	60.3	60.3	60.3	60.3	78.7	78.7	78.7
Peak heating load (kW)	6.77	2.65	1.06	2.85	2.25	1.39	4.89	4.16	2.65
Peak DHW load (kW)	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Peak heating load (W/m²)	65.6	43.9	17.6	47.3	37.3	23.1	62.1	52.9	33.7
Peak DHW load (W/m²)	111.4	190.7	190.7	190.7	190.7	190.7	146.1	146.1	146.1

From Table 5-5, for the domestic typologies it can be seen that peak space heating load ranges from 6.77 kW for the low rise, low efficiency flat to 1.06 kW for the low rise, high efficiency flat. In all cases, the domestic hot water profile was consistent with a peak load of 11.5 kW. As would be expected, for each model it can be seen that the space heating load in W/m², reduces as properties become more efficient. A higher heat load is generally observed in high efficiency houses compared to high efficiency flats and that is due to the larger exposed surface area, for example from heat losses through the roof.

Table 5-6 Peak space heating and hot water loads from non-domestic modelling.

	Office				Retail		
	Pre 1960s Solid brick walls	Pre 1960s Insulated walls	Modern Partially glazed	Modern Fully glazed	High street small	High street large, catering	High street large, no catering
Peak heating load (W/m²)	51.2	38.1	38.6	44.2	45.5	34.4	36.6
Peak DHW load (W/m²)	1.8	1.8	1.8	1.8	1.0	2.1	0.7

For offices it can be seen that the peak space heating load varies from 51.2 W/m² for the pre 1960s solid brick wall office, to 38.1 W/m² for the pre 1960s office with insulated walls. It is also evident that the peak load is higher for the fully glazed modern office, compared to the modern partially glazed case due to the larger heat loss through the windows.

Retail peak loads per m^2, are seen to be higher for the fully glazed high street shop, compared to larger central premises with partial glazing. Whilst DHW demand is low across all commercial cases, the catering case has a higher hot water demand as expected, and a lower space heat demand due the residual process heat created.

Load duration curves

An additional output of the load modelling process are load duration curves for each model, illustrating the size of hourly space heating and DHW peak loads throughout the year, with results sorted to illustrate their frequency.

Figure 5-8 shows the load duration curve for domestic properties. Here it can be seen that those properties providing the greatest heat load throughout the year are the low and medium efficiency properties. Comparatively, the uplift in peak load for DHW in high efficiency properties with less space heating demand can be observed.

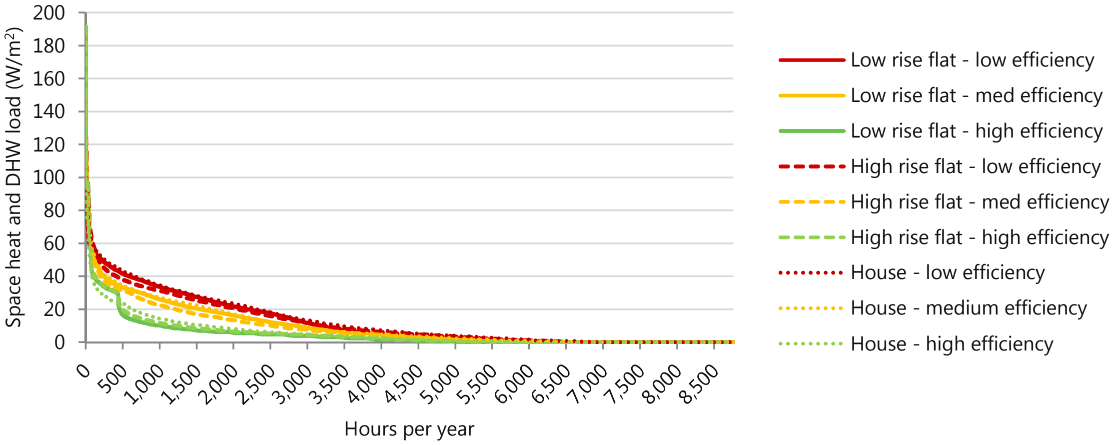


Figure 5-8 Load duration curve for low rise flats, high rise flats and houses.

In Figure 5-9 the load duration curve for the non-domestic models is shown. As shown, the retail models, in particular the small high street case is seen to have a large prolonged heat demand throughout the year. The load from the pre 1960s solid walled office and modern fully glazed office are also higher, with the partially glazed modern office and insulated pre 1960s office performing similar to one another.

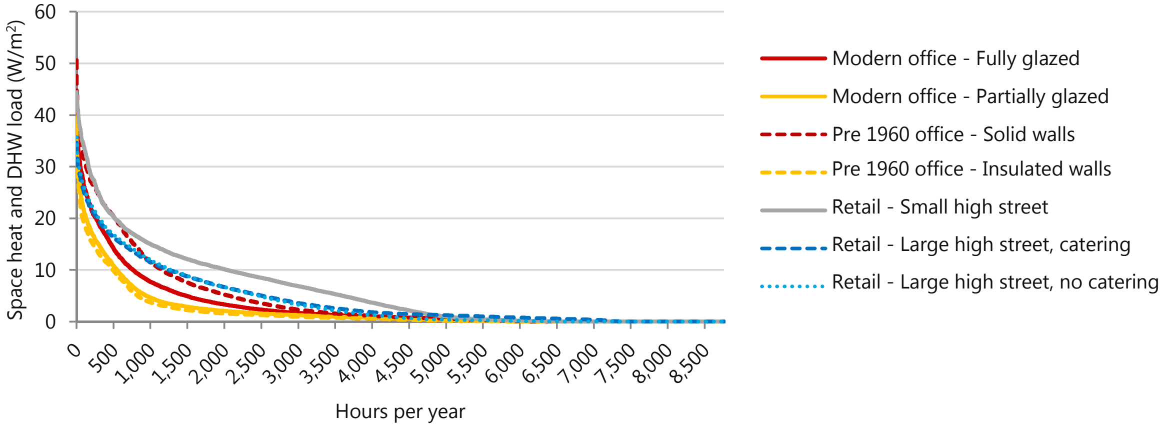


Figure 5-9 Load duration curve for non-domestic office and retail buildings.

5.5 District heating connection strategies

This section describes the strategies considered in relation to retrofitting each of the domestic and non-domestic typologies for connection to district heating networks. Factors such as the type of connection (direct or indirect), pipework routing, interventions required in gas vs. electric properties and domestic hot water production are discussed but issues are only considered to the property boundary.

District heating connection strategy

Three different strategies for connecting properties to a district heating main (which we assume are already present in the public highway) are illustrated in Figure 5-10. These options are:

1. **Individual connection from the public highway to the boundary of each property:** This scenario is the most costly and labour intensive to apply on a mass scale, due to the high excavation costs for each property. Works would include trench excavation, back-filling and re-instatement of surfaces as required, with pipe work rising up and entering into the building.
2. **Shared connection from the main district heating branches to multiple buildings:** Here, economic feasibility would be higher, given there is only one branch to the road main. There may be possible cross boundary and coordination issues when passing through adjacent properties, driveways and/or front gardens.
3. **Shared connection through the roof of multiple properties:** This solution would represent the best engineering solution, given road excavation, pipework length and the number of connections is significantly reduced. In reality however, this option is likely to be particularly challenging due to legal issues regarding covenants and wayleaves (i.e. rights of access specifically for trench excavation, access and maintenance) and co-ordination of multiple property owners.

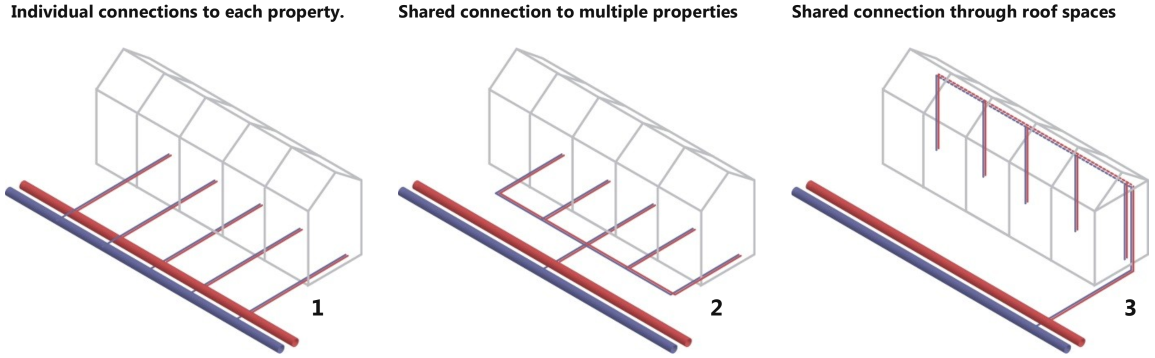


Figure 5-10 District heating connection strategy to street main (illustration for houses).

For the purposes of this study (and in the later costing work), an individual network connection to each property has been selected, given the likely mix of ownership across the London building stock and the difficulty envisaged in co-ordinating and getting agreements for shared connections. It should be noted however that to deliver this at scale an area based approach to promoting and recruiting properties for retrofitting for district heating connection should be pursued and as part of this solution a shared connection to multiple properties would be more cost effective. Broadly, this approach could be applied across the majority of typologies, particularly small retail high street units.

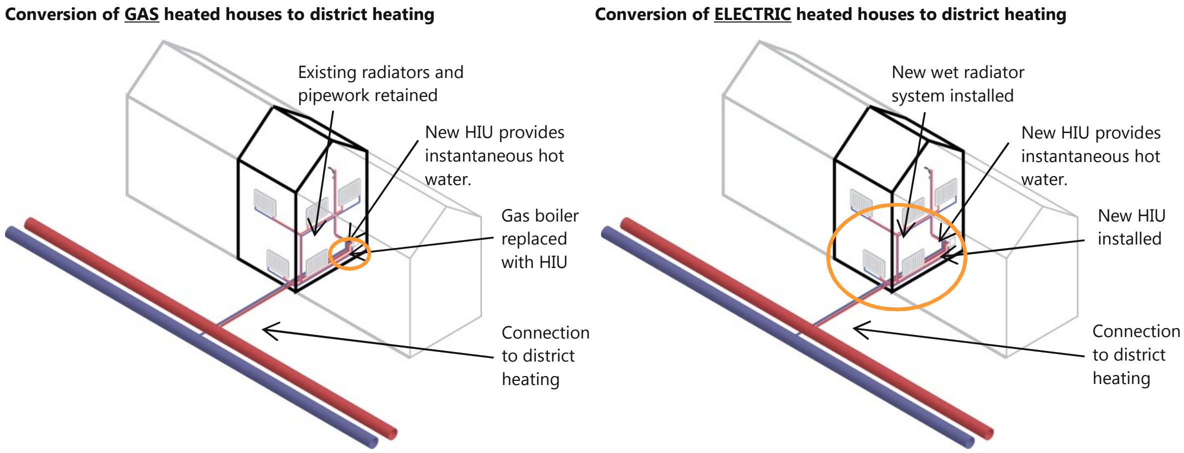
Direct vs. indirect district heating connection
District heating connections can be considered as ether direct or indirect based on the hydraulic separation between primary flow and the secondary flow within a building. Whilst the flow is continuous for direct systems, indirect heating systems have a heat interface unit (HIU) separating the primary from the secondary flow.

When connecting each typology, it has been assumed that an indirect connection to district heating is the preferred approach. Though direct connections reduce losses in the system and can be considered more economical than the indirect connection, there is increased possibility for cross contamination and leakage. As the indirect connection is the highest cost this has been assumed throughout.

5.6 Domestic retrofit strategy

Retrofit strategy for houses
For gas heated homes, existing radiators would be retained and a new HIU would be installed to directly replace the boiler along with new mains pipework to the home to provide the heating and hot water. The HIU would provide heating as well as pressurised instantaneous hot water. The boiler would be replaced by an HIU and then the hot water cylinder, if present, would also be removed which would create some additional space in the home. The HIU would be a packaged unit with new secondary pump, control valves and heat meter for billing on the primary side.

Two-pipe radiator systems are well suited for conversion to district heating systems with little or no modifications required provided they are fitted with appropriately selected thermostatic radiator valves (TRVs). For electrically heated homes, a new wet heating distribution system would need to be installed including TRV, timer and a central thermostat control. Any existing electric space heating system would be removed, together with the hot water cylinder and immersion heater if present. Similarly to the gas heated home, a HIU with new mains pipework would be installed.


Conversion of GAS heated houses to district heating

Conversion of ELECTRIC heated houses to district heating

Figure 5-11 District heating connection strategy for gas (left) and electric (right) houses.

Although it is proposed to remove the domestic hot water tanks in both scenarios, it is possible to retain existing hot water cylinders should this be preferred by residents as these cylinders can be converted though care is needed to ensure they deliver a return temperature which is acceptable to the system operator.

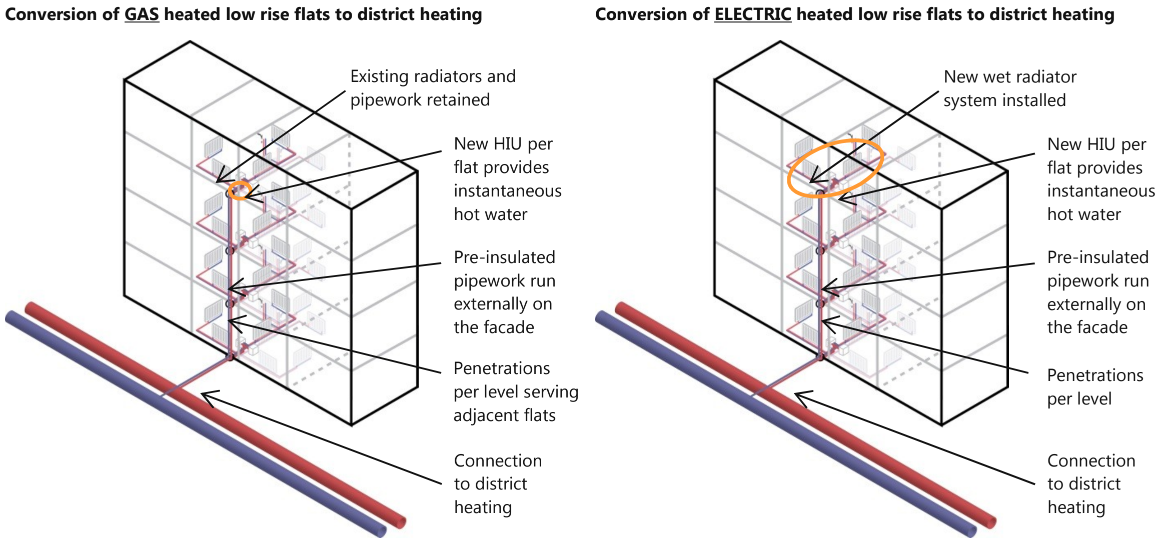
The benefit of removing the hot water tank in favour of an HIU is the additional space created, the additional flexibility of instantaneous hot water in dwellings with multiple occupants and/or high hot water demand and the role it plays in addressing the threat of legionella in networks with lower supply temperature, below 60 °C. An additional benefit of replacing the DHW cylinder with an instantaneous HIU is that this reduces the return temperature to the district heating network and allows greater capacity within the network, lower pumping costs and increased efficiency of central plant in some cases.

Retrofit strategy for low rise flats

As set out in the building stock review (Section 0), two architectures for low rise flats have been considered. The first is a low rise converted flat, typically converted from pre-war multi-level terrace houses. The second is a low rise purpose built flat, more likely to be stand-alone buildings.

Figure 5-12 illustrates the connection strategy for gas and electric converted flats, respectively. As shown, due to a lack of internal riser space, it is proposed to run insulated pipework up the façade externally, with penetrations per level entering into floor plates and serving two adjacent flats at a time (to reduce pipework length). Pipework can be boxed in where aesthetics or planning considerations require this.

Where flats have an existing gas boiler and radiator network, the boiler would be replaced with a new HIU in each flat, providing heat to the existing radiator network, as well as instantaneous hot water. Where properties currently have electric heating, a new wet radiator system would be installed with a new HIU providing heating and hot water. Excavation of a trench at street level, back-filling and re-instatement of surfaces would be required.

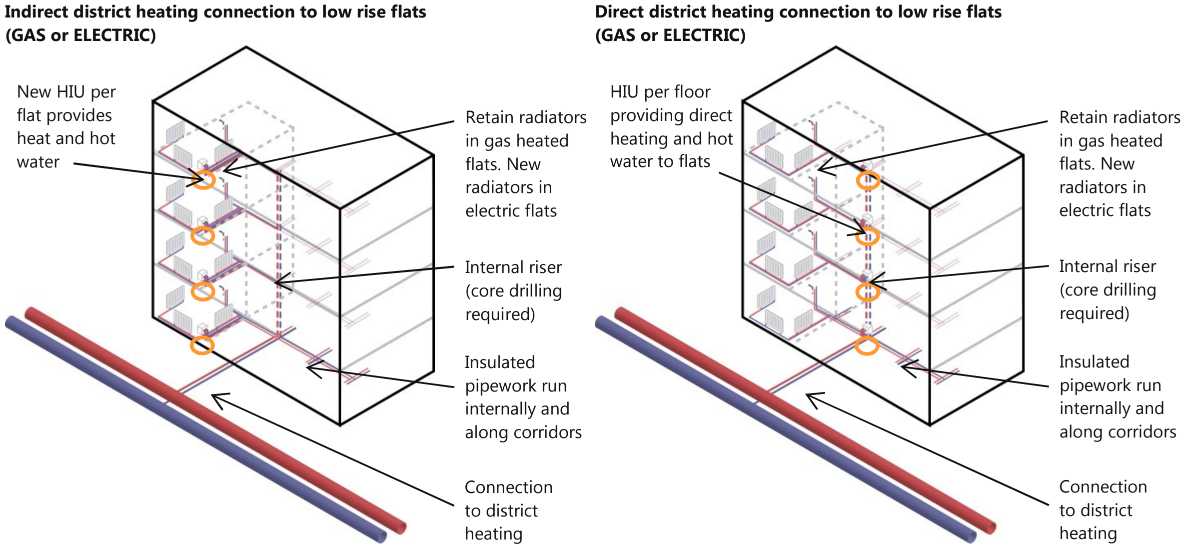

Conversion of GAS heated low rise flats to district heating

Conversion of ELECTRIC heated low rise flats to district heating

Figure 5-12 District heating connection strategy for gas (left) and electric (right) low rise converted flats.

For purpose built flats, it is more likely that the building will have greater space to run district heating pipework internally. As such, the connection strategy for this building type (left image of Figure 5-13), shows pipework running internally and through corridors to each flat. Individual HIUs would then be added to each flat, with similar provisions as described previously for conversion of gas and electric heating systems.

It should be noted that in order to mitigate any risk of overheating in corridors the pipework should be insulated to a standard in excess of BS5422 and provision for ventilation should be ensured.


Indirect district heating connection to low rise flats (GAS or ELECTRIC)

Direct district heating connection to low rise flats (GAS or ELECTRIC)

Figure 5-13 District heating connection strategy with indirect (left) and direct (right) connection into low rise purpose built flats

The right-hand image in Figure 5-13 shows an alternative conversion approach for retrofitting low rise flats and is shown for information. Here, instead of each flat having its own HIU and indirect connection, there is an HIU per floor with a direct connection to each flat. This would reduce investment and maintenance costs however it could introduce some ownership complexity.

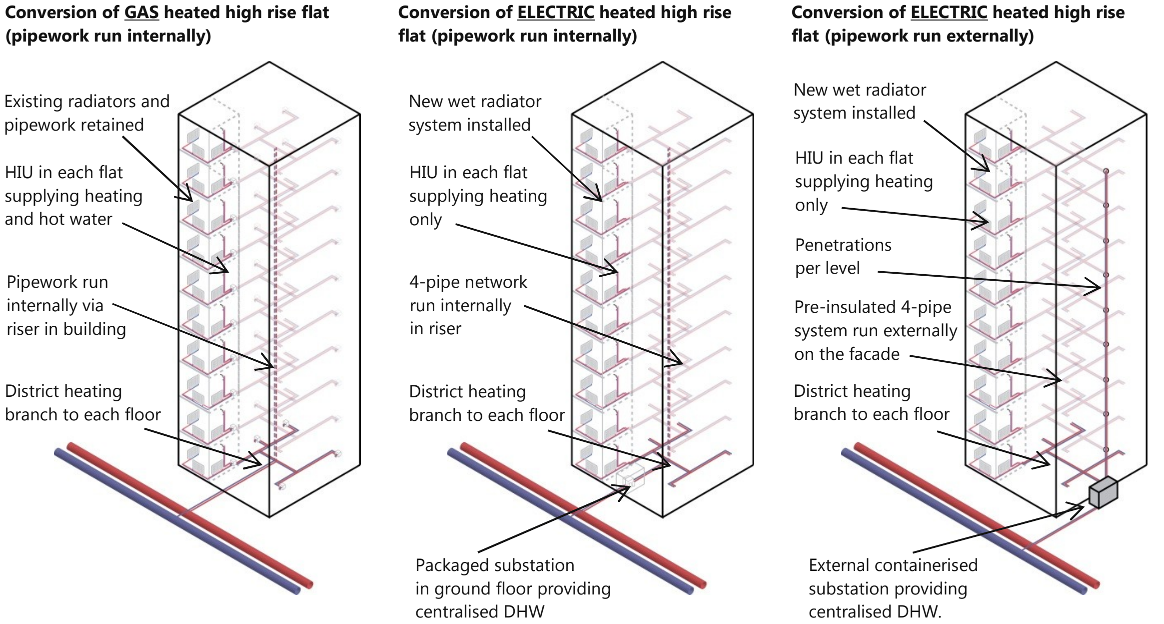
Retrofit strategy for high rise flats

Figure 5-14 shows three strategies for connecting high rise flats to district heating. In the first image, a strategy for converting a high rise building with individual gas boilers in each flat is shown. The next two images show two alternative approaches for connecting electrically heated high rise buildings, where services are run internally and externally respectively. Depending on the height of the building, hydraulic separation between levels may be needed.

In the gas heated high rise building, it is proposed to retain the existing radiator circuit in each flat, remove the gas boiler and hot water cylinder (where present), then install a HIU supplying heating and instantaneous hot water. In the diagram shown, district heating pipework would rise up into the building via an existing or constructed riser then run internally, branching off to each floor, and then to each flat. This internal approach avoids interference with the cladding and external installation associated with an external riser solution. To ensure that the proposed internal riser route is feasible a structural survey would be required to assess any wall penetrations needed. It would also be possible to run pipework externally, as shown for the electric typologies if the structural survey for the internal riser solution suggested that this option was not practical.

For electrically heated high rise flats, because all existing heating and hot water infrastructure would be removed, it presents the opportunity to provide DHW through a centralised system located at ground level with vertical distribution. The cost implications of this are reviewed in Work Package 2B.

The benefit of centralised hot water generation includes reduced maintenance and increased security of equipment, less risk of tampering or damage within flats, as well as the ability to restrict space heating to a defined heating season. A centralised DHW production approach also allows the district system supplying space heating to operate at lower temperatures, whilst ensuring that hot water can be supplied at a temperature above 60 °C to mitigate against Legionella in the cylinders, possibly with local boosting.



Conversion of GAS heated high rise flat (pipework run internally)

Conversion of ELECTRIC heated high rise flat (pipework run internally)

Conversion of ELECTRIC heated high rise flat (pipework run externally)

Figure 5-14 District heating connection strategy for gas (left image) and electric (middle and right images) high rise flats.

With a centralised approach there would be two separate distribution networks, one for LTHW (low temperature hot water) and another for DHW, thus it would be a 4-pipe system. Each flat would have a new radiator network installed, together with an interface unit housing the isolation valves and meters for both DHW (flow only) and LTHW. This could be located within the suspended ceiling within the corridor in a secured casing to eliminate the necessity for dwelling access for maintenance or isolation.

Depending on available space, the centralised hot water store and associated plate heat exchanger equipment and pumps could be a packaged substation at ground level inside the flat, or an external containerised substation. If there is no space to run risers internally, it may be more practical to run insulated pipework externally, entering into each floor plate. If multiple penetrations up the building are required and the work cannot be combined with any other regeneration work that requires scaffolding, then the cost of scaffolding would need to be factored in to the costs plus the removal and re-instatement of any insulation or rain-screen systems.

5.7 Non-domestic retrofit strategy

Retrofit strategy for properties with central gas boilers

Where there are existing gas boilers it is relatively simple to connect to district heating. As illustrated for the two scenarios in Figure 5-15, one or all of the gas boilers would be removed and replaced with a heat exchanger. Where multiple boilers are present, some could be retained to provide additional top up heat or back up.

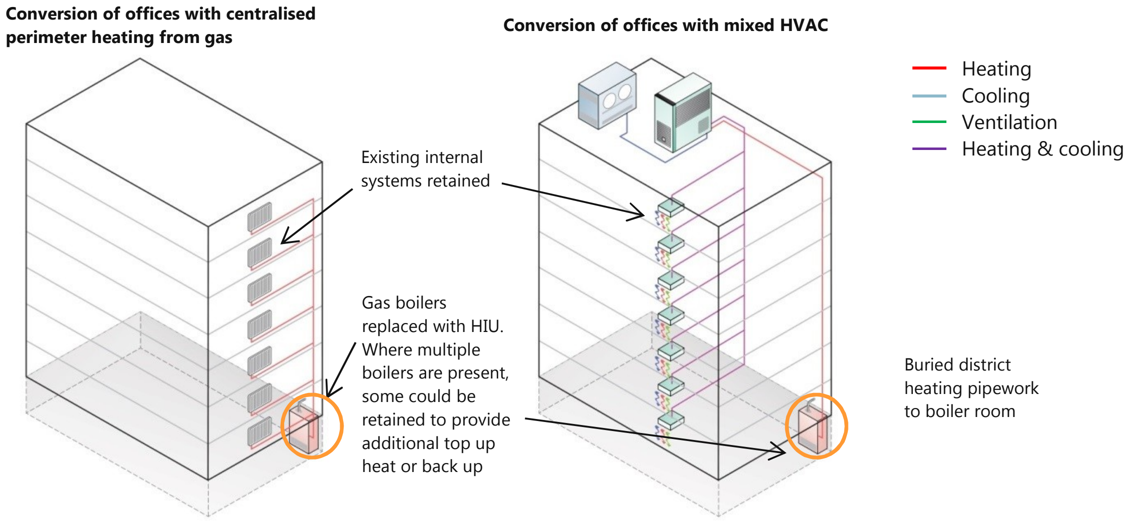


Figure 5-15 District heating connection strategy for gas heated centralised perimeter heating (left) and mixed HVAC (right).

Retrofit strategy for properties with electric heating via heat pumps

Heat pump systems supply a wet system that provide heating and cooling to a building. When a large air source heat pump serves a building it is often located on the roof of the property.

To adapt this system to district heating will likely require a riser to bring the district heating connection to a roof level. Existing secondary circulation would be retained. This includes most piping, fan coil units and radiators. Where direct electric panel heaters are installed a connection to district heating would require a full system retrofit, replacing with a wet heating system.

Retrofit strategy for properties with electric heating via variable refrigerant flow

Electric heating of offices and retail is often carried out using variable refrigerant flow (VRF) systems. Variable refrigerant flow (VRF) systems are where a refrigerant circuit is used to distribute energy to terminal units. The heating and cooling are typically by rooftop plant. Heating and cooling in this case are intrinsically linked; rejected heat from one zone can be used to heat another or vice versa. In this instance, connecting VRF systems to district heating would be challenging as it requires re-working the entire HVAC system. This would require either installation of a parallel wet heat distribution system or connection of a water-to-refrigerant heat exchanger.

An alternative option for connecting VRF systems to district heating is via an energy loop system, where there are simultaneous heating and cooling demands from a number of zones within buildings, especially in retail and all electric offices with heat pumps and VRF systems.

It involves a low temperature water loop (circa 15-30 °C), in which many retail or office units in multiple buildings can connect to enable them to be able to draw off or dump heat into the energy loop. This allows heat recovery between each unit that would not be possible from separate systems and can reduce overall energy consumption. This option may be viable for low temperature networks. Figure 5-16 illustrates this connection strategy (right), together with the strategy for upgrading electric offices with panel heaters (left).

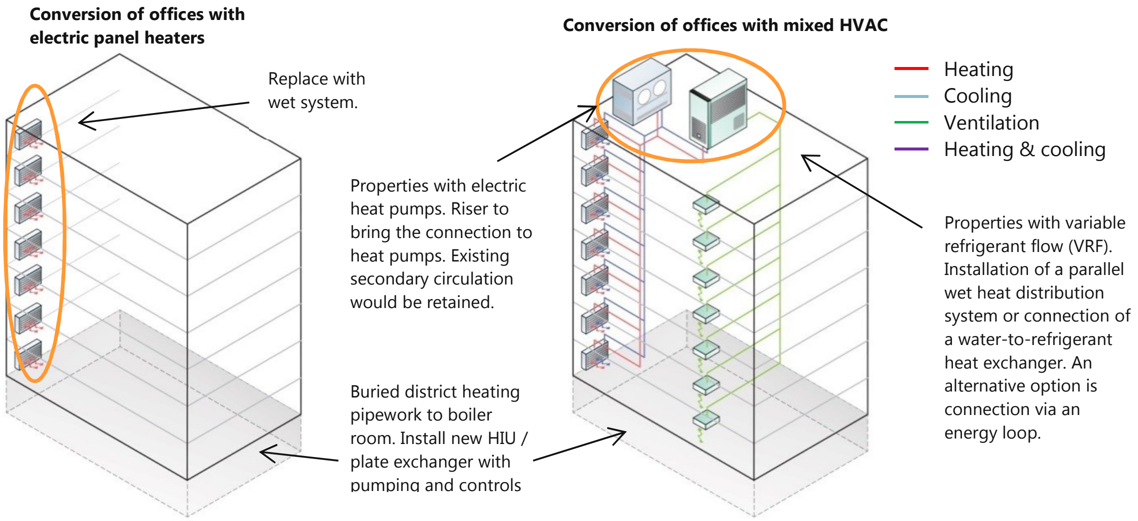


Figure 5-16 District heating connection strategy for electrically heated panel heaters (left) and mixed HVAC (right).

5.8 Summary

This Work Package covered much ground in terms of further refining the building typologies and establishing the basis for connection to district heating feeding into the costing exercise in the next chapter (Work Package 2B). Overall, connection strategies have been established for each typology with commentary on key issues.

Broadly speaking, connection to gas heated properties is technically easier as it principally involves replacing the boiler and hot water cylinder (if present) with a heat interface unit, which can supply instantaneous heating and hot water. Electrically heated properties may require a new wet system to be installed, which is likely to cause greater cost and disruption.

Further discussion around how the connection strategies may differ, e.g. to allow safe hot water generation in low temperature district heating scenarios are discussed in Chapter 9. Here, options exist, e.g. the potential incorporation of centralised vs. decentralised DHW production for the high rise electrically heated flats. These issues are further investigated in the costing exercise in the next chapter.

The criteria discussed in sections 0 to 5.5 covering building architecture, fabric performance, heating system and connection strategy has been used to refine the definition of building typologies for the purpose of developing detailed energy and cost models for the subsequent Work Packages. This information is summarised in full page data tables in Appendix C (see Tables C-1 and C-2 for domestic and non-domestic buildings respectively).

6 Building Typology Retrofit Cost Modelling (WP2B)

6.1 Overview

Further to the review of connection strategies, this next Work Package provides an estimation of the financial cost to retrofit each building typology for connection to a district heating network. Here it should be noted that the scope of the costing exercise only includes costs from the property boundary, and excludes the capital cost associated with the wider district heating network infrastructure. All assumptions and cost reference figures are set out in the methodology. Opportunities for realising shared districting heating connections for adjacent single properties are not considered to provide conservative cost estimates.

6.2 Pipework design

In order to support the capital costing exercise, indicative district heating pipework layouts were produced for each typology together with pipe sizing calculations. The following section describes this process.

District heating pipe sizing in houses

Figure 6-1 illustrates the assumptions made relating to pipework lengths for the house typologies, together with the resulting pipework diameters and insulation thickness calculation. As shown, a 5m length of 32mm diameter pre-insulated district heating pipework is required externally. A further 5m of steel pipework of 32mm diameter with insulation has then been costed running internally within the building to the HIU.

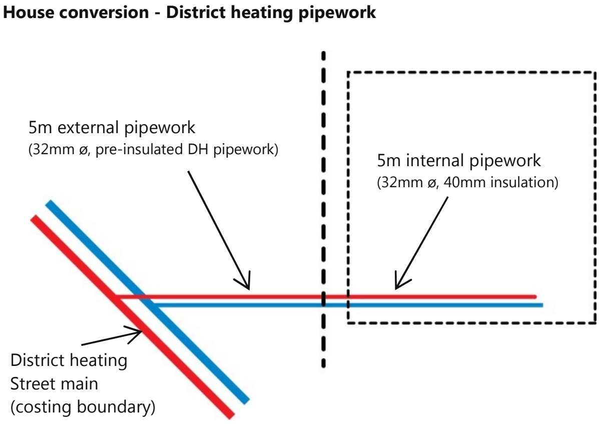


Figure 6-1 Pipework length and thickness assumptions for house typology.

District heating pipe sizing in low rise flats

The left-hand diagram in Figure 6-2 illustrates the pipework design considerations for the low rise converted flat. Here, the property was considered to have four floors, with district heating pipework serving two adjacent properties per floor (i.e. 8 flats in total). A 5m length 50mm diameter pre-insulated district heating pipe from the building towards the street main has been costed. Running externally, a riser of 50mm diameter steel pipework, plus 40mm insulation is included, reducing down to 40mm diameter serving the top floor flats. Branching inside the dwellings and further pipework to the HIU has also been provided.

The right-hand diagram in Figure 6-2 shows the strategy for the low rise purpose built flat, considered to have four floors with 8 properties per floor (i.e. 32 flats in total). Here, a larger 65mm diameter, and longer 10m pre-insulated district heating pipework from the street main has been sized. This pipework then runs internally with a 65mm riser (plus 40mm insulation), reducing to 50mm riser (40mm insulation) serving the final floor. On each floor 15m of pipework has been assumed for a main branch per floor. A length of 5m of pipework has then been costed running internally in each flat to the HIU.

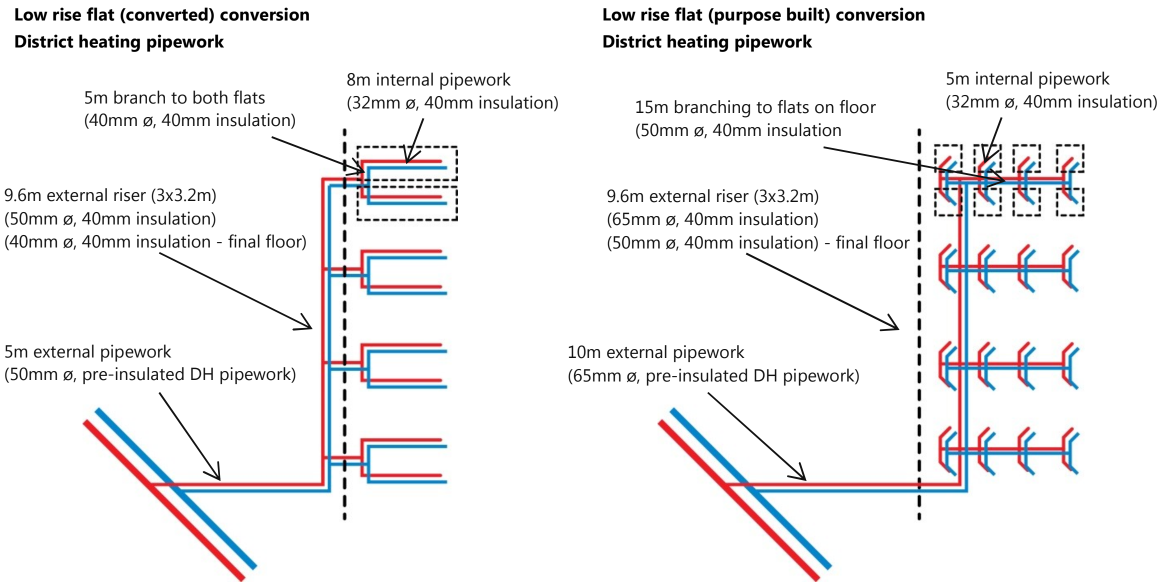


Figure 6-2 Pipework length and thickness assumptions for low rise flat (converted flat on left; purpose built flat on right).

To inform the pipework sizes for low rise and high rise flats, diversity calculations were applied to pipework thicknesses serving each floor, based on the Danish Standard DS 439[12]. The diversity calculations used for heating and hot water are given in Equation 1 and 2 below. This standard is appropriate for multiple dwellings where occupants of each dwelling have lifestyles that are independent of each other. Figure 6-3 illustrates these diversity levels in graphical format, showing that heating diversity factors becomes lower than DHW the higher the number of dwellings.

Equation 1 Heat demand diversity calculation.

$$Fq = 0.62 + (0.38/n) \qquad (1)$$

Where

Fq = *Diversification factor for heat demand*
N = *Number of dwellings*

Equation 2 Hot water demand diversity calculation

$$Fh = (1.19n + 18.8\sqrt{n} + 17.6) / (37.598n) \qquad (2)$$

Where

Fh = *Diversification factor for hot water demand*
N = *Number of dwellings*

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[12] Dansk Standard DS 439, 2009, Norm for vandinstallationer, https://webshop.ds.dk/da-dk/standard/ds-4392009

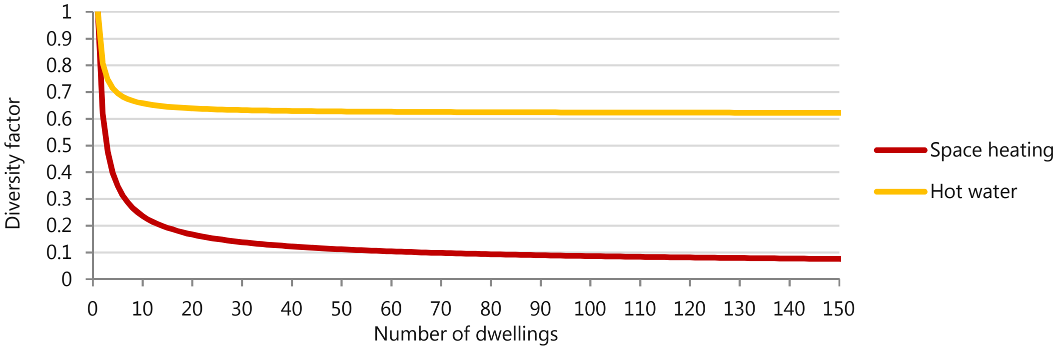

Figure 6-3 Diversity factors for heating and hot water (graph drawn based upon diversity factors in Danish Standard DS 439).

District heating pipe sizing in low rise flats

Figure 6-2 shows the district heating pipework assumptions for a 10 story high rise flat, containing 4 dwellings per floor (i.e. 40 dwellings in totals). The left-hand diagram illustrates the design assumptions for an approach whereby DHW is supplied instantaneously through HIUs in each apartment. The right-hand diagram shows an alternative approach whereby DHW is supplied via a centralised store in a 4-pipe solution.

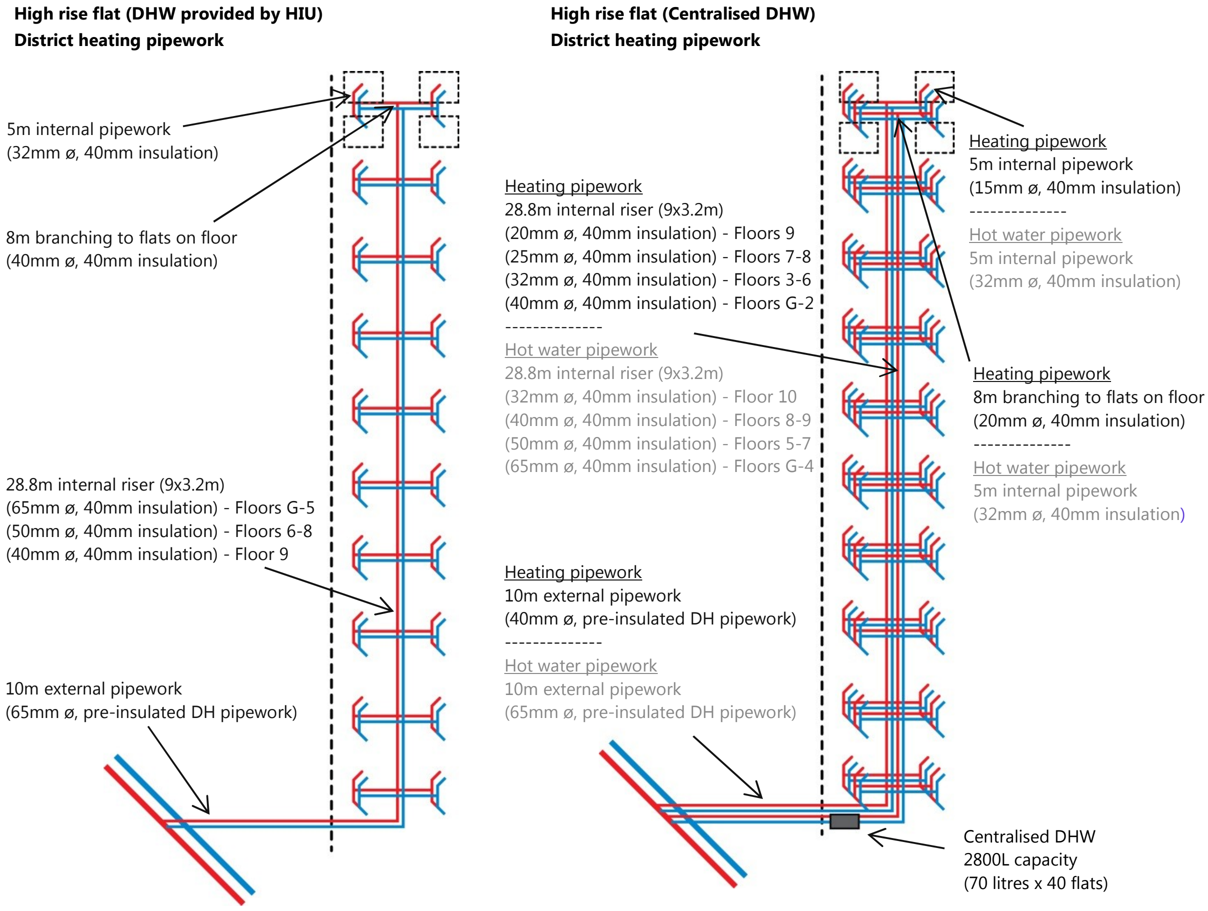

Figure 6-4 Pipework length and thickness assumptions for high rise flat (centralised DHW option shown on right).

Where DHW is supplied by the HIU in each flat, a 65mm pre-insulated district heating branch from the street main has been sized, with an internal riser reducing down to 40mm by the top floor. 8m of pipework has been assumed for a main branch per floor. 5m of pipework has then been costed in each dwelling.

For the centralised DHW typology, a 4-pipe solution has been costed. A 40mm pre-insulated district heating branch from the street main has been sized for space heating, plus a 65mm branch for hot water. Assumptions for all above ground pipework is then as shown on the drawing. The central hot water store of 2,800 litres has been provided based on a 70 litre per flat allowance as per CIBSE guide G[13].

As it was found to be of lower cost, the option with the individual HIUs is selected in the cost summaries presented in Section 1.1. See Section 6.6 for the cost comparison of the two options.

District heating pipe sizing in commercial buildings

A similar approach has been taken for specifying the non-domestic pipework design, based on the heating system in each case. Assumptions for pipe sizes and insulation levels are illustrated in Figure 6-5 and Table 6-1.

For all models connection from the street to the HIU was considered. For heat pump and VRF systems further additional piping is included. For VRF systems this is the full routing of a wet heating system. For heat pumps this is for a riser only, as it is assumed that the heat pump is located on the roof, then feeding a wet heating system.

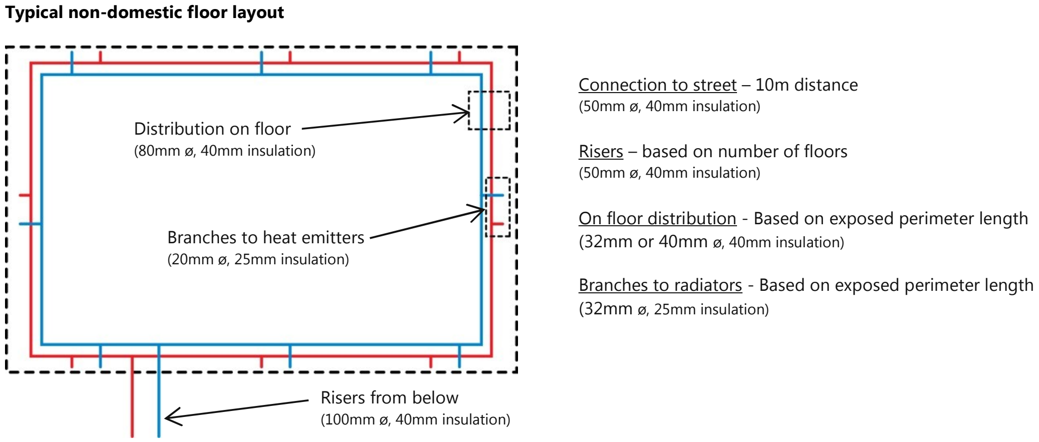

Figure 6-5 Schematic of different pipe types for a typical commercial floor layout.

Table 6-1 Pipework sizing and insulation levels for non-domestic typologies.

Item	Diameter (mm)	Insulation thickness (mm)	Distance
Connection from street	50	40	5m for small buildings, 10m for large buildings
Connection to HIU	50	40	10m for small buildings, 20m for large buildings
Risers	50	40	Based on number of floors
On floor distribution	32 or 40	40	Based on exposed perimeter length
Branch to radiators	32	25	Based on exposed perimeter length

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[13] CIBSE Guide G, Public Health & Plumbing Engineering, 2014, Chartered Institution of Building Services Engineers

6.3 Cost references

The following section describes the unit costs assumed for internal works, external works and additional costs including builders' works, contractor preliminaries and overheads. Costs are based on a combination of BuroHappold internal references and project experience, plus the industry costing guide SPON'S[14] figures including labour.

External works

Further to the pipework design assumptions described Table 6-2 gives the unit cost data used for below ground district heating pipework i.e. the cost of a branch from the street main into the property. Figures are based on BuroHappold experience and represent the cost of flow and return district heating pipework including trenching. For the connection to the street main a further trenching and cost allowance has been provided as per Table 6-4, excluding traffic management costs.

Table 6-2 Below ground pre-insulated district heating pipework costs. Cost per metre is for flow and return pipework including trenching and insulation. Pipework diameter represents the internal pipe diameter.

Pipework diameter	£ per m	Reference
125 mm	£ 270	BH reference values
100 mm	£ 230	BH reference values
80 mm	£ 205	BH reference values
65 mm	£ 195	BH reference values
50 mm	£ 180	BH reference values
40 mm	£ 170	BH reference values
32 mm	£ 160	BH reference values

Table 6-3 Assumptions for cost of connection to street main (excluding traffic management costs).

	£ per m	Reference
600 x 1000mm trench	£ 300	BH reference values
Connection to street main	£ 500	BH reference values

Internal works

Regarding internal works, the cost of above ground district heating pipework, assumed to be insulated steel piping are based on the values in Table 6-4.

Table 6-4 Cost references for above steel pipework with 40mm of insulation. Pipework diameter represents the internal pipe diameter.

Pipework diameter	Pipework - £ per m	Insulation - £ per m	Reference
80 mm	£ 52.12	£ 17.05	SPON'S p245, p374
65 mm	£ 42.96	£ 14.32	SPON'S p245, p374
50 mm	£ 35.98	£ 13.19	SPON'S p245, p374
40 mm	£ 29.43	£ 12.11	SPON'S p245, p374
32 mm	£ 25.97	£ 11.72	SPON'S p245, p374
25 mm	£ 22.52	£ 11.23	SPON'S p245, p374
20 mm	£ 19.27	£ 10.71	SPON'S p245, p374
15 mm	£ 17.92	£ 10.52	SPON'S p245, p374

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[14] SPON'S Mechanical and Electrical Services Price Book 2015. 46th Edition. AECOM.

For electric heated buildings, new radiators with TRVs have been costed. In all cases, the radiator size is based upon an 'idealised' system, with a 10% oversizing allowance, based on the properties simulated space heating load (in practice however, it would not be uncommon for radiators to be far more oversized in properties). Associated costs, together with radiator pipework costing figures are given in Table 6-5 and Table 6-6, respectively.

Table 6-5 Assumptions for new radiator costs. Domestic radiator sizes determined based upon peak loads with 10% safety margin and an assumed number of heated rooms per dwelling. Stelrad radiator handbook[15] used for radiator sizing at Δ50t. for the Vita Value K1 series.

	Output (W)	Cost	Cost reference
450 x 1800 mm	1,309	£ 204.78	SPON'S p360
450 x 1600 mm	1,163	£ 197.60	SPON'S p360
450 x 1100 mm	800	£ 136.81	SPON'S p360
450 x 900 mm	654	£ 117.40	SPON'S p360
450 x 800 mm	582	£ 107.69	SPON'S p360
450 x 700 mm	509	£ 97.98	SPON'S p360
450 x 600 mm	436	£ 88.27	SPON'S p360
300 x 500 mm	250	£ 73.7	SPON'S p360
Thermostatic radiator value	-	£ 39.94	SPON'S p369

Table 6-6 Radiator pipework costs.

Pipework diameter	Pipework - £ per m	Insulation - £ per m	Reference
20 mm	£ 13.56	£ 7.76	SPON'S p376, p371

Costs used for domestic HIUs, including installation and testing costs, plus the meter are given in Table 6-7, based on a recent project quote obtained for residential apartment building. Costs for non-domestic HIUs, shown in Table 6-8 are based on SPON'S values for low temperature hot water heat exchangers. For large offices, an allowance of two HIUs is provided. Costs for heat meters and pumping applied to commercial properties are given in Table 6-9.

Table 6-7 Domestic HIU cost. Cost includes meter, installation and testing.

Pipework diameter	Cost (£)	Reference
Heating only	£ 2,500	BH project quote
Heating + DHW	£ 2,200	BH project quote

Table 6-8 Non-domestic HIU cost. Valves, fixtures and fittings included through the addition of a % overhead for builders works.

Size (kW)	Capacity (l/s)	Cost (£)	Reference
107	2.38	£ 2,557	SPON'S p357, LTHW Heat Exchanger
245	5.46	£ 3,789	SPON'S p357, LTHW Heat Exchanger
287	6.38	£ 4,177	SPON'S p357, LTHW Heat Exchanger
328	7.31	£ 4,534	SPON'S p357, LTHW Heat Exchanger
364	8.11	£ 5,332	SPON'S p357, LTHW Heat Exchanger
403	8.96	£ 5,584	SPON'S p357, LTHW Heat Exchanger

Table 6-9 Heat meter and pumps costs. Valves, fixtures and fittings are included through the addition of a % overhead for builders works.

	Cost (£)	Reference
Heat meter	£ 500	SPONS p9
Pump (0.25 kW)	£ 1,750	SPON'S p352
Pump (4-5 kW)	£ 3 000	SPON'S p352, average value

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[15] Stelrad radiator book 2016. https://www.stelrad.com/support-information/downloads/

Additional costs

Although labour is allowed for in the cost data provided, a further labour allowance has been allocated to the costing models to account for additional resource required due to the works being in existing buildings.

Table 6-10 gives the labour allowance applied for domestic properties, whereby an allowance of two labourers for two to three days has been allowed for in gas and electric properties, respectively. Efficiency savings have been applied in the larger low rise and high rise properties with higher tenancy numbers to account for concurrent works.

Table 6-10 Assumptions for additional labour allowance for domestic retrofit works. Labour cost based on rate of £26.16/hour from SPONS.

Building	Conversion	Labour allowance per dwelling	Dwellings	Time efficiency
Mid terrace house	Gas	2 labourers for 2 days	1	-
Mid terrace house	Electric	2 labourers for 3 days	1	-
Low rise flat, converted	Gas	2 labourers for 2 days	8	-
Low rise flat, converted	Electric	2 labourers for 3 days	8	-
Low rise flat, purpose built	Gas	2 labourers for 2 days	32	25%
Low rise flat, purpose built	Electric	2 labourers for 3 days	32	25%
High rise flat	Gas	2 labourers for 2 days	40	25%
High rise flat	Electric	2 labourers for 3 days	40	25%

A similar approach was applied to the non-domestic buildings, depending on the size of the property and complexity of the heating system conversion, as illustrated in Table 6-11, with the largest allowance being for the conversion of the VRF systems, followed by heat pumps then gas boilers.

Table 6-11 Assumptions for additional labour allowance for non-domestic works. Labour cost based on rate of £26.16/day from SPONS.

Building	Conversion	Labour allowance per dwelling
Office and retail (large)	Gas	2 labourers for 4 days
Office and retail (large)	Heat pump	2 labourers for 5 days
Office and retail (large)	VRF	2 labourers for 10 days
Office and retail (small)	Gas	2 labourers for 2 days
Office and retail (small)	Heat pump	2 labourers for 2.5 days
Office and retail (small)	VRF	2 labourers for 5 days

Finally, as shown in Table 6-12, a 10% increase in capital costs has been applied to account for builders works, including factors such as site visits, core drilling, the removal of existing heating and DHW plant, as well as making good of surfaces and road finishes. A further allowance of 25% increase in capital cost has been applied to allow for Contractor preliminaries and overheads.

Table 6-12 Additional cost uplifts for builders works (i.e. site visits, core drilling, removal of existing heating and DHW systems and making good of finishes) and Contractor preliminaries and overheads.

	CapX increase	Reference
Builders works	10%	BH reference values
Contractor preliminaries and overheads	25%	BH reference values

Exclusions

As previously noted, traffic management costs have been excluded from the costing exercise. Furthermore, the boundary for the costing assessment does not include the installation of the main district heating network and associated infrastructure. Efficiency savings from shared district heating connections are also not included, so as to provide conservative cost estimates. Value Added Tax (VAT) is excluded.

6.4 Cost summary

A summary of the district heating conversion costs in £/m² is given for electrical and gas heated typologies in Figure 6-6 and Figure 6-7, respectively. Cost breakdowns per dwelling and building (in terms of total costs, then costs per m²) are given in full page datasets in Appendix C (see Table C-3 and C-4).

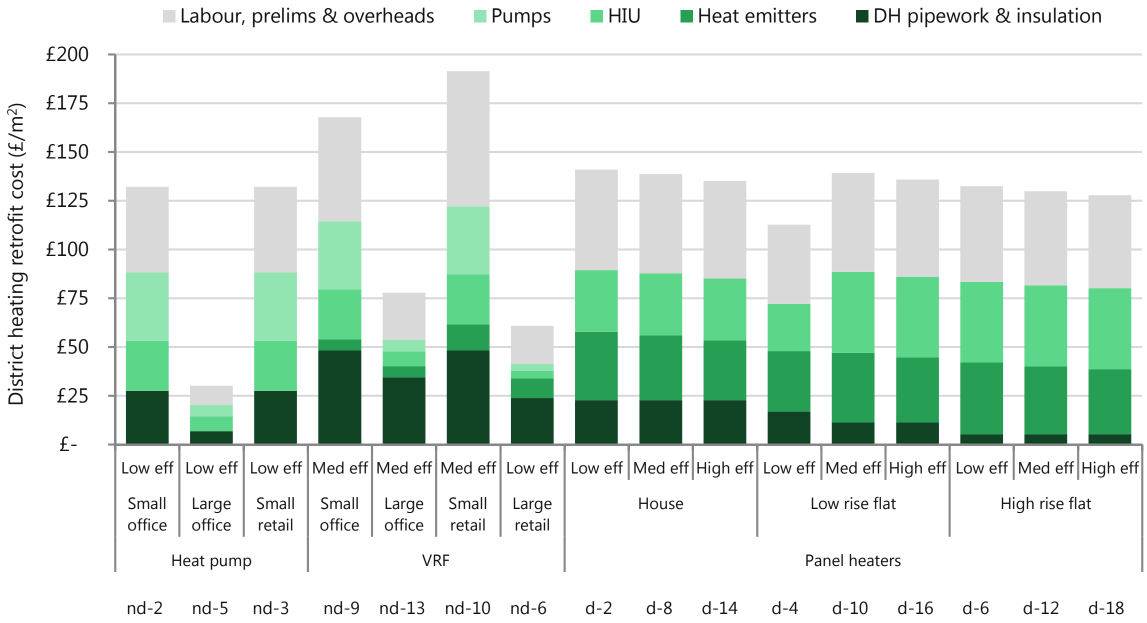

Figure 6-6 Summary of district heating retrofit costs by typology - electric heating conversion results.

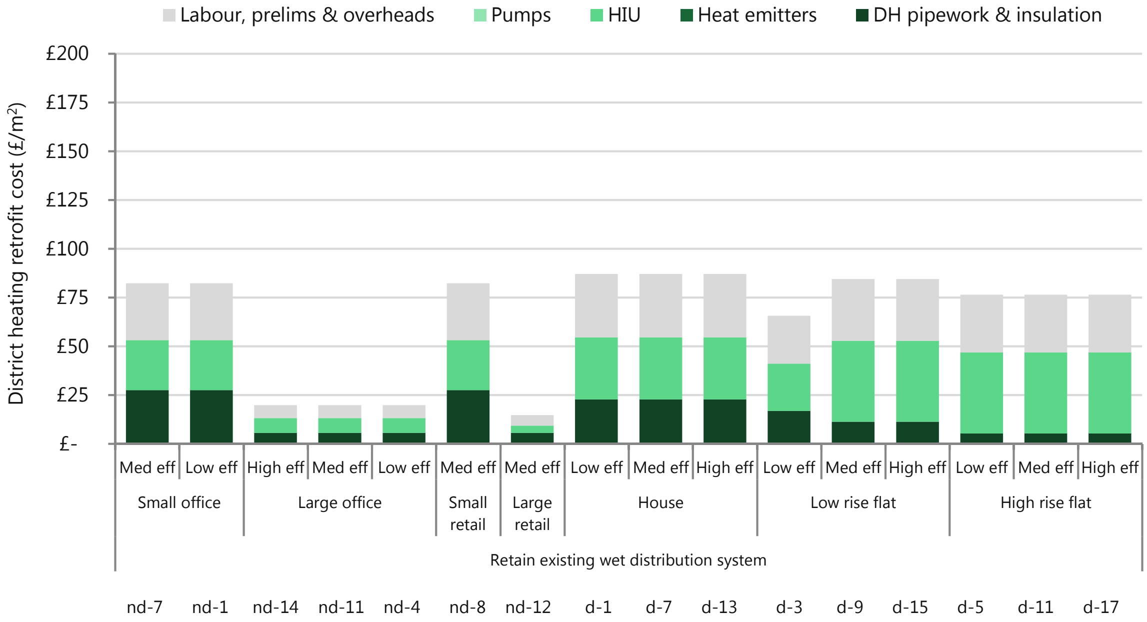

Figure 6-7 Summary of district heating retrofit costs by typology – gas heating conversion results.

6.5 Observations

Upon reviewing the costing data, a number of trends can be observed, as summarised below:

Domestic retrofit

Domestic (electric conversion):

- Connection costs for electric heated domestic properties reduce slightly as the property becomes more efficient; this is due to the better insulated properties needing smaller output radiators.
- Per m^2, the retrofit cost for the low efficiency low rise flat is less than it's medium and high efficiency counterparts (i.e. £113/m^2, compared to £139m^2 and £135m^2); this is because that typology represents the converted flat, modelled as having a larger floor area to the purpose built flat typologies.
- In terms of absolute costs, the retrofit cost for converted flats is higher at £11,600, compared to £8,400 and £8,200 for the medium and high efficiency low rise flats respectively.
- With the exception of the low rise converted flat, the retrofit costs for houses are the most expensive, followed by the low rise flats, then high rise flats. The average cost to convert a house is £10,900 (£138/m^2), compared to £9,400 (£129/m^2) for low rise flats and £7,800 (£130/m^2) for high rise flats.

Domestic (gas conversion):

- Per m^2, the lowest cost typologies for conversion to district heating from gas are the low-rise low efficiency flat (£66/m^2), followed by all high rise flat typologies (£76/m^2), the purpose built flats (£84/m^2) and houses (£87/m^2). In absolute terms the high rise flat is the lowest cost (£4,600), followed by the low rise converted flat (£5,100), then the low rise purpose built flat (£6,780) and the house at £6,850).
- The comparative average conversion costs for gas heated domestic properties are £6,850 for the house, £5,650 for low rise flat and £4,600 for high rise flat conversions. The principal difference between costs for gas heated and electrically heated properties being the installation of the new wet heating system and associated heat emitters.

Domestic (all typologies):

- The cost per m^2 for district heating pipework costs in domestic properties is lowest in the high rise flats, with costs per dwelling as low as £320 per dwelling in medium and high efficiency properties, compared to costs around £680 for low-rise purpose built flats and £1,750 and £1,790 respectively for houses and converted flat.
- In terms of total building costs, the conversion of the electrically heated 10 storey high rise low efficiency flat with 40 dwellings is the highest cost at ~£320,000. By comparison, the conversion of the same typology from gas is ~£185,000.

Non-domestic retrofit

Non-domestic (electric conversion):

- Higher costs are observed in the conversion of medium efficiency buildings, compared to low efficiency buildings. In particular, this is driven by the higher pipework costs associated with non-domestic VRF typologies, compared to heat pump solutions.
- The lowest cost per m^2 is the conversion of the low efficiency large 1,000m^2 office with electric heat pumps at £30/m^2, where there is already a wet system in place. This is followed by the large medium efficiency retail conversion from VRF at £61/m^2 and large medium efficiency office with VRF at £78/m^2. For small premises, both the low efficiency small office and small retail are the lowest cost at £132/m^2.

Non-domestic (gas conversion):

- Per m^2, the large retail typology is shown to be the lowest cost to retrofit at £15/m^2, followed by the large office typologies at £20/m^2, compared to £82/m^2 for the retrofit of small office and retail units.

6.6 Centralised DHW storage

In the costing exercise presented, the strategy assumed for the conversion of the high rise electric flat was to have DHW provided instantaneously from HIUs within each apartment, opposed to the option of having a centralised DHW store. For information, the cost sensitivity of this is illustrated in Figure 6-8.

The costs for the DHW store are based on a £12,500 allowance for a 3,000 litre storage vessel (SPON'S p289), and £13,500 allowance for plate heat exchanger, pumps, valves and associated metering (SPONS p9, p357) and £500/m^2 allowance for a 3m by 4m insulated external store. Further costs associated with the 4-pipe solution are based on the pipework design presented earlier in Figure 6-4.

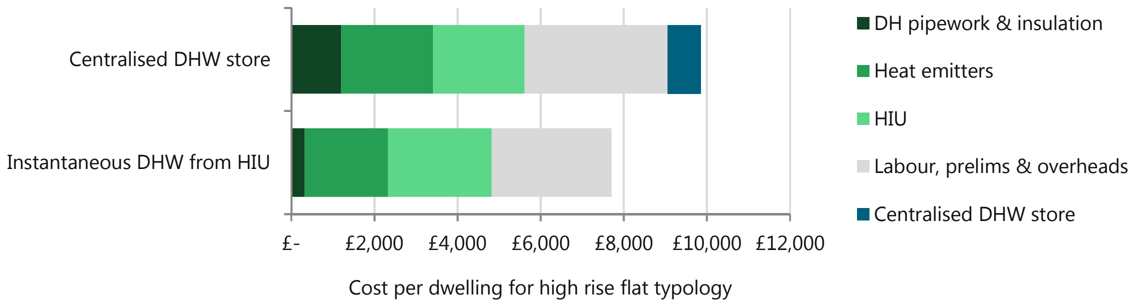

Figure 6-8 Capital cost comparison for high rise, low efficiency electric flat conversion – centralised DHW vs. instantaneous heat from HIU. The total cost per dwelling for the instantaneous DHW from HIU option is £ 7,983, based on the low efficiency high rise flat. The centralised DHW store cost is £9,857 per dwelling. The total building retrofit costs are £319,316 and £394,289 respectively.

As shown, the addition of the store and associated additional pipework, going from a 2-pipe solution to 4-pipe strategy is found to increase capital costs by approximately 25%, equivalent to approximately £2,000 per dwelling. Per m^2, this increases conversion costs from £128/m^2, to £163/m^2

A separate centralised DHW store is only a necessary consideration at low temperatures as such this option will not be considered further until Work Package 4.

6.7 Summary

Overall, this costing exercise has found that the lowest cost typologies to retrofit per m^2, are all of the large office and retail typologies, with gas and electric heat pump conversion having the lowest costs. For domestic typologies, the conversion from gas is less expensive than from electricity, with a general trend that high rise flats are the least expensive to retrofit per dwelling, followed by low rise flats and houses.

In general, it is the cost of HIUs, new heat emitters in electric properties and pumps in commercial buildings having the largest impacts on costs per m^2. By comparison, the costs of heating pipework per m^2 are found to vary more considerably between properties, particularly where multiple dwellings are retrofitted together (e.g. low and high rise buildings) and the total dwelling cost is a function of the average cost per building, demonstrating economies of scale.

In the next chapter, the payback calculation compared to the existing counterfactual heating case is carried out to determine a measure of cost effectiveness that compares retrofitting costs for the 32 identified typologies.

7 Cost Effectiveness & Retrofit Spatial Mapping (WP3A)

7.1 Overview

In this work package, the cost effectiveness of district heating retrofit is assessed based upon a discounted payback calculation, comparing the capital and annualised running costs of a district heated property to the existing counterfactual case (e.g. gas boiler, electric heating). The method allows the costs of retrofitting the 32 typologies to be compared against one another to determine their relative cost effectiveness, with findings spatially mapped for London at LSOA level. The study provides intelligence about the existing building stock that can help to inform district heating pre-feasibility studies about the cost and opportunity for retrofitting existing buildings for connection to local heat networks as part of a strategic district heating expansion programme and an integrated decarbonisation plan.

7.2 Payback model inputs

To undertake the payback calculation, reference fuel costs, outlined in Table 7-1, have been taken from the retail values of DECC Energy and Emissions Projections[16]. Counterfactual capital costs and operation and maintenance are based upon the figures in Table 7-2 and Table 7-3, respectively. District heating O&M costs are also given.

Table 7-1 Payback model assumptions for discount rate and fuel costs.

Model inputs	Value	Unit	Reference
Discount rate	3.5%	-	HM Treasury Green Book
Fuel cost (residential gas)	40	£/MWh	DECC 2016 retail prices
Fuel cost (services gas)	27	£/MWh	DECC 2016 retail prices
Fuel cost (residential electricity)	150	£/MWh	DECC 2016 retail prices
Fuel cost (services electricity)	108	£/MWh	DECC 2016 retail prices

Table 7-2 Capital cost assumptions for counterfactual cases.

Model inputs	Value	Unit	Reference
Electric panel heaters	175	£	BH reference values
Residential gas boiler	165	£/kW	BH reference values
Commercial gas boiler	90	£/kW	SPON'S p32
Heat pump	1,250	£	SPON'S p24
VRF - Air cooled chiller	41	m^2 GIA	SPON'S p122
VRF – 2 pipe system	125	£/kW	SPON'S p144
VRF – Heat rejection	57.5	£/kW	SPON'S p122
VRF – Pumps (small building)	1,750	£	SPON'S p352
VRF - Pumps (large building)	3,000	£	SPON'S p352
Plant replacement period	15	Years	BH reference values
% of plant to replace	90%	-	BH reference values
Builders works	10%	-	BH reference values
Preliminaries & overheads	25%	-	BH reference values

Table 7-3 Operation and maintenance (O&M) costs assumed.

Model inputs	Value	Unit	Reference
Residential gas boiler	200	£	Poyry study & Heattrust.org
Commercial gas boiler	3	£/kW	Poyry study

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[16] *DECC Energy & Emissions Projections.* Annex M. Growth assumptions and prices. Reference scenario (November 2015)

Electric panel heaters	17	£/kW	Poyry study
VRF	25	£/kW	Poyry study
Heat pump	9	£/kW	Poyry study
District heating HIU (domestic)	50	£	Poyry study
District heating HIU (non-domestic)	2.5	£/kW	Poyry study

7.3 Baseline energy use

Energy use per typology is based upon baseline primary energy use calculations generated through the Strathclyde University ESP-r modelling process (described earlier in section 5.3), with annual fuel usage for each counterfactual case, determined using the baseline system efficiencies for each typology.

The counterfactual annual fuel use per typology in kWh/m^2 is illustrated in Figure 7-1. Here, it can be seen that energy use for the non-domestic electric heat pump and VRF typologies are generally the lowest due to seasonal efficiencies associated with those heating systems. For domestic typologies, the reduction in energy requirements as the property becomes more efficient can be observed, with DHW becoming an increasing proportion of the overall heat demand of the property as the property becomes more thermally efficient. Tabulated primary energy use and fuel usage data is given a full page data table in Appendix C (see Table C-5).

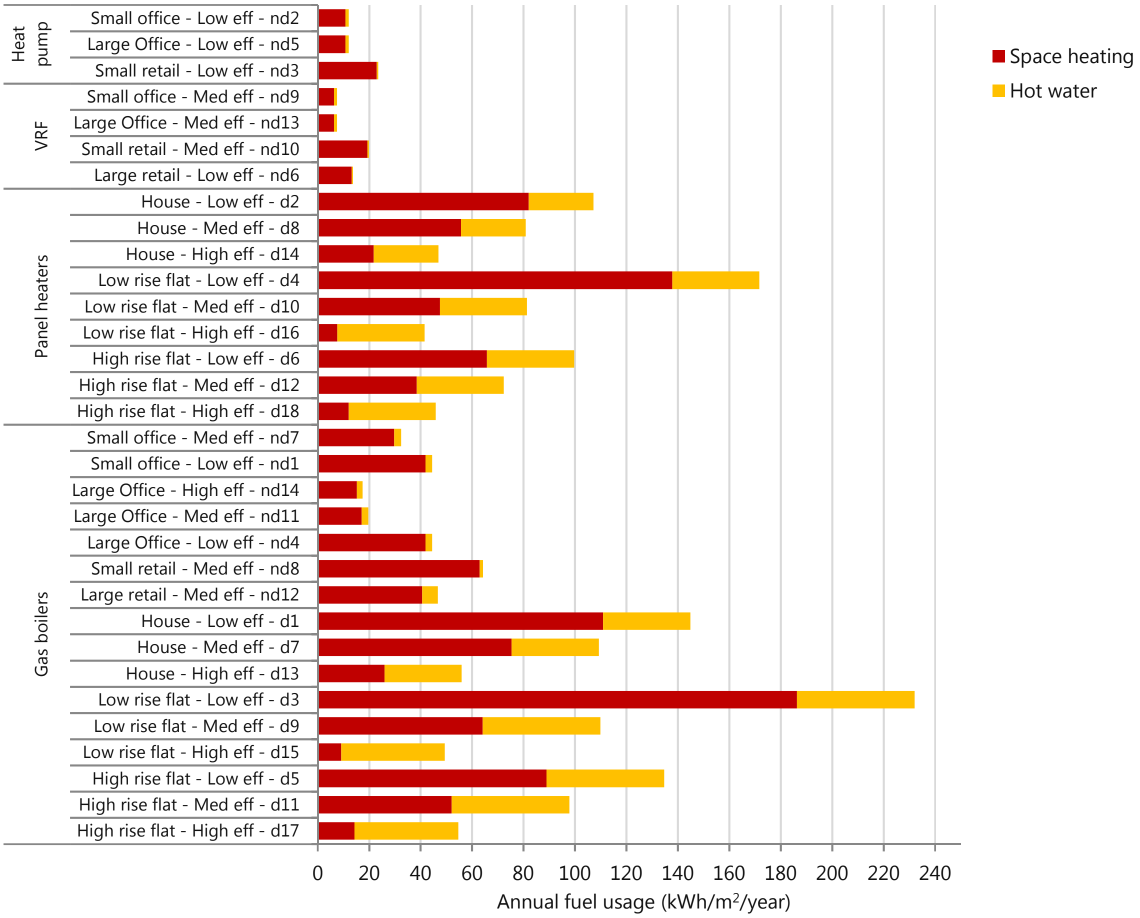

Figure 7-1 Baseline energy use (i.e. fuel usage with system efficiencies applied, thus representing counterfactual cases). For information, the low rise flat is a solid walled converted flat with large single glazing area, and the house is a 3 bedroom mid-terrace.

7.4 Cost effectiveness study

Table 7-4 overleaf gives the output of the cost effectiveness analysis model. The payback calculation compares the lifetime costs of the district heating retrofit investment and user running costs vs. a counterfactual case, i.e. the annualised capital and running costs of an existing gas boiler or electric heating system. The assessment of 'cost effectiveness' compares the retrofitting costs for the 32 identified typologies and is determined based upon whether a 30 year payback can be achieved within the theoretical range of heat retail prices investigated. This 30 year payback is based upon guidance for the economic evaluation of heat supply from the Sustainable Design and Construction Supplementary Planning Guidance and Energy Planning Guidance [17].

In agreement with the GLA, where a typology payback is less than 15 years across the range of heat prices tested it is described as high cost effectiveness, whereas medium cost effectiveness is described as 15-30 years. Where the payback for a typology is above 30 years, the district heating case is described as low cost effectiveness. For reference, the fixed counterfactual cost to supply a MWh of heat (with total cost considering annualised fuel usage, plant replacement cost and O&Ms) are shown. The high, medium and low cost effectiveness categories give a cost distinction to the 32 typologies giving an initial relative likelihood of connection to a local heat network that can then be used as intelligence when undertaking a pre-feasibility study for a new or expanding district heating networks.

The methodology used i.e. testing multiple heat prices, and using the Green Book 3.5% discount interest rate, was selected to be able to illustrate the relative attractiveness of district heating retrofit across all identified typologies, rather than a detailed calculation of financial payback. No market interventions, subsidies or additional policy interventions to support decarbonisation of heat supply are assumed in this calculation. As such, the assessment is not meant to represent the decision making of network operators or potential customers who will have varying requirements in terms of payback/discount rate, but rather to allow the most cost effective typologies to be identified spatially so that they can be considered as potential consumers when undertaking energy Masterplanning.

In practice, district heating cost effectiveness would be a function of the variable cost of heat from district heating price plus fixed charges. For domestic customers in the private sector the costs are typically benchmarked against the equivalent costs of heat from a gas boiler. In the social housing sector landlords typically pick up fixed costs, with energy costs passed through at cost. Levelised heat cost for gas heated domestic properties are in the range of 7.5-20p/kWh (£100-200/MWh) depending on usage of heating (larger, less efficient properties have a lower unit cost as there are more energy units over which to spread the fixed costs). For new build projects with heating supply to individual domestic customers in the private sector prices are typically in the range 12-17p/kWh (£120-170/MWh based on BuroHappold's experience of the market) for highly thermally efficient 2-4 bedroom flats respectively. UK Government states that heat networks can be 30% cheaper than the equivalent cost of heating through gas[18].

For non-domestic customers with high energy use the fixed costs of the heating system are less important and the costs of the variable energy used tend to dominate, along with the efficiency of the fuel's conversion to useful heat. Compared to natural gas prices in the range £21-41/MWh for 'Very Small' to 'Medium' customers[19] (equivalent to a heat price of £26-51/MWh at 80% boiler efficiency) typical market prices for district heating supply for non-domestic users are in BuroHappold's experience around £40-50/MWh, though some older schemes have lower tariffs. Many of these schemes have variable charges which are indexed to the cost of natural gas, often a key input cost.

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[17] Energy Planning, Greater London Authority guidance on preparing energy assessments
https://www.london.gov.uk/sites/default/files/gla_energy_planning_guidance_-_march_2016_for_web.pdf

[18] Assessment of the Costs, Performance, and Characteristics of UK Heat Networks, AECOM,
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/424254/heat_networks.pdf

[19] Department for Business, Energy and Industrial Strategy, Quarterly energy prices tables, Sep 2016,
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/555985/QEP_Q216_Tables_Annex.pdf

Table 7-4 District heating cost effectiveness calculation compared to counterfactual case. High cost effectiveness means a payback of 15 years or less is possible. Medium cost effectiveness is paybacks of 15-30 years. Low cost effectiveness is if the payback is above 30 years. Values above 50 years are shown in grey. If payback is listed as "n/a" it is above 100 years. The calculated counterfactual cost of heat is also shown.

District heating heat price (£/MWh)			25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	Counterfactual cost (£/MWh)
Typology			Payback period (years) at different district heating unit prices																			
Electric heating conversion	nd-2	Small office - Low eff. - Heat pump	49	52	55	59	65	71	80	94	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£559
	nd-5	Large Office - Low eff. - Heat pump	4	4	4	4	4	4	4	4	5	5	5	5	6	6	6	6	7	7	7	£521
	nd-3	Small retail - Low eff. - Heat pump	34	36	39	43	48	54	63	76	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£361
	nd-9	Small office - Med eff. - VRF	67	71	76	81	89	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£992
	nd-13	Large Office - Med eff. - VRF	12	12	12	12	13	13	13	14	14	14	15	15	16	17	17	18	18	18	19	£794
	nd-10	Small retail - Med eff. - VRF	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£477
	nd-6	Large retail - Low eff. - VRF	17	17	18	19	20	21	23	24	26	28	30	33	41	47	55	69	n/a	n/a	n/a	£472
	d-2	House - Low eff. - Panel heaters	10	10	11	11	12	12	13	14	15	16	17	18	22	24	26	30	34	34	41	£180
	d-8	House - Med eff. - Panel heaters	14	14	15	16	16	17	18	19	21	22	24	26	31	34	39	45	54	54	70	£188
	d-14	House - High eff. - Panel heaters	25	27	28	30	31	33	36	39	42	46	51	57	83	n/a	n/a	n/a	n/a	n/a	n/a	£211
	d-4	Low rise flat - Low eff. - Panel heaters	7	8	9	9	10	10	11	13	14	15	17	19	19	21	22	24	26	30	34	£177
	d-10	Low rise flat - Med eff. - Panel heaters	13	14	15	15	16	17	18	19	20	21	23	24	28	31	35	39	45	45	54	£198
	d-16	Low rise flat - High eff. - Panel heaters	27	28	30	31	33	35	37	39	42	46	50	55	71	88	n/a	n/a	n/a	n/a	n/a	£243
	d-6	High rise flat - Low eff. - Panel heaters	10	10	11	11	12	13	13	14	15	16	17	18	21	23	25	27	31	31	35	£191
	d-12	High rise flat - Med eff. - Panel heaters	14	15	15	16	17	18	18	20	21	22	23	25	29	32	36	40	46	46	55	£204
	d-18	High rise flat - High eff. - Panel heaters	22	23	24	26	27	28	30	31	33	36	38	42	50	57	66	80	n/a	n/a	n/a	£234
Gas heating conversion	nd-7	Small office - Med eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£120
	nd-1	Small office - Low eff. - Gas boilers	64	81	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£100
	nd-14	Large Office - High eff. - Gas boilers	45	87	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£55
	nd-11	Large Office - Med eff. - Gas boilers	35	50	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£52
	nd-4	Large Office - Low eff. - Gas boilers	19	29	73	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£40
	nd-8	Small retail - Med eff. - Gas boilers	49	60	84	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£80
	nd-12	Large retail - Med eff. - Gas boilers	22	38	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£37
	d-1	House - Low eff. - Gas boilers	18	20	23	28	35	47	83	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£66
	d-7	House - Med eff. - Gas boilers	22	24	28	33	41	54	91	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£74
	d-13	House - High eff. - Gas boilers	35	40	46	56	72	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£106
	d-3	Low rise flat - Low eff. - Gas boilers	16	17	19	21	22	24	32	54	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£63
	d-9	Low rise flat - Med eff. - Gas boilers	17	18	20	23	26	30	36	46	65	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£85
	d-15	Low rise flat - High eff. - Gas boilers	25	26	28	31	34	37	42	48	57	72	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£140
	d-5	High rise flat - Low eff. - Gas boilers	13	14	16	18	21	24	29	38	54	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£77
	d-11	High rise flat - Med eff. - Gas boilers	15	17	18	20	23	26	30	36	45	63	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£91
	d-17	High rise flat - High eff. - Gas boilers	20	22	24	26	28	31	35	39	46	56	75	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£130

7.5 Observations

For domestic properties, from Table 7-4, it is the electrically heated properties, particularly the dwellings with a low fabric efficiency would be the most cost effective to retrofit. Across gas heated domestic properties, the low and medium efficiency high rise flats are also of high to medium cost effectiveness, with low-rise flats preferable to retrofit than houses. Principally however, it should be the electric heated properties that are focused upon first.

For the non-domestic properties, gas-heated commercial premises are generally seen to be of low cost effectiveness to retrofit, with the lowest payback here being the small units. For the electrically heated non-domestic properties, the large office with heat pump as its baseline system is shown to be the most cost effective; this is because of the low connection cost given that typology already has a wet system installed. The large office and large retail typologies with VRF are also shown to be cost effective to retrofit, despite a new wet system needing to be installed, principally because the district heating running cost would be lower than the cost of electricity as well as the reduced O&M costs.

Typologies not found to be cost effective include all of the small office and small retail unit typologies, due to the higher capital cost per m^2. The high efficiency domestic typologies are also found to be of low cost effectiveness in most cases, due to the baseline fuel usage being low, meaning the investment in district heating is not found to be as cost effective. It is also important to remember this is from a financial perspective with no consideration of the delivery of social goals, such as fuel poverty, or environmental ones, such as carbon reduction, so these would need to be integrated into considerations when developing a decarbonisation strategy for a district or neighbourhood.

7.6 Spatial mapping of cost effectiveness

Table 7-5 gives a summary of the maximum cost effectiveness achieved for each typology within the range of theoretical heat prices, with electric heating conversion results shown on the left and gas heating conversion results on the right. Based on these outputs a series of spatial maps for London have been produced, illustrating the number and density of "high" and "high and medium" cost effective properties respectively per LSOA, overlaid against the London Energy Plan district heating priority areas. These maps are given over the next four pages for the domestic and non-domestic buildings combined.

Table 7-5 Summary of cost effectiveness results (illustrating best payback period across all heat retail prices assessed).

Typology			Cost effectiveness
Electric heating conversion	nd-2	Small office - Low eff - Heat pump	LOW
	nd-5	Large Office - Low eff - Heat pump	HIGH
	nd-3	Small retail - Low eff - Heat pump	LOW
	nd-9	Small office - Med eff - VRF	LOW
	nd-13	Large Office - Med eff - VRF	HIGH
	nd-10	Small retail - Med eff - VRF	LOW
	nd-6	Large retail - Low eff - VRF	MEDIUM
	d-2	House - Low eff - Panel heaters	HIGH
	d-8	House - Med eff - Panel heaters	HIGH
	d-14	House - High eff - Panel heaters	MEDIUM
	d-4	Low rise flat - Low eff - Panel heaters	HIGH
	d-10	Low rise flat - Med eff - Panel heaters	HIGH
	d-16	Low rise flat - High eff - Panel heaters	MEDIUM
	d-6	High rise flat - Low eff - Panel heaters	HIGH
	d-12	High rise flat - Med eff - Panel heaters	HIGH
	d-18	High rise flat - High eff - Panel heaters	MEDIUM

Typology			Cost effectiveness
Gas heating conversion	nd-7	Small office - Med eff - Gas boilers	LOW
	nd-1	Small office - Low eff - Gas boilers	LOW
	nd-14	Large Office - High eff - Gas boilers	LOW
	nd-11	Large Office - Med eff - Gas boilers	LOW
	nd-4	Large Office - Low eff - Gas boilers	MEDIUM
	nd-8	Small retail - Med eff - Gas boilers	LOW
	nd-12	Large retail - Med eff - Gas boilers	MEDIUM
	d-1	House - Low eff - Gas boilers	MEDIUM
	d-7	House - Med eff - Gas boilers	MEDIUM
	d-13	House - High eff - Gas boilers	LOW
	d-3	Low rise flat - Low eff - Gas boilers	MEDIUM
	d-9	Low rise flat - Med eff - Gas boilers	MEDIUM
	d-15	Low rise flat - High eff - Gas boilers	MEDIUM
	d-5	High rise flat - Low eff - Gas boilers	HIGH
	d-11	High rise flat - Med eff - Gas boilers	HIGH
	d-17	High rise flat - High eff - Gas boilers	MEDIUM

Number of "high" cost effective properties – Domestic and non-domestic

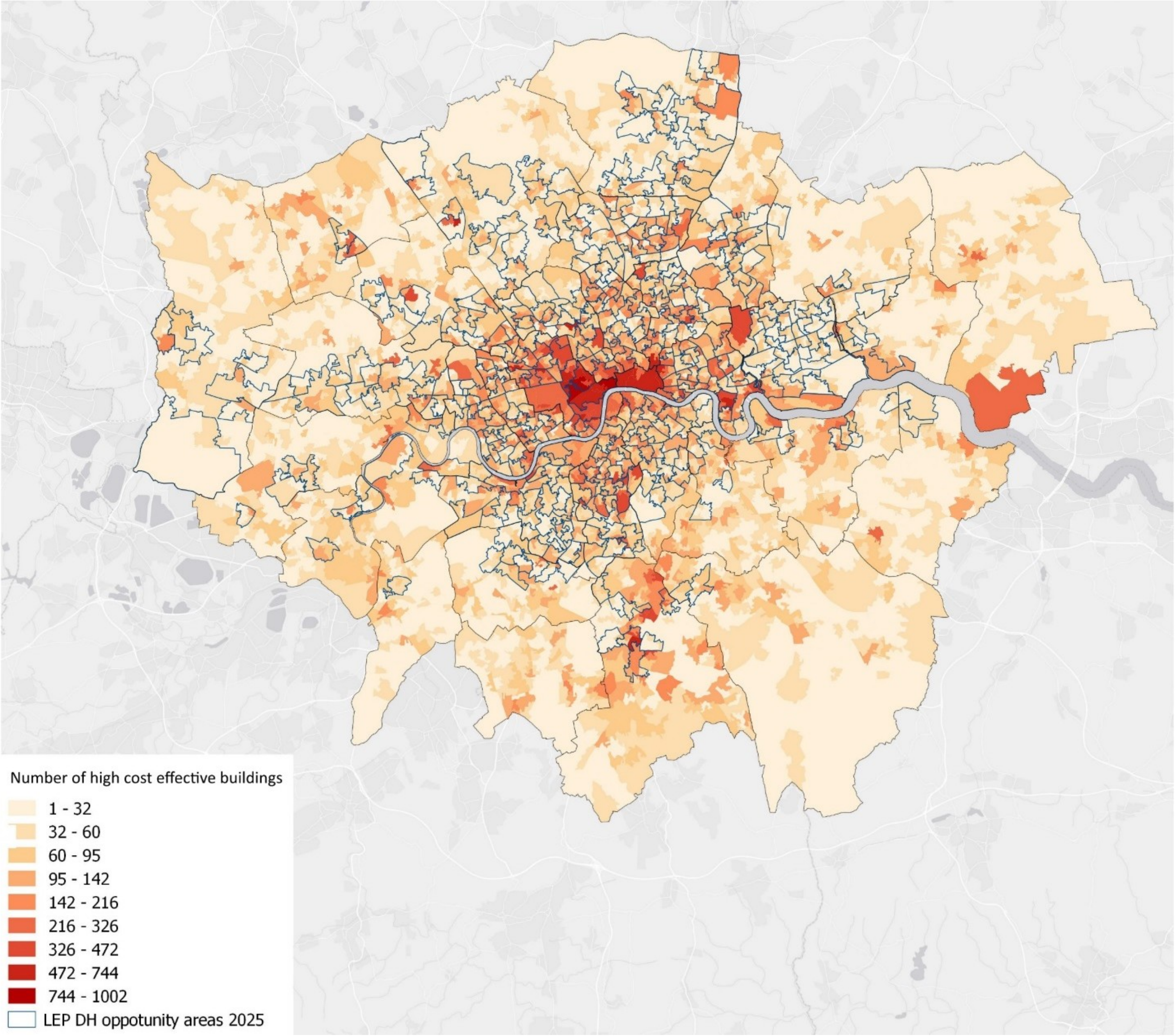

Figure 7-2 Spatial mapping of the number of high cost effective buildings per LSOA (domestic and non-domestic combined).

Table 7-6 LSOAs with the largest number high cost effective properties.

	High cost effectiveness – domestic	#	High cost effectiveness – non-domestic	#	High cost effectiveness – combined	#
1	Westminster 018B	680	Westminster 013E	581	Westminster 018D	1002
2	Sutton 001D	656	Hackney 027G	424	Westminster 013E	917
3	Westminster 018D	631	Brent 015A	389	Westminster 018B	818
4	Westminster 011E	604	Westminster 018D	371	Westminster 018C	744
5	Westminster 010F	600	Tower Hamlets 033B	296	Westminster 011E	738
6	Westminster 021B	557	Brent 024B	260	Sutton 001D	692
7	Westminster 018C	553	Haringey 015B	218	Hackney 027G	669
8	City of London 001G	539	Greenwich 011F	217	Tower Hamlets 033B	657
9	City of London 001A	530	Bromley 037A	211	City of London 001F	632
10	Barnet 030F	516	Westminster 013B	206	City of London 001G	623

Number of "high and medium" cost effective properties – Domestic and non-domestic

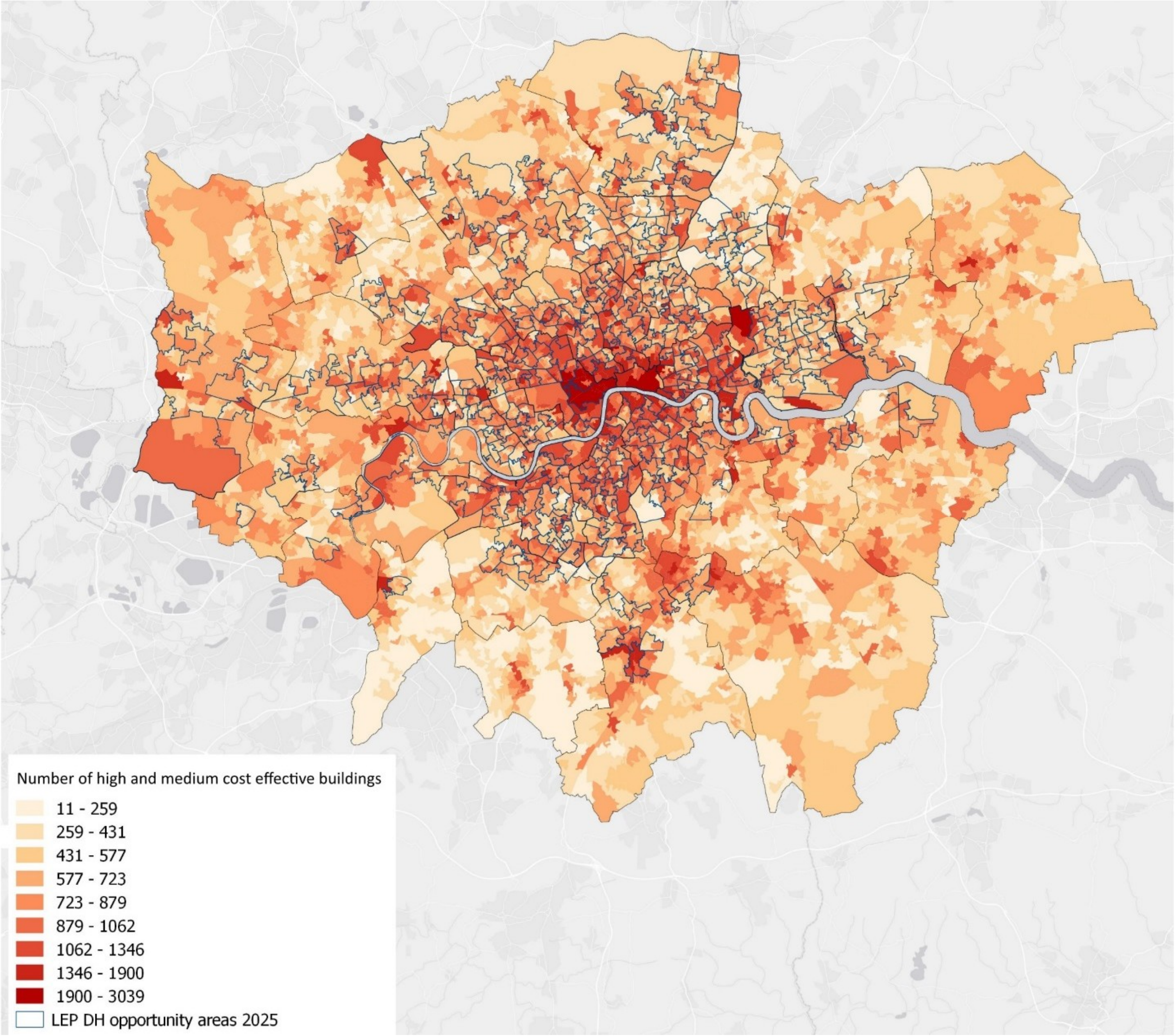

Figure 7-3 Spatial mapping of the number of high and medium cost effective buildings per LSOA (domestic and non-domestic combined).

Table 7-7 LSOAs with the largest number high and medium cost effective properties.

	High & med cost effectiveness – dom.		**High & med cost effectiveness – non-dom.**		**High & med cost effectiveness – combined**	
1	Newham 013G	2497	Westminster 013E	2076	Westminster 018D	3039
2	Sutton 001D	2222	Westminster 018D	1377	Westminster 013E	2865
3	Westminster 011E	2052	Westminster 018C	1148	Newham 013G	2583
4	Hillingdon 027E	1965	Hackney 027G	803	Westminster 011E	2459
5	Sutton 024C	1882	Westminster 013B	754	Westminster 018C	2379
6	Sutton 022B	1837	Brent 024B	729	Sutton 001D	2310
7	Waltham Forest 018B	1707	City of London 001F	628	Westminster 018B	2310
8	Westminster 018B	1695	Westminster 018A	624	City of London 001F	2116
9	Hammersmith & Fulham 021C	1685	Westminster 018B	615	Westminster 018A	2094
10	Westminster 018D	1662	Westminster 011B	609	Westminster 011B	2089

Density of high cost effective properties – Domestic and non-domestic

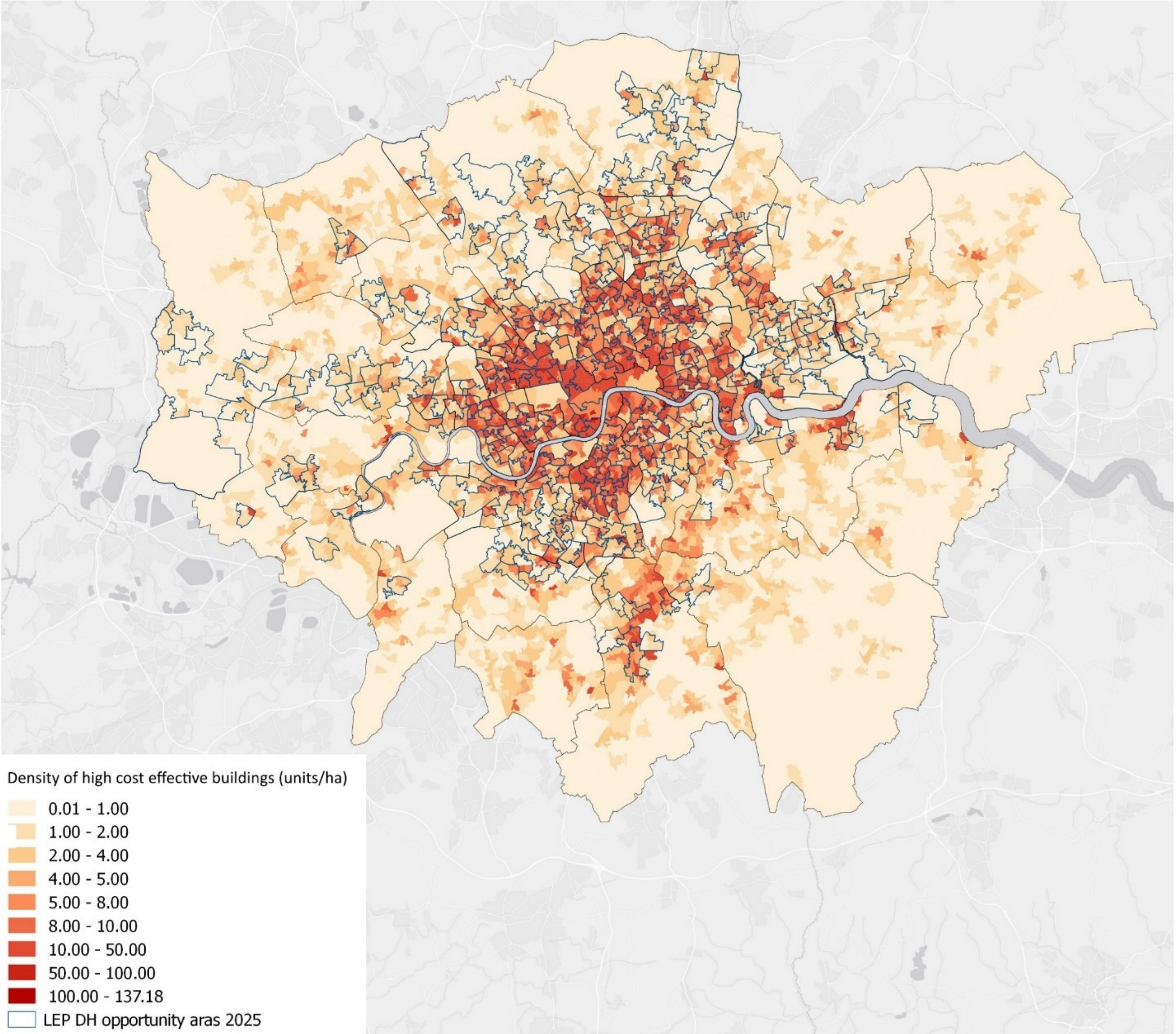

Figure 7-4 Spatial mapping of the density of high cost effective buildings per LSOA (domestic and non-domestic combined).

Table 7-8 LSOAs with the largest density of high cost effective properties.

	High cost effectiveness – domestic	**#/ha**	**High cost effectiveness – non-dom.**	**#/ha**	**High cost effectiveness – combined**	**#/ha**
1	Tower Hamlets 032D	136	Brent 015A	18	Tower Hamlets 032D	137
2	Westminster 021B	116	Hackney 027G	12	Westminster 021B	117
3	Hammersmith & Fulham 023E	109	Westminster 016B	11	Hammersmith & Fulham 023E	109
4	Southwark 003K	102	Westminster 013E	11	Southwark 003K	102
5	Tower Hamlets 028H	99	Brent 022D	11	Tower Hamlets 028H	99
6	Westminster 024E	96	Westminster 013F	11	Westminster 024E	96
7	Westminster 014F	77	Kensington and Chelsea 014E	9	Westminster 014F	77
8	Westminster 023F	76	Hillingdon 023B	9	Westminster 023F	76
9	Westminster 021D	70	Tower Hamlets 033B	8	Westminster 021D	70
10	Westminster 022D	68	Westminster 017C	8	Westminster 022D	68

Density of high and medium cost effective properties – Domestic and non-domestic

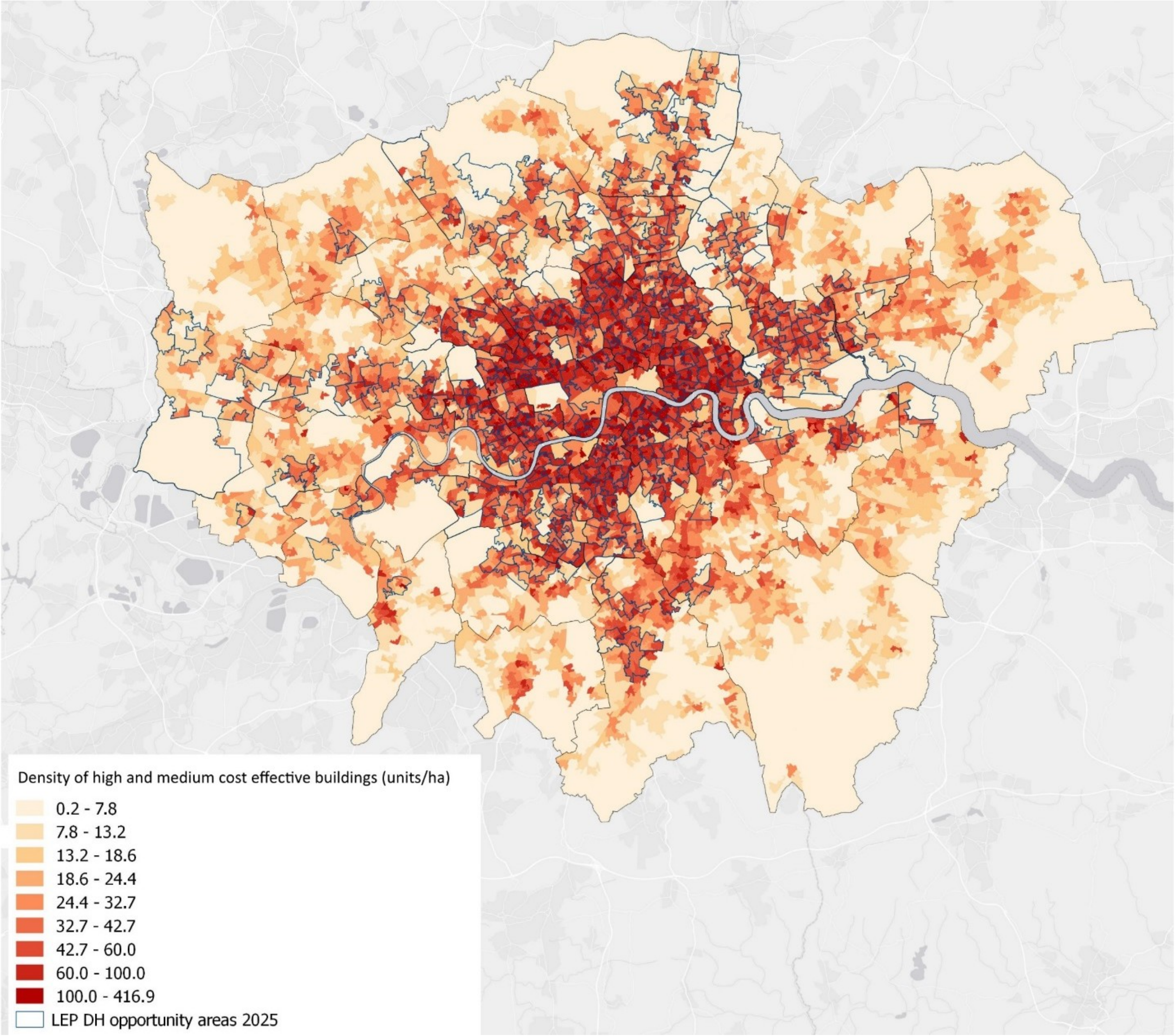

Figure 7-5 Spatial mapping of the density of high and medium cost effective buildings per LSOA (domestic and non-domestic combined).

Table 7-9 LSOAs with the largest density of high and medium cost effective properties (number per hectare).

	High & med cost effectiveness – dom.		**High & med cost effectiveness – non-dom.**		**High & med cost effectiveness – combined**	
1	Tower Hamlets 032D	415	Westminster 013E	40	Tower Hamlets 032D	417
2	Westminster 024E	357	Brent 022D	35	Westminster 024E	359
3	Tower Hamlets 028H	342	Brent 024D	34	Tower Hamlets 028H	343
4	Hounslow 010B	342	Westminster 018D	27	Hounslow 010B	342
5	Hounslow 014B	316	Westminster 013B	26	Hounslow 014B	317
6	Southwark 003K	292	Westminster 013F	23	Southwark 003K	292
7	Westminster 022D	283	Hackney 027G	23	Westminster 022D	283
8	Islington 011F	261	Bromley 020C	21	Islington 011F	266
9	Southwark 014G	261	Westminster 013D	21	Southwark 014G	265
10	Wandsworth 008B	256	Westminster 018A	20	Wandsworth 008B	256

7.7 Cost effectiveness spatial mapping summary

The LSOA maps generally show that the largest densities of cost effective buildings tend to be found more towards central London, with the densest concentration in Westminster. Many clusters of LSOAs in outer London have large numbers of cost effective domestic properties. There is a good correlation between the areas with cost effective building stock and the London Energy Plan's priority areas for district heating.

In terms of the LSOAs with the largest numbers of "high" cost effective domestic properties (i.e. low and medium efficiency electric houses and flats, together with gas heated high rise flats), Figure 7-2 showed this to be LSOAs within Westminster, Sutton, the City of London and Barnet. With respect to the high cost effective non-domestic buildings (i.e. electrically heated large offices), areas in Westminster, Hackney and Brent are the top three LSOAs. With domestic and non-domestic results combined, Westminster LSOAs make up the top five LSOAs, followed by Sutton, Hackney, Tower Hamlets and LSOAs for the City of London.

In terms of density, the LSOA regions with the largest number of high cost effective domestic properties, as shown in Figure 7-4, fall within Tower Hamlets, Westminster, Hammersmith & Fulham and Southwark. For the non-domestic buildings, the results indicate that Brent, Hackney, Westminster have the highest density of high cost effective typologies. In terms of the location of the LSOAs with the highest density of high cost effective building typologies (domestic and non-domestic), these are in Tower Hamlets, Westminster, Hammersmith & Fulham and Southwark.

In terms of the LSOAs with the largest numbers of "high and medium" cost effective domestic properties (i.e. now bringing in high efficiency electric dwellings, low rise gas heated flats and low and medium efficiency houses), Figure 7-3 showed this to be LSOAs within Newham, Sutton, Westminster, Hillingdon, Waltham Forest and Hammersmith & Fulham. For high and medium non-domestic properties (i.e. now bringing in large gas and electric retail typologies as well as the large low efficiency gas heated offices), LSOAs within Westminster, Hackney, Brent and the City of London have the largest numbers of properties. With domestic and non-domestic results combined, areas within Westminster, Newham, Sutton and the City of London all feature in the top ten LSOAs.

With respect to density, the LSOAs with the highest density of high and medium cost effective domestic properties, shown in Figure 7-5, were found to be within Tower Hamlets, Westminster, Hounslow, Southwark, Islington and Wandsworth. For non-domestic properties, LSOAs within Westminster, Brent, Hackney and Bromley feature in the top ten. For domestic and non-domestic results combined, LSOAs within Tower Hamlets, Westminster, Hounslow, Southwark, Islington and Wandsworth featured in the top ten.

7.8 Discussion

In this chapter, cost effectiveness was studied for all 32 typologies across a range of district heating heat retail prices from £25/MWh to £115/MWh, with properties spatially mapped based on the highest level of relative cost effectiveness achieved. The principal reason for this was to illustrate the overall attractiveness of each typology against each other and a range of theoretical heat prices, whilst also giving an indication of how relative cost effectiveness for each typology could improve with changing parameters, e.g. through increasing counterfactual fuel prices, economies of scale, reductions in capital cost, policy driven subsidies etc.

For gas heated flats the results illustrated that these typologies achieve high cost effectiveness at district heating retail prices up to £35/MWh and medium cost effectiveness up to £60/MWh. In a further sensitivity test undertaken, if gas prices increased by 20% high cost effectiveness can be achieved at district heating retail prices up to £50/MWh, with medium cost effectiveness up to £70/MWh. If gas prices increased by 50%, then high cost effectiveness can be achieved at district heating retail prices up to £65/MWh, with medium cost effectiveness up to £85/MWh.

To illustrate the impact that subsidies for district heating retrofit could have on the relative cost effectiveness for each typology, Table 7-10 illustrates how cost effectiveness, this time assessed against a fixed district heating heat retail price of £60/MWh, can be improved with increasing levels of capital grant funding obtained. Here it is shown that with capital grant funding set at a level of 20% to 40% all low and medium efficiency electric domestic properties can achieve high cost effectiveness at £60/MWh. With capital funding reaching 60% low and high rise gas heated flats can achieve high cost effectiveness. At this level of funding, low and medium efficiency houses can also achieve medium levels of cost effectiveness. This illustrates that relatively modest quantities of grant funding can have a significant impact on the overall cost effectiveness of retrofitting for the 32 building typologies.

Table 7-10 Assessment of the cost effectiveness of district heating retrofit with increasing levels of capital funding obtained vs. counterfactual case. District heating retail price is set at £60/MWh. Figures rounded to nearest £100.

		% Capital funding obtained	**0%**		**20%**		**40%**		**60%**	
			Payback (years)	**Capital funding**	**Payback (years)**	**Capital funding**	**Payback (years)**	**Capital funding**	**Payback (years)**	**Capital funding**
Electric heating conversion	nd-2	Small office - Low eff. - Heat pump	94	£0	42	£2,800	25	£5,600	14	£8,400
	nd-5	Large Office - Low eff. - Heat pump	4	£0	3	£4,200	2	£8,300	1	£12,500
	nd-3	Small retail - Low eff. - Heat pump	76	£0	39	£2,800	23	£5,600	13	£8,400
	nd-9	Small office - Med eff. - VRF	no	£0	45	£3,600	26	£7,100	14	£10,700
	nd-13	Large Office - Med eff. - VRF	14	£0	10	£10,400	7	£20,900	4	£31,300
	nd-10	Small retail - Med eff. - VRF	no	£0	no	£4,700	43	£9,300	21	£14,000
	nd-6	Large retail - Low eff. - VRF	24	£0	17	£14,000	12	£28,000	7	£42,000
	d-2	House - Low eff. - Panel heaters	14	£0	11	£2,200	7	£4,500	5	£6,700
	d-8	House - Med eff. - Panel heaters	19	£0	14	£2,200	10	£4,500	6	£6,700
	d-14	House - High eff. - Panel heaters	39	£0	26	£2,200	17	£4,500	10	£6,700
	d-4	Low rise flat - Low eff. - Panel heaters	9	£0	6	£1,800	5	£3,600	3	£5,400
	d-10	Low rise flat - Med eff. - Panel heaters	19	£0	14	£1,800	10	£3,500	6	£5,300
	d-16	Low rise flat - High eff. - Panel heaters	39	£0	26	£1,800	17	£3,500	10	£5,300
	d-6	High rise flat - Low eff. - Panel heaters	14	£0	10	£1,700	7	£3,300	4	£5,000
	d-12	High rise flat - Med eff. - Panel heaters	20	£0	14	£1,700	10	£3,300	6	£5,000
	d-18	High rise flat - High eff. - Panel heaters	31	£0	22	£1,700	14	£3,300	9	£5,000
Gas heating conversion	nd-7	Small office - Med eff. - Gas boilers	no	£0	no	£1,800	51	£3,500	23	£5,300
	nd-1	Small office - Low eff. - Gas boilers	no	£0	no	£1,800	53	£3,500	23	£5,300
	nd-14	Large Office - High eff. - Gas boilers	no	£0	no	£2,100	503	£4,200	no	£6,300
	nd-11	Large Office - Med eff. - Gas boilers	no	£0	no	£2,100	503	£4,200	no	£6,300
	nd-4	Large Office - Low eff. - Gas boilers	no	£0	no	£2,100	503	£4,200	no	£6,300
	nd-8	Small retail - Med eff. - Gas boilers	no	£0	no	£1,800	82	£3,500	28	£5,300
	nd-12	Large retail - Med eff. - Gas boilers	no	£0	no	£2,100	503	£4,200	no	£6,300
	d-1	House - Low eff. - Gas boilers	no	£0	69	£1,400	34	£2,700	17	£4,100
	d-7	House - Med eff. - Gas boilers	no	£0	60	£1,400	32	£2,700	16	£4,100
	d-13	House - High eff. - Gas boilers	no	£0	80	£1,400	36	£2,700	18	£4,100
	d-3	Low rise flat - Low eff. - Gas boilers	54	£0	33	£1,000	20	£2,000	11	£3,100
	d-9	Low rise flat - Med eff. - Gas boilers	46	£0	29	£1,000	19	£2,000	10	£3,100
	d-15	Low rise flat - High eff. - Gas boilers	48	£0	30	£1,000	19	£2,000	11	£3,100
	d-5	High rise flat - Low eff. - Gas boilers	38	£0	25	£900	17	£1,800	9	£2,800
	d-11	High rise flat - Med eff. - Gas boilers	36	£0	24	£900	16	£1,800	9	£2,800
	d-17	High rise flat - High eff. - Gas boilers	39	£0	26	£900	17	£1,800	10	£2,800

8 Pilot study (WP3B)

8.1 Overview

In this Work Package, further cost effectiveness studies have been carried out for four pilot areas of London. The pilot study areas, each consisting of two adjacent MSOAs in Islington, Sutton, Enfield and Camden, were selected by the GLA following a spatial review of the retrofit typology assessment and London's existing or imminent district heating networks from the London Energy Plan (LEP).

Results are presented at Census output area, which are equivalent to approximately 40-250 households, giving them a higher level of granularity than the LSOAs previously assessed. Information such as existing and proposed networks from the London Energy Plan are overlaid, together with conservation areas[20] where information was readily available, to better understand the opportunities that exist in areas with typologies falling into the high cost effectiveness category. These conservation areas are highlighted as these areas are not suited to external wall insulation, thus district heating retrofits may be more applicable.

It should be noted that analysis uses Census output area data for parameters such as number of buildings, property type, heating system and building height, however information such as thermal performance of domestic buildings (e.g. wall construction information) was not readily available for the analysis. Furthermore, EPC coverage was not significant enough to map to all Census output areas for the non-domestic buildings. As such, data was extrapolated for these parameters based on previous information gathered for the LSOA studies.

Due to these factors, the approach should be taken as a proof of concept study rather than a detailed feasibility study, for which the accuracy can be greatly increased through the use of more detailed datasets e.g. local authority building stock data, load/energy consumption data and/or on-site survey data.

8.2 Selection of pilot study areas

Figure 8-1 contains a map of London illustrating the MSOAs (Middle-Level Super Output Areas) considered for the pilot study. The areas shortlisted were a combination of existing district heating network areas from the London Energy Plan, additional areas of interest for district heating identified by the GLA, together with MSOAs with large numbers of gas and electric properties that are categorised as cost effective, covering a range of all identified typologies. Following consultation with the GLA, the MSOAs that were selected for the study were:

- Islington (022/023): Including the Bunhill Energy Centre and the E.On Citigen CHP site.
- Enfield (030/033): Including an 18 MW energy from waste CHP plant.
- Sutton (010/011): Including a waste to energy plant is being built with circa 20 MW heat energy potential.
- Camden (002/008): Including the Gospel Oak heat network runs along and utilises surplus heat generated by the Royal Free Hospital through a CHP energy centre.

Westminster MSOAs (020/021/022/023/024) were also considered given they contained many cost effective properties and are in proximity to the Pimlico district heating network. These areas were not selected for the study however, but would be a good candidate to investigate further to better understand network costs in areas with increased density and likely extent of traffic flow management issues.

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[20] The term conservation area refers to a UK zoning law, whereby local planning ordinances place restrictions on certain types of building renovation that might affect the visual appearance or historic character of a building.

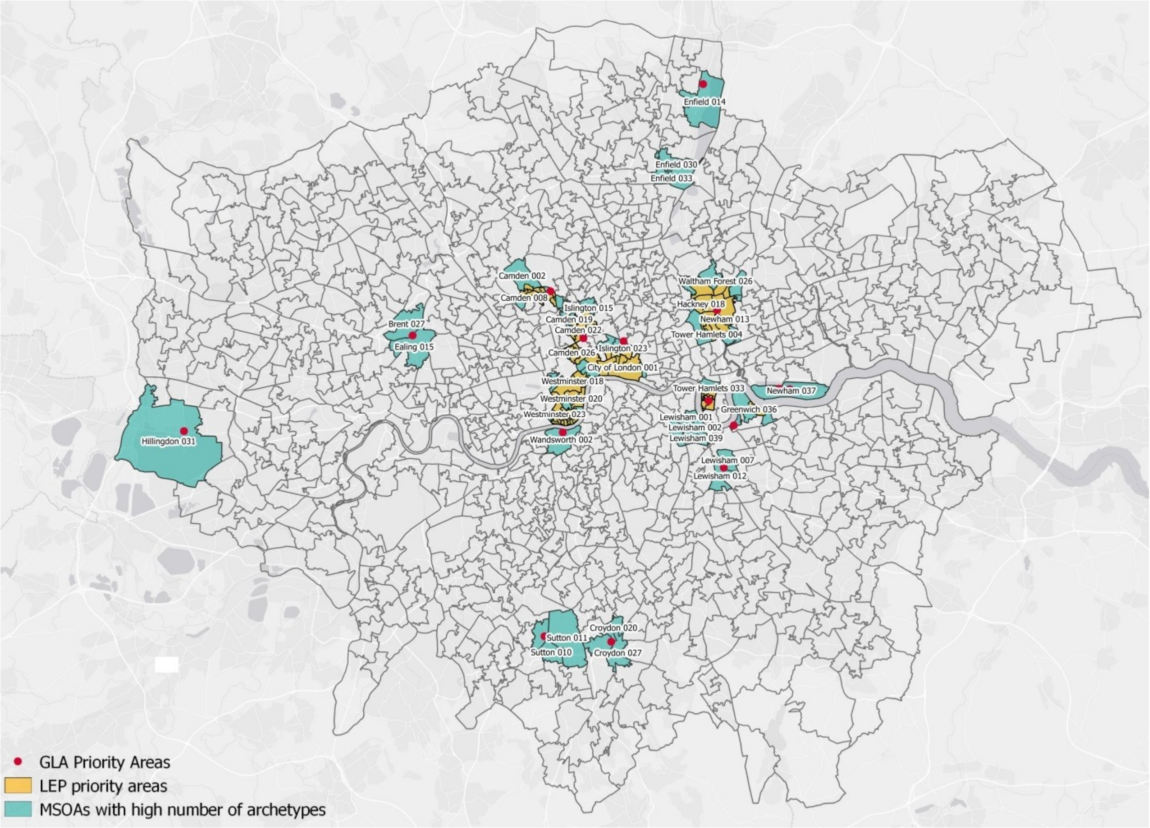

Figure 8-1 Map of London illustrating the London Energy Plan (LEP) and GLA priority areas shortlisted for the pilot study, together with MSOAs with a large range of cost effective properties.

8.3 Data processing methodology

Mapping layers

For the pilot study, MSOA level maps were produced illustrating the relative cost effectiveness at Census output area. Existing and proposed heat networks and conservation areas were included as layers in the maps, as per data inputs shown in Figure 8-2.

Table 8-1 Additional GIS layers added to pilot study maps.

Dataset	Details Used
London Energy Plan	Existing and proposed heat network locations
Islington conversation areas	Islington Council GIS Shapefile
Camden conversation areas	Camden Council GIS Shapefile
Sutton conversation areas	Sutton: Site development policies DPD – Appendix 1. https://www.sutton.gov.uk/downloads/download/510/site_development_policies_dpd
Enfield conversation areas	Enfield: Enfield Site Conservation Areas https://new.enfield.gov.uk/services/planning/heritage-conservation-and-countryside/conservation-areas/

Domestic datasets

Table 8-2 summarises the datasets used to develop a representative list of the pilot areas domestic building stock, describing the methodology undertaken at each step. These datasets were combined to estimate the number of domestic properties that fall into each typology for which cost effectiveness of retrofit for district heating has been assessed.

Table 8-2 Domestic building typology inputs for the pilot study.

Input	Dataset	Methodology
OAs level characteristics	Office for National Statistics (ONS) neighbourhood statistics, Housing,2011	Data for building count by property type was used. The Census output area results were aggregated per LSOA and factored to match the 2014 LSOA results of Work Package 1 and 2.
	Office for National Statistics (ONS) neighbourhood statistics, Central Heating,2011	Data for building count by heating system and heating fuel was used. The proportion of electric and gas central heated systems per Census output area was applied to the number of flats and houses.
	Office for National Statistics (ONS) neighbourhood statistics, Lowest Floor Level,2001	Building count by low rise and high rise. All properties up to 4th floor were taken as low rise. All properties with fifth floor or higher were taken as high rise.
LSOAs level characteristics	Office for National Statistics (ONS) neighbourhood statistics, 2014	Building count by build period was used to estimate number of low, medium and high efficiency buildings.
Addressing	London Datastore, 2011 Boundaries, Office for National Statistics and London-wards-2014	Census output area GIS shapefiles.

To represent domestic building efficiency, the LSOA data generated from Work Package 1A and 1B was extrapolated to Census output areas as a proxy for efficiency.

Domestic datasets

Table 8-3 describes the datasets used for the non-domestic dataset. Here, datasets were combined to estimate the number of non-domestic properties that fall into each typology category.

Table 8-3 Non-domestic building typology inputs for the pilot study.

Input	Dataset	Details Used
Address level characteristics	Ordnance Survey Address-Base-Plus, Nov 2015 and 2011 Census Output Areas.	Building location and use. Used to estimate the number of offices and retail buildings within each Census output area
	Energy Performance Certificate (EPC) register	Building type, floor area, EPC rating and heating fuel for 1,070 buildings across the pilot areas
LSOA level characteristics	Thermal typologies as per non-domestic LSOA analysis from Work Package 1	Building type and thermal typologies for all office and retail as percentages
Addressing	London Datastore Statistical GIS Boundary Files	OAs GIS shapefiles

Across all four pilot areas there was a total of 5,527 office and retail buildings. Of these buildings, 1,070 had EPC records. For each Census output area, where EPC data covered less than 25% of office and retail buildings, the heating system and energy efficiency information was extrapolated from the LSOA data produced in Work Package 1. Where EPC data covered more than 25% of office and retail buildings, the EPC information was extrapolated to all office and retail buildings in that area.

8.4 Pilot study mapping for Islington

Figure 8-2 shows the pilot study map developed for Islington, showing the number of buildings falling into the high cost effectiveness typologies (based on the typologies previously defined in the previous Work Package).

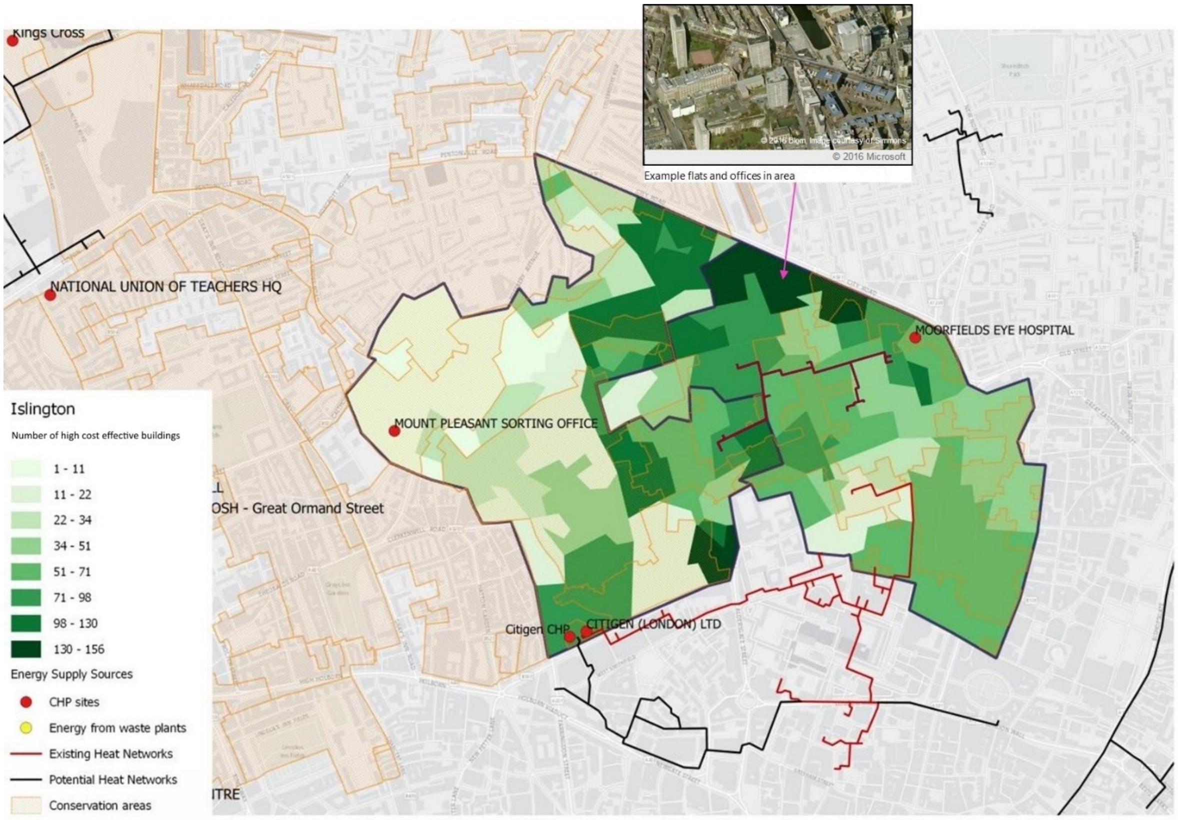

Figure 8-2 Number of high cost effective properties in Islington (022/023) MSOAs by Census output area.

In terms of the number of buildings, the model based output indicates that the areas to the north-west of Moorfield hospital have the largest number of buildings falling into the high cost effective category. Upon further review of these areas it can be seen that these areas do indeed contain high numbers of flats and offices.

Note that for this map (and all others in this pilot study analysis) it cannot be known for sure if the properties shown specifically are electric heated, without a site inspection. In the darkest areas the number of dwellings falling into the high cost effective category account for more than 40% of the total dwellings.

Further locations highlighted as having a higher number of buildings fall into the high cost effective category include the areas close to the Bunhill heat network. The area adjacent to Citigen CHP plant is also one of the areas in Islington where there are higher numbers of properties that are categorised as high cost effective.

Figure 8-3 below illustrates the heat demand density in kWh/m^2 for the buildings categorised as high cost effective (calculated based on the ESP-r energy calculations for typology). As shown below, the areas in the study area with the highest modelled density of high cost effective buildings are, as expected, those with high rise flats.

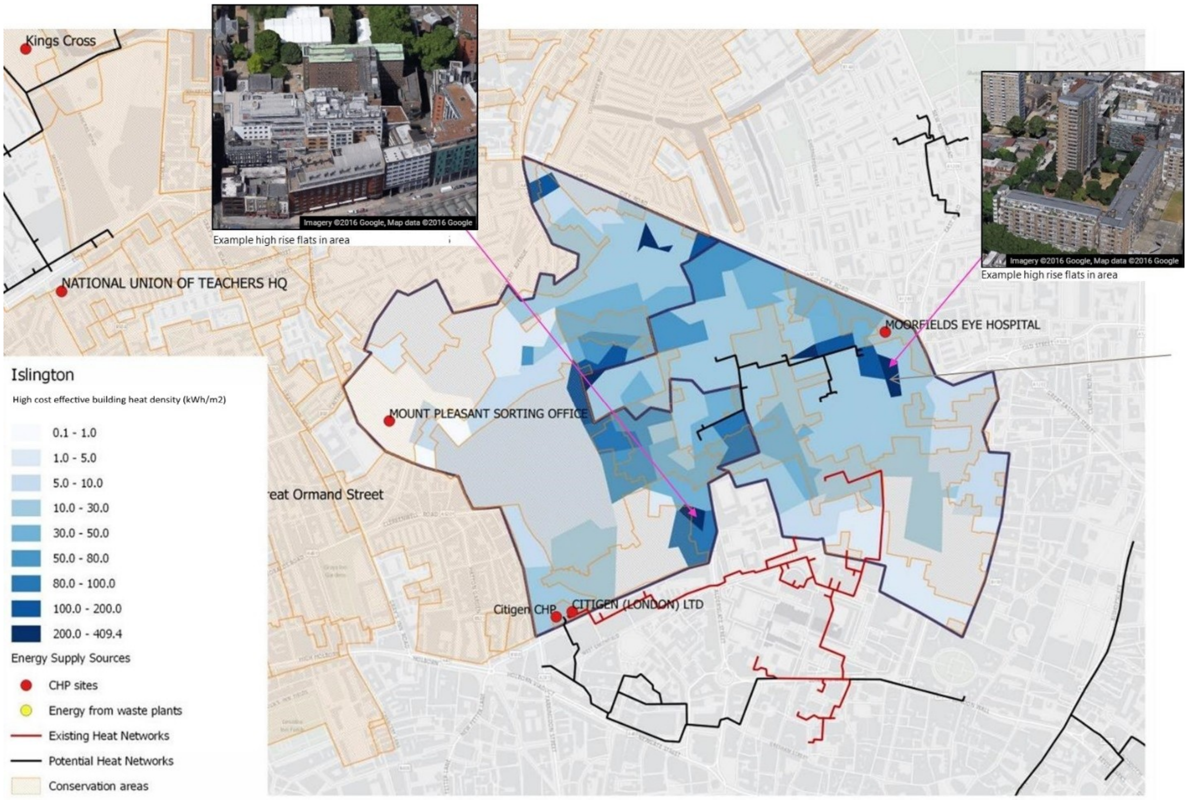

Figure 8-3 Heat demand density of high cost effective properties in Islington (022/023) MSOAs by Census output area.

In summary, the model based approach indicates that there is a high proportion of properties that fall into the high cost effective category in Islington and therefore further investigation of the area with more detailed datasets would be recommended.

8.5 Pilot study mapping for Enfield

Figure 8-4 shows the number of high cost effective buildings in the Enfield LSOAs. This area of Enfield is of high interest for district heating connections due to the proposed Upper Lee Valley network that will be developed in the studied area and the Edmonton Eco Park 18 MW CHP waste to energy plant that can provide low carbon heat into the heat network.

In the studied area of Enfield there are some of the highest numbers of high cost effective buildings, especially close to the Silver Street train station. In this part of Enfield there are a lot of high and low rise flats and consequently the high cost effective properties account for approximately 75% of the total properties. The Edmonton Park also has a large number of high cost effective buildings along with the area to the east of Edmonton Leisure Centre.

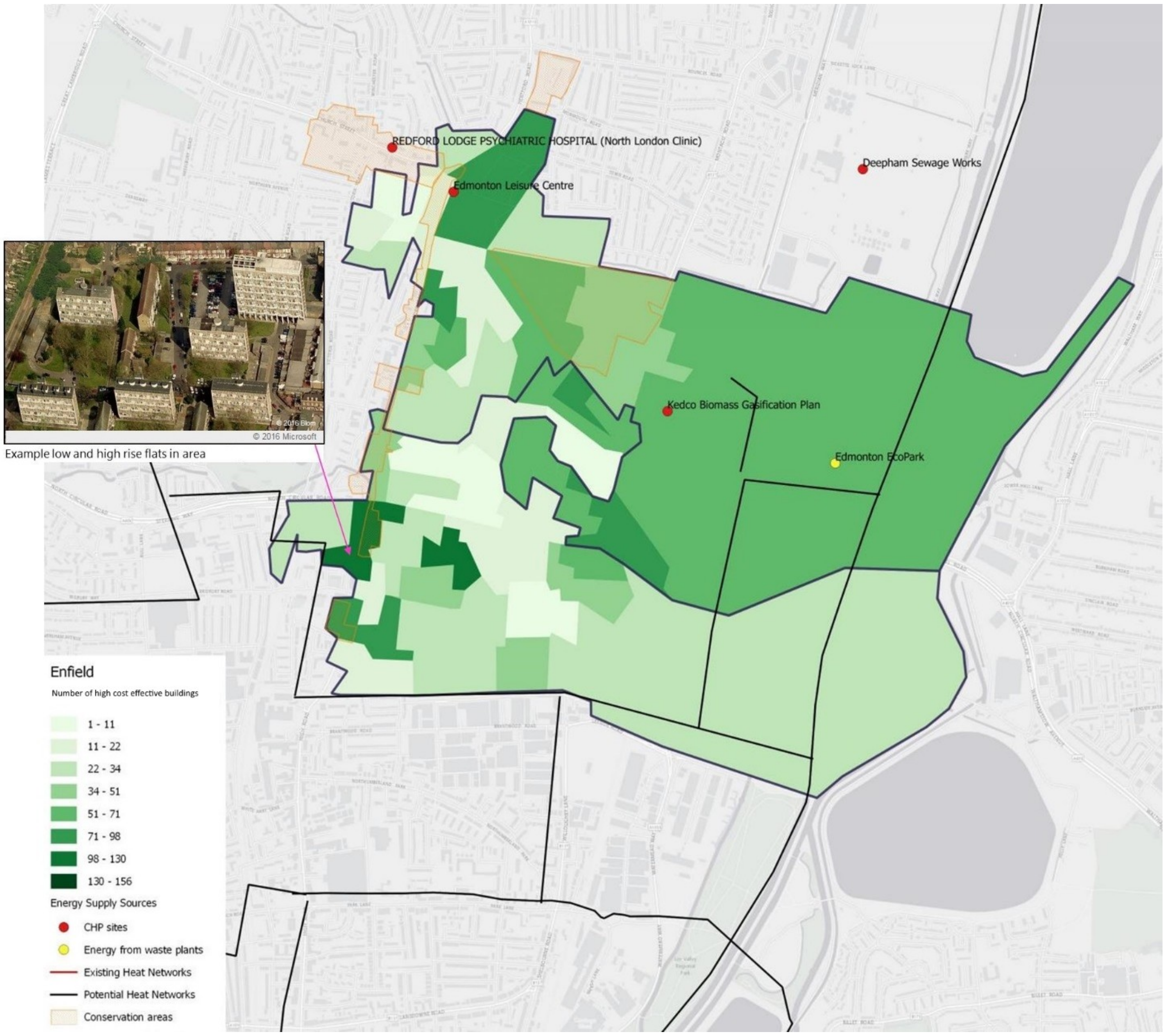

Figure 8-4 Number of high cost effective properties in Enfield (030/033) MSOAs by Census output area.

Figure 8-5 shows the heat demand density of the high cost effective properties in Enfield. Here, it can be seen that in Edmonton Park the results between heat density and number of cost effective buildings are very different to each other; while the number of buildings is quite high, the overall heat density from the cost effective buildings is very low compared to other sites of Enfield.

This is a significant observation since both factors are quite important for the development of the heat network. Although the number of buildings is a good indicator of the potential district heating connections, the heat density is a good indicator of the heat line density of the network and consequently the viability of the network. Heat networks with high heat line densities tend to perform better compared to low line density networks.

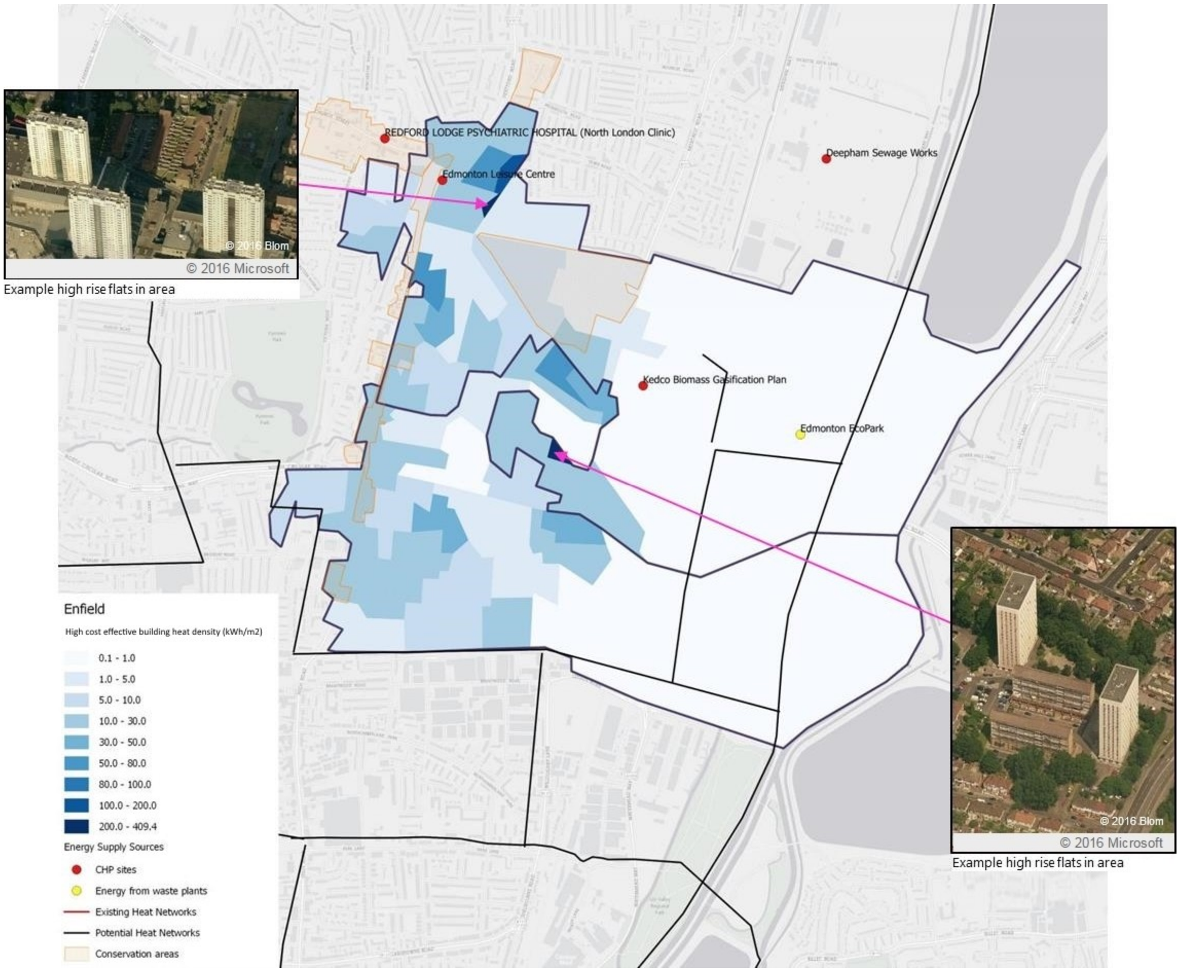

Figure 8-5 Heat demand density of high cost effective properties in Enfield (030/033) MSOAs by Census output area.

In summary, there also appears to be a large amount of buildings in Enfield that fall into the high cost effective category and further investigation of the area with more detailed datasets would be recommended but consideration should be made that the heat density of these buildings is low in many areas.

8.6 Pilot study mapping for Sutton

Figure 8-6 illustrates the number of high cost effective buildings in the Sutton MSOAs. The dominant typologies in Sutton are gas heated houses and low rise flats which fall into the medium retrofit cost effectiveness category. These medium cost effective buildings in Sutton make up to 90% of the total building stock.

To the south-east of Beddington Park is a Census output area with a high proportion of buildings that fall into the high cost effective category. Upon closer review of this area on street mapping software, it can be seen that this area contains some low density large offices and low-rise flats.

To the south-west of Beddington Park, there is a large non-domestic area with various buildings (e.g. Royal Mail Croydon Centre, Sewage Treatment Works Company). Most of these buildings do not fall into the assessed non-domestic typologies, however they could provide additional connectable loads and/or secondary heat sources.

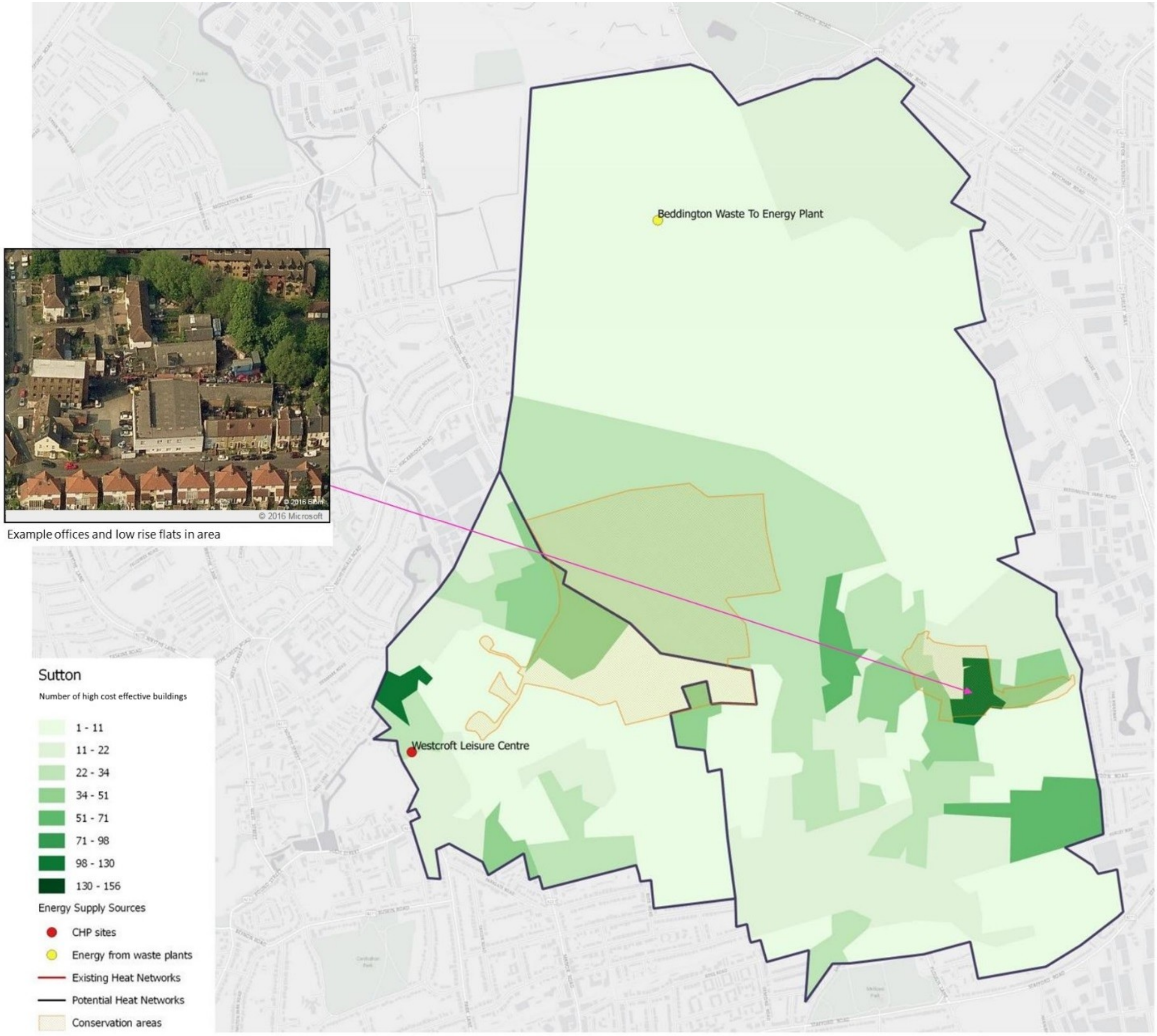

Figure 8-6 Number of high and medium cost effective properties in Sutton (010/011) MSOAs by Census output area.

Figure 8-7 illustrates the heat demand density for the Sutton pilot study. Higher density can be seen to the west of the Westcroft Leisure Centre, where there are some flats. More broadly however, it can be seen that the heat density of the cost effective buildings in Sutton is mostly low due to general low residential density, compared to more central locations of London such as Islington.

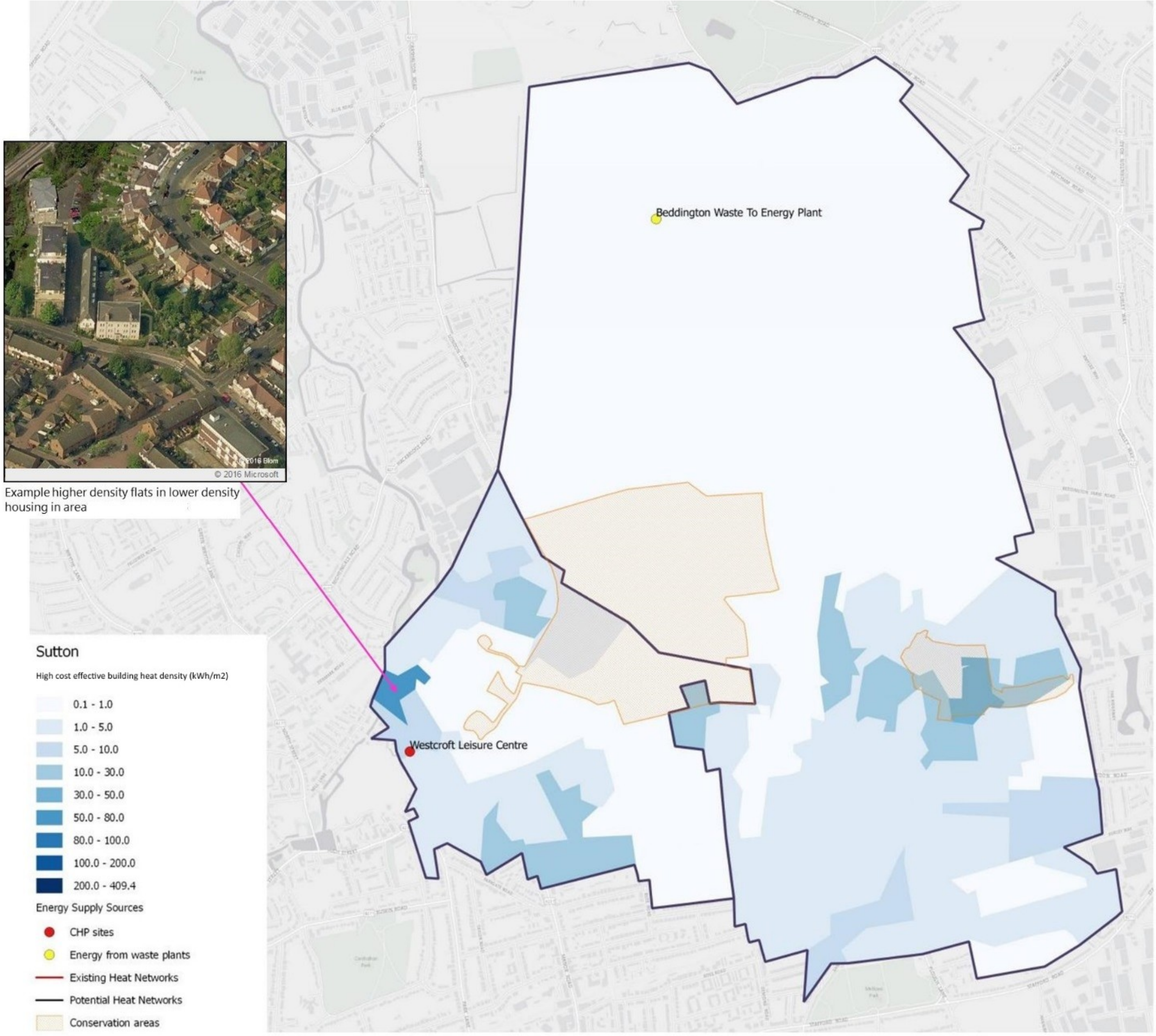

Figure 8-7 Heat demand density of high cost effective properties in Sutton (010/011) MSOAs by Census output area.

In summary, the number and density of buildings falling into the high cost effective category in Sutton appears lower than that of Islington and Enfield, but there are some areas with high cost effectiveness buildings that could be investigated further along with the medium cost effectiveness buildings.

8.7 Pilot study mapping for Camden

Figure 8-9 shows the number of buildings falling into the high cost effective category in the two Camden MSOAs. The output area showing the highest number of cost effective buildings is the site north of the Swiss Cottage Sports Centre. Overall, the number of high cost effective buildings is estimated to be relatively low, compared to Islington and Enfield. Approximately 65% of the modelled dwellings are gas heated flats of medium cost effectiveness.

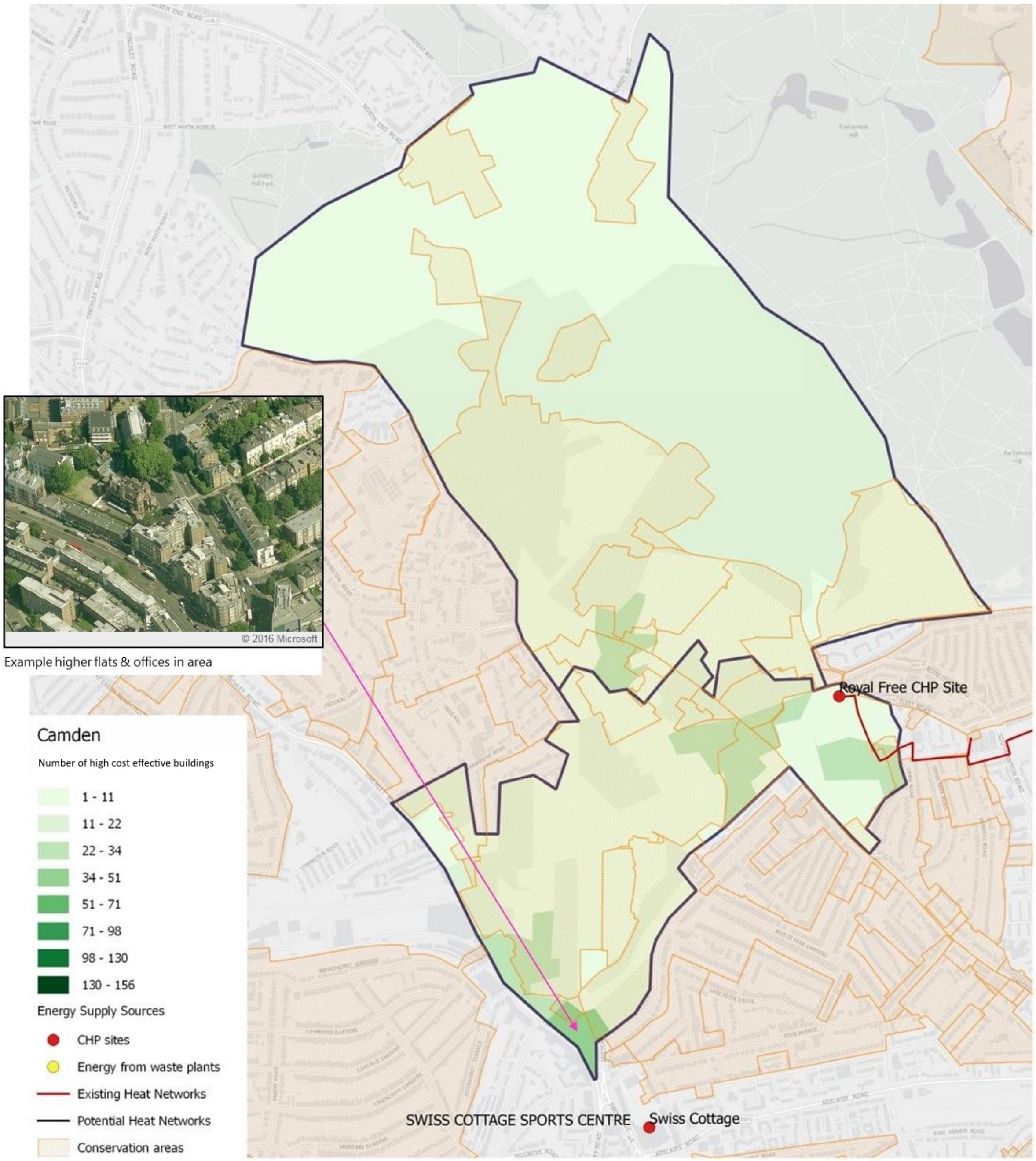

Figure 8-8 Number of high cost effective properties in Camden (002/008) MSOAs by Census output area.

Figure 8-9 illustrates the heat demand density of the properties falling into the high cost effective category in Camden. It is understood that the Gospel Oak heat network (supplied by the Royal Free CHP site) could be potentially considered for expansion to existing buildings. However, the cost effectiveness of the existing buildings in the immediate area is relatively low, with the exception of a higher cost effectiveness site approximately 1 km away to the south-east.

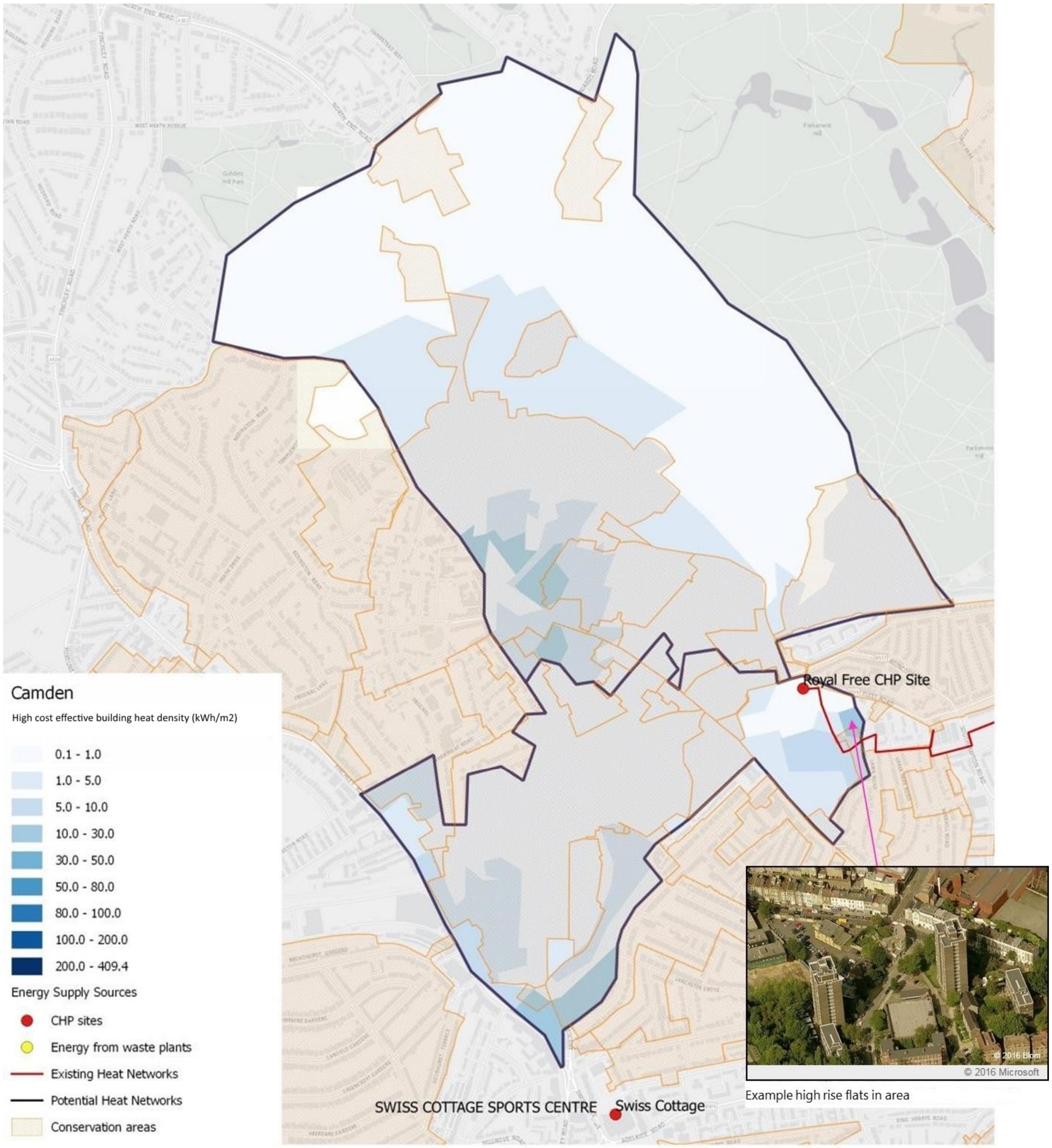

Figure 8-9 Heat demand density of high cost effective properties in Camden (002/008) MSOAs by Census output area.

8.8 Summary

As previously noted the results of this pilot study are not based on ‘full’ data at Census output area, as accurate data for thermal efficiency in each Census output area was not available (thus figures were extrapolated from the LSOA data), but the results do act as an intelligence tool for assessing opportunity across London and can be used to help inform pre-feasibility. The observations made were therefore a summary of the model-based outputs only. To increase reliability of the study more detailed datasets e.g. local authority building stock data, load/energy consumption data and/or on-site survey data should be sought as part of the feasibility study for an area.

Based on the outputs for Islington, mapping showed areas close to Citigen CHP plant potentially contained high numbers of high cost effective properties, together with the site to the north-west of Moorfield hospital, close to the Bunhill heat network. In the studied area of Enfield, the data indicated high numbers of high cost effective buildings close to the Silver Street train station, near to the proposed Upper Lee Valley network. For Sutton and Camden, the dominant typologies were found to be gas heated houses and low rise flats which have medium retrofit cost effectiveness.

With regard to heat density, Islington has the highest heat density of buildings that are categorised as either medium or high cost effective, especially at the eastern part of the studied area. The heat density of the other three areas is quite low which is an indicator of low heat line density for any future network.

Regarding EPC data, for Sutton and Camden the available information from EPCs was approximately 30% of the total non-domestic buildings while for Islington and Enfield this amount is around 20%. Although the number of non-domestic buildings is significantly less than domestic, their higher energy consumption, as function of their larger size, would provide useful connectable load.

It should be noted that in this approach, which could feed in to a pre-feasibility study, only the number of “high” cost effective buildings and heat density were considered as indicators of heat network viability. In terms of the number of high and medium cost effective buildings Islington, Sutton and Enfield have a similar number of buildings (Enfield 8,300 properties, Sutton 10,600 properties and Islington 9,200 properties) while Camden has the lowest number of high and medium cost effective buildings (circa 5,600) which is linked to the general lower density in the area compared to the other three areas.

In the maps, Camden is seen to have the largest conservation areas compared to the other pilot study sites. Where conservation measures prevent fabric upgrades such as new double glazing or external solid wall insulation being applied, these buildings may be good candidates for low carbon district heating.

9 4G Optimum Level of Energy Efficiency Retrofit (WP4A)

9.1 Overview

The final study in this report is a review of the cost optimum level of energy efficiency retrofit to support the implementation of 4th generation (4G) district heating networks with supply temperatures from 70 °C to 40 °C. The study sets out how the proportion of annual energy demand met through district heating can be increased through a fabric energy retrofit to Building Regulations standard and beyond. Cost modelling covering all typologies is undertaken for the associated retrofit measures and cost effectiveness is calculated.

9.2 Method

Using the ESP-r software (described earlier in Section 5.4), the first step in this analysis was to undertake load modelling at different supply temperature scenarios e.g. 70 °C, 60 °C, 50 °C, 40 °C. Load profiles were prepared for a specific model representative of each typology along with a temperature reduction strategy to determine the percentage of annual unmet energy demand.

Two different strategies to address the unmet energy demand were then tested. Firstly, the use of larger heat emitters investigated using radiator conversion factors and secondly, the impact of fabric efficiency measure investigated through re-running the ESP-r models. Capital costing was then undertaken and cost effectiveness assessed (based on the approach in Section 7.4), applied to the 40 °C supply temperature scenario, which required energy efficiency upgrades, considering the impact of increased capital costs and domestic hot water provisions. Note that further recommendations for the design of the building's secondary systems and DHW options are given in Appendix B.

9.3 Load modelling at reduced supply temperatures

Domestic buildings

Figure 9-1 contains a load duration curve for the low efficiency house (applicable to gas and electric typologies d-7 and d-8), illustrating the percentage of annual heat demand that can be met with district heating being supplied at temperatures from 70 °C to 40 °C. For reference, the baseline case represents an idealised system (e.g. wet system at 82/71, or electric heating system) capable of meeting 100% of the demand.

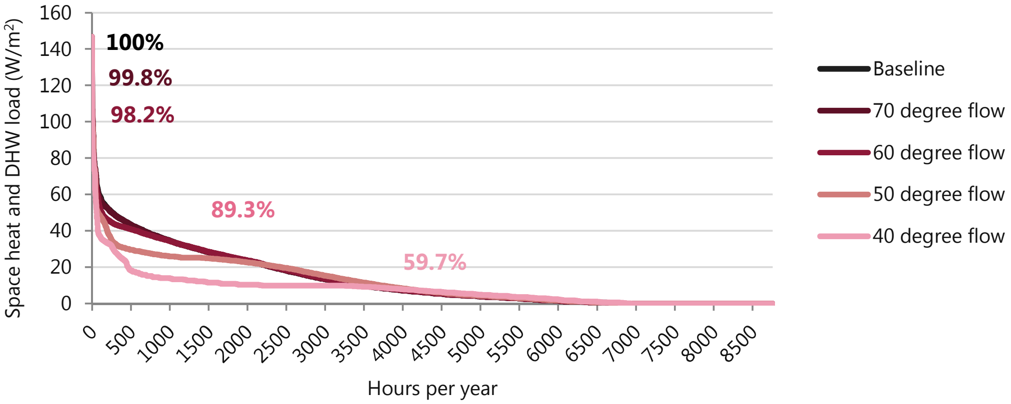

Figure 9-1 Low efficiency house - Load duration curve at different heating supply temperatures (typologies d-7 and d-8).

As shown in Figure 9-1, at a supply temperature of 70 °C, it is estimated that 99.8% of the annual heat demand of a low efficiency house can be met. Similarly, at a 60 °C supply temperature, 98.2% can be met. At a supply temperature of 50 °C, this drops to 89.3% and then at a supply temperature of 40 °C there is a more significant reduction observed down to 59.7% of the annual heat demand.

Figure 9-2 and Figure 9-3 illustrate how the percentage of annual heat demand improves for the medium and high efficiency building typologies respectively. As shown, for the medium efficiency typology, the proportion of heat demand met at a 50 °C supply temperature scenario increases to 92% (compared to 89.3% in the low efficiency building typology). For the high efficiency building typology, this percentage increases further to 96.7%. At the 40 °C district heating supply temperature, the proportion of annual heat demand met increases to 66.6% for the medium efficiency building typology (compared to 89.3% in the low efficiency building typology) and 81.4% in the high efficiency building typology.

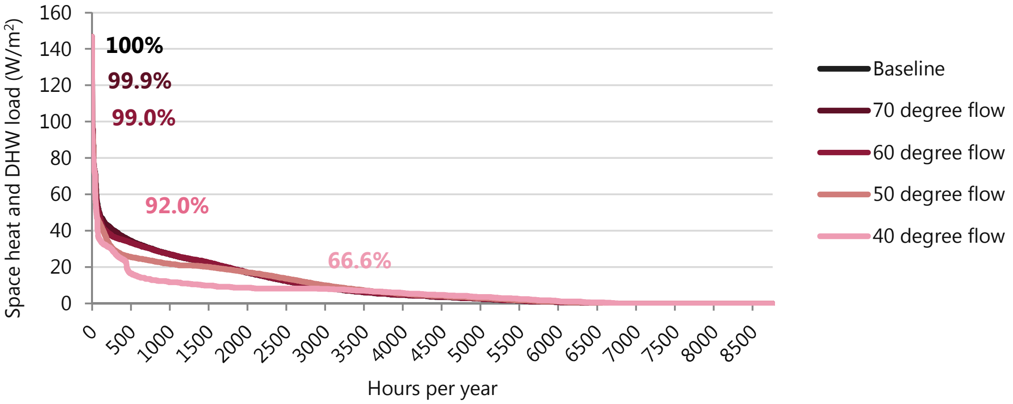

Figure 9-2 Medium efficiency house - Load duration curve at different heating supply temperatures (typologies d-13 and d-14).

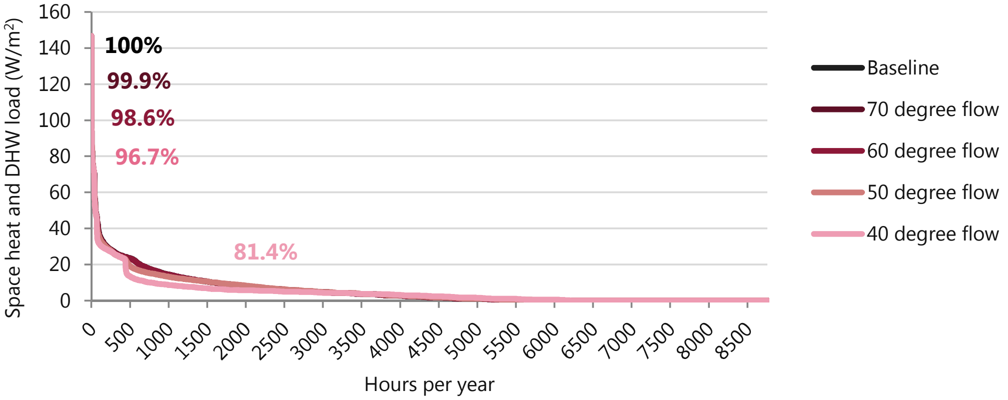

Figure 9-3 High efficiency house - Load duration curve at different heating supply temperatures (typologies d-3 and d-4).

Non-domestic buildings

To illustrate the proportion of annual heat demand met in the non-domestic building typologies, Figure 9-5 shows the respective load duration curve for the pre-1960s solid walled office model and Figure 9-4 gives the results for the small high street retail case. In both cases the models have single glazed windows and solid brick walls with no insulation, thus they represent a low level of fabric efficiency.

As shown, the percentage of annual heat demand being met, broadly follows that of the low efficiency house model. The retail high street model is shown to have the lowest overall percentage (50.7%) of annual heat demand being met by district heating at a supply temperature of 40 °C, due to its high levels of glazing and longer hours of operation. Comparatively, 61% of heat demand is met in the office typology at the 40 °C supply temperature.

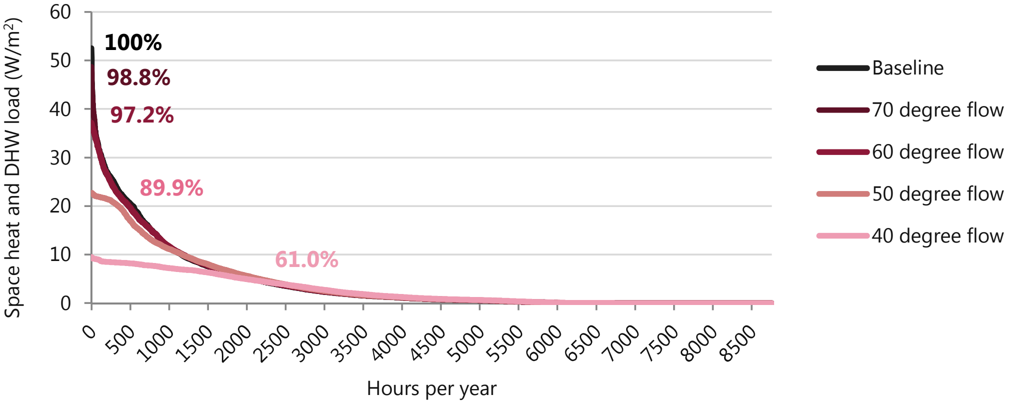

Figure 9-4 Load duration curve for pre 1960s solid wall office model (represents typologies nd-1 and nd-4).

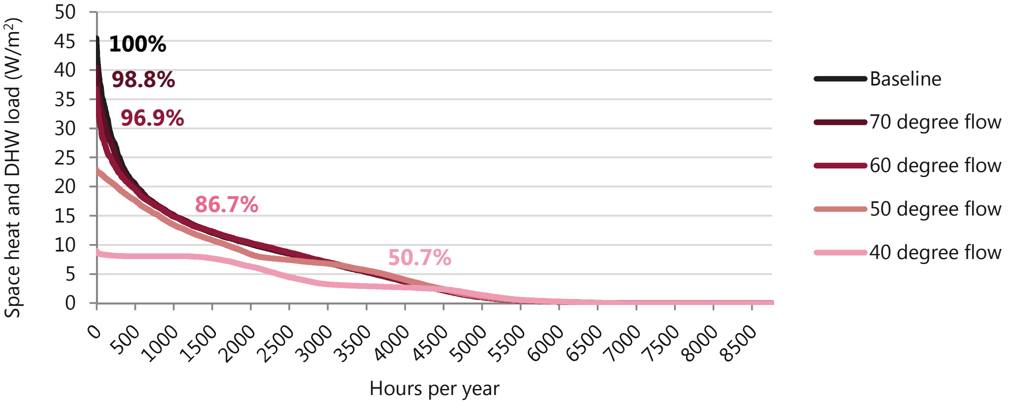

Figure 9-5 Load duration curve for high street retail model (represents typologies nd-3, nd-10 and nd-13).

Table 9-1 summarises the load modelling results illustrating the percentage of annual heat demand met at the different flow temperatures mapped to all typologies. As shown, there is a general trend that can be observed across the domestic properties, whereby lower temperature district heating performs better for medium and high efficiency properties than it does for the low efficiency properties. At the 40 °C supply temperature, the low rise high efficiency flat has the highest percentage of annual heat demand being met at 92.6%. The lowest proportion of annual heat demand met at 40 °C is the small high street retail units at 50.7% with full single glazing.

Table 9-1 Modelling results illustrating percentage of annual heat demand met at different heating supply temperatures.

Typology			Percentage of annual heat demand met				
			Baseline	70 °C	60 °C	50 °C	40 °C
Electric heating conversion	nd-2	Small office - Low eff - Heat pump	100%	98.8%	97.2%	89.9%	61.0%
	nd-5	Large Office - Low eff - Heat pump	100%	98.8%	97.2%	89.9%	61.0%
	nd-3	Small retail - Low eff - Heat pump	100%	98.8%	96.9%	86.7%	50.7%
	nd-9	Small office - Med eff - VRF	100%	98.8%	97.1%	89.7%	62.6%
	nd-13	Large Office - Med eff - VRF	100%	98.8%	97.1%	89.7%	62.6%
	nd-10	Small retail - Med eff - VRF	100%	98.8%	96.9%	86.7%	50.7%
	nd-6	Large retail - Low eff - VRF	100%	98.8%	96.3%	86.4%	53.4%
	d-2	House - Low eff - Panel heaters	100%	99.8%	98.2%	89.3%	59.7%
	d-8	House - Med eff - Panel heaters	100%	99.9%	99.0%	92.0%	66.6%
	d-14	House - High eff - Panel heaters	100%	99.8%	99.6%	96.7%	81.4%
	d-4	Low rise flat - Low eff - Panel heaters	100%	99.8%	98.7%	90.4%	59.6%
	d-10	Low rise flat - Med eff - Panel heaters	100%	99.8%	99.8%	92.3%	70.1%
	d-16	Low rise flat - High eff - Panel heaters	100%	99.9%	99.8%	98.8%	92.6%
	d-6	High rise flat - Low eff - Panel heaters	100%	99.8%	98.3%	89.4%	64.2%
	d-12	High rise flat - Med eff - Panel heaters	100%	99.8%	99.2%	93.7%	74.0%
	d-18	High rise flat - High eff - Panel heaters	100%	99.9%	99.7%	98.2%	89.7%
Gas heating conversion	nd-7	Small office - Med eff - Gas boilers	100%	98.8%	97.2%	89.9%	61.0%
	nd-1	Small office - Low eff - Gas boilers	100%	99.2%	97.8%	89.8%	60.0%
	nd-14	Large Office - High eff - Gas boilers	100%	99.0%	97.3%	89.9%	62.8%
	nd-11	Large Office - Med eff - Gas boilers	100%	99.0%	97.3%	89.9%	62.8%
	nd-4	Large Office - Low eff - Gas boilers	100%	99.2%	97.8%	89.8%	60.0%
	nd-8	Small retail - Med eff - Gas boilers	100%	98.8%	96.9%	86.7%	50.7%
	nd-12	Large retail - Med eff - Gas boilers	100%	99.6%	97.4%	88.7%	59.1%
	d-1	House - Low eff - Gas boilers	100%	99.8%	98.2%	89.3%	59.7%
	d-7	House - Med eff - Gas boilers	100%	99.9%	99.0%	92.0%	66.6%
	d-13	House - High eff - Gas boilers	100%	99.8%	99.6%	96.7%	81.4%
	d-3	Low rise flat - Low eff - Gas boilers	100%	99.8%	98.7%	90.4%	59.6%
	d-9	Low rise flat - Med eff - Gas boilers	100%	99.8%	99.8%	92.3%	70.1%
	d-15	Low rise flat - High eff - Gas boilers	100%	99.9%	99.8%	98.8%	92.6%
	d-5	High rise flat - Low eff - Gas boilers	100%	99.8%	98.3%	89.4%	64.2%
	d-11	High rise flat - Med eff - Gas boilers	100%	99.8%	99.2%	93.7%	74.0%
	d-17	High rise flat - High eff - Gas boilers	100%	99.9%	99.7%	98.2%	89.7%

9.4 Radiator sizing assessment

In order to increase the proportion of annual heat demand being met in properties retrofitted with district heating, a radiator sizing assessment was carried out to understand to what degree the size of radiators in a property may need to increase in order to meet 100% of the load. For this assessment a simple scenario was tested reviewing the radiator sizing for the living room in the low efficiency house typology.

To determine the increase in radiator size, manufacturer radiator conversion factors were used, as set out in Table 9-2. These figures are set against a base Delta T of 50 °C, whereby the Delta T is the temperature difference between the average radiator temperature (i.e. heating supply and return temperatures) and the design room temperature.

Table 9-2 Manufacturer radiator sizing conversion factors [21].

Delta T factors at base temperature of 50 °C					
5 °C	0.0501	30 °C	0.5148	55 °C	1.1319
10 °C	0.1234	35 °C	0.6290	60 °C	1.2675
15 °C	0.2091	40 °C	0.7482	65 °C	1.4065
20 °C	0.3039	45 °C	0.8720	70 °C	1.5487
25 °C	0.4061	50 °C	1.0000	75 °C	1.6940

These conversion factors are also illustrated below for information. For systems not operating at a Delta T of 50 °C (e.g. lower temperature networks would have a lower Delta T), the radiator size can therefore be determined by dividing the room heat output by the radiator conversion factor.

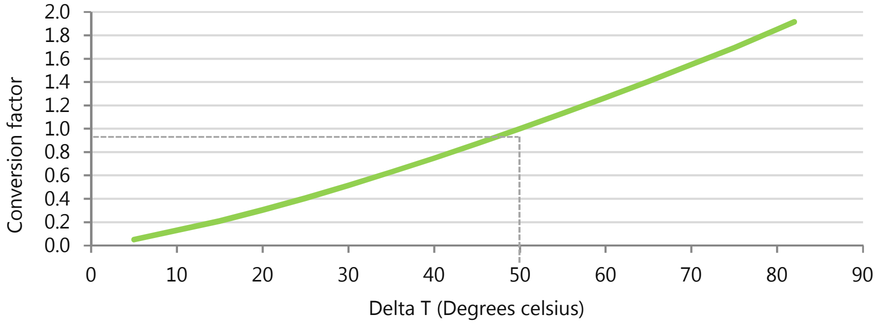

Figure 9-6 Radiator sizing conversion factors/

Table 9-3 sets out the calculated conversion factors for the a baseline heating system at 82/71°C, together with heating supply temperatures from 70 °C to 40 °C, where by the Delta T is based on an internal living room temperature of 22-23°C as per CIBSE Guide A[22].

Table 9-3 Calculated radiator conversion factors for heating supply temperature scenarios.

Heating supply temperature	°C	82	70	60	50	40
Heating return temperature	°C	71	50	40	30	20
Average radiator temperature	°C	76.5	60	50	40	30
Design room temperature	°C	22.5	22.5	22.5	22.5	22.5
Delta T for radiator sizing	°C	54	37.5	27.5	17.5	7.5
Radiator conversion factor	-	1.096	0.686	0.464	0.262	0.080

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[21] Stelrad radiator book 2016. https://www.stelrad.com/support-information/downloads/

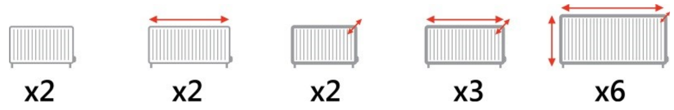
[22] CIBSE Guide A – Environmental Design 2015 edition. Chartered Institute of Building Services Engineers

According to the ESP-r simulations, the peak heat load for the living room (floor area 13.3m^2) in the low efficiency house typology is 1.06 kW. Including a 10% radiator oversizing allowance, as would be typical practice, this increases to 1.166 kW. The calculations in Table 9-4 set out what sized radiators are required to meet this load for each heating supply temperature scenario compared to a baseline wet system at 82/71.

Radiator outputs, dimensions and costs are based on manufacturer literature[23]. It should be noted that multiple combinations exist for possible radiator sizes and heat outputs. In the determination of the most suitable approach when selecting new radiator sizes, consideration has been given to the radiator dimensions in the base case in order to select units with similar dimensions where possible to minimise disruption.

Table 9-4 Calculation in radiator size increase to meet 100% of the load in the low efficiency house typology living room.

Heating supply temperature	**°C**	**82**	**70**	**60**	**50**	**40**
Living room load (inc. 10% allowance)	W	1,166	1,166	1,166	1,166	1,166
Equivalent output needed	W	1,064	1,700	2,514	4,454	14,616
Number of radiators	-	2	2	2	3	6
Radiator output	W	654	872	1,268	1,550	2,490
Radiator width	mm	900	1,200	900	1,100	1,400
Radiator height	mm	450	450	450	450	600
Radiator depth to wall	mm	80	80	135	135	135
Radiator unit cost excluding labour	£	£23.23	£23.23	£38.14	£44.75	£68.61
Total cost excluding piping & labour	£	£46.46	£46.46	£76.28	£134.25	£411.66



For the baseline heating system with a supply temperature of 82 °C, two 900mm x 450mm radiators have been sized to meet the room's heating load. With district heating at a 70 °C supply temperature, the required heat output from the radiators increases significantly from 1,064 W to 1,700 W, however, this can be met through the installation of slightly wider radiators. Similarly, at a heating supply temperature of 60 °C, the room output can be met with new radiators, keeping the same width and height as the base case, only slightly thicker, becoming double panel units.

At the heating supply temperature of 50 °C the heat output required from the radiators is now over four times larger than the base case, meaning that the most practical solution would be to have three radiators in the room (or potentially two large radiators, in place of the two existing radiators), which is likely to be acceptable depending on space provision. Again, these radiators would be wider than the base case, but also they would be thicker units. Minor upgrades to the fabric e.g. improved air tightness are likely to reduce this need further.

Finally, at the district heating supply temperature of 40 °C, the radiator conversion factor applied means that the equivalent heat output needed from the radiators is too high to be acceptable or feasible, as it would result in a significant increase to the required number and size of radiators. An alternative approach would therefore be required.

Whilst the analysis above has not covered all typologies in this assessment, different efficiency levels, or indeed all rooms in the low efficiency house model, it serves to illustrate the challenges of meeting the space heating load for 4th generation district heating with larger heat emitters alone. It does however illustrates that at supply temperatures of 70 °C, 60 °C and 50 °C building level retrofit works are not needed in order to meet required levels of thermal comfort but for supply temperatures of 40 °C there is a requirement for building fabric retrofit measures as well.

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[23] Stelrad radiator book 2016. https://www.stelrad.com/support-information/downloads/

9.5 Domestic energy efficiency assessment

In order to better understand how to increase the annual heat demand met from 4th generation district heating networks at 40 °C supply temperatures, (for which would energy efficiency improvements are required), a building fabric upgrade study has been carried out on the low efficiency house typology. From the domestic typology assessment summary (see Figure 4-1), this typology was found to be the most prevalent across London. It, together with the low-rise, low efficiency flat also shares the lowest proportion of annual heat demand being met from a supply temperature of 40 °C, across the domestic building typologies of 59.7% and 59.6% respectively (in the analysis presented previously in Table 9-1).

In this energy efficiency study, a number of retrofit strategies have been considered based on a combination of air tightness improvements, building fabric upgrades to Building Regulations Part L1B[24] as well as building fabric improvements moving towards Passivhaus[25] levels of insulation. Measures were selected to represent a low/no cost solution, together with two tiers of fabric retrofits to give results as thermal classes capable of being extrapolated to all domestic typologies. These measures are set out in Table 9-5 below.

Table 9-5 Building fabric upgrade strategies modelled for the low efficiency house building typology. All fabric U-values are in W/m^2.K ACH stands for air change rate. Dimensions shown in the roof column represent insulation thickness.

	Walls	Windows	Roof	ACH
Baseline	Solid walls, U=2.10	Single glazed, U=2.10, g=0.85	50-150mm, U=0.4	1
Half air infiltration	Solid walls, U=2.10	Single glazed, U=2.10, g=0.85	50-150mm, U=0.4	0.5
U-values to Part L1B	Insulated, U=0.30	Double glazed, U=1.4, g=0.85	300mm, U=0.11	1
U-values to Part L1B + half infiltration	Insulated, U=0.30	Double glazed, U=1.4, g=0.85	300mm, U=0.11	0.5
Passivhaus U-values	Insulated, U=0.12	Triple glazed, U=0.8	300mm, U=0.11	1
Passivhaus U-values + half infiltration	Insulated, U=0.12	Triple glazed, U=0.8	300mm, U=0.11	0.5

In the table above, the Part L1B compliant U-value of 0.3 W/m^2.K can be achieved on the solid walled property with approximately 60mm of internal insulation, or 100mm of external insulation applied to the solid brick wall. The Passivhaus compliant U-value of 0.12 W/m^2.K can be achieved with 180mm of internal insulation or 250mm of external insulation. Only Passivhaus U-values are tested opposed to Passivhaus levels of airtightness, as this would require a far more extensive level of retrofit in addition to the installation of a whole house mechanical ventilation system with heat recovery, which is beyond the aims of this study.

In Figure 9-7 the annual primary energy saving from each of the retrofit scenarios are shown. Note that all results given, are based upon a supply temperature of 82°C. The analysis at 40 °C supply temperature is discussed in the proceeding section.

As shown, all measures provide significant levels of energy savings. The low/no cost air tightness upgrade is shown to reduce total heat demand by 21%. The addition of new double glazing and wall insulation compliant with Building Regulations achieve a 54% reduction in heat demand, increasing to 68% when infiltration is halved. The Passivhaus U-values as a standalone measure are seen to be not as effective as the Building Regulations upgrade with improved infiltration. However, when Passivhaus is applied with the infiltration halved it is seen to be the most effective approach at reducing the annual heat load.

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[24] Building Regulations Part L1B, Conservation of fuel and power in existing dwellings 2010 (incorporating 2010, 2011, 2013 and 2016 amendments). https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l

[25] Passivhaus standard, http://www.passivhaus.org.uk/

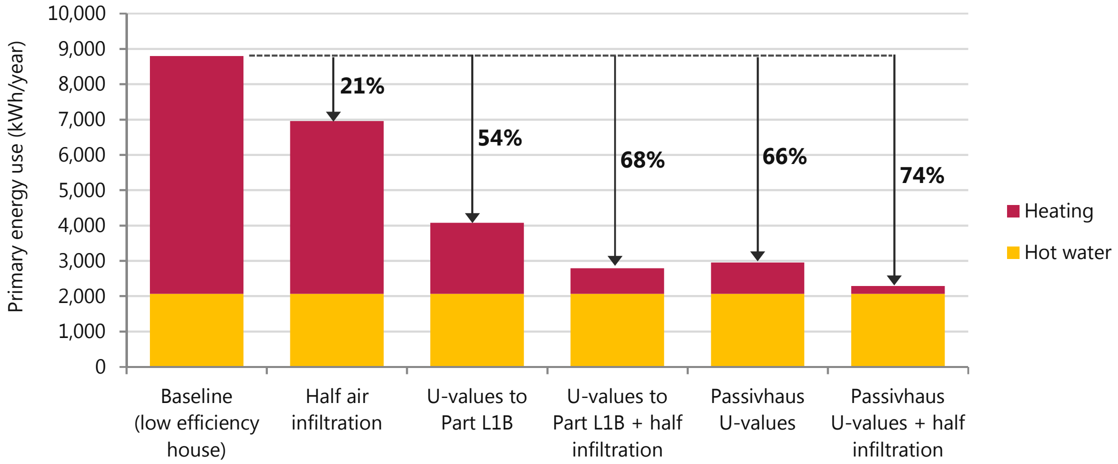

Figure 9-7 Reduction in annual heat demand (for heat) from fabric upgrade measures applied to the low rise house building typology. Results presented are based on a heating supply temperature of 82 °C.

To illustrate what impact the energy efficiency retrofits have on the percentage of annual heat demand met at a district heating supply temperature of 40 °C, Figure 9-8 shows a revised load duration curve for the low efficiency house typology with a retrofit scenario applied.

In this graph the load duration curves labelled as 'baseline: no retrofit' and '40 flow: no retrofit' represent the results from the analysis presented earlier in Figure 9-1, for reference. The two new load duration curves for 'baseline: with retrofit' and '40 flow: with retrofit' then represent the same analysis, but now with the fabric upgrade applied (which in this case is the U-values to Part L2B + half infiltration).

As shown, because the building has undergone retrofit works, the baseline heat demand is lower, and the proportion of heat demand that can be met with the district heating supply at 40 °C has increased (in this case to 95.9%).

This represents a promising result for the technical feasibility of 4th generation district heating retrofits, as it has already been shown in the earlier radiator sizing analysis, that the incorporation of larger radiators can meet the remaining load (which now is much smaller than it originally was).

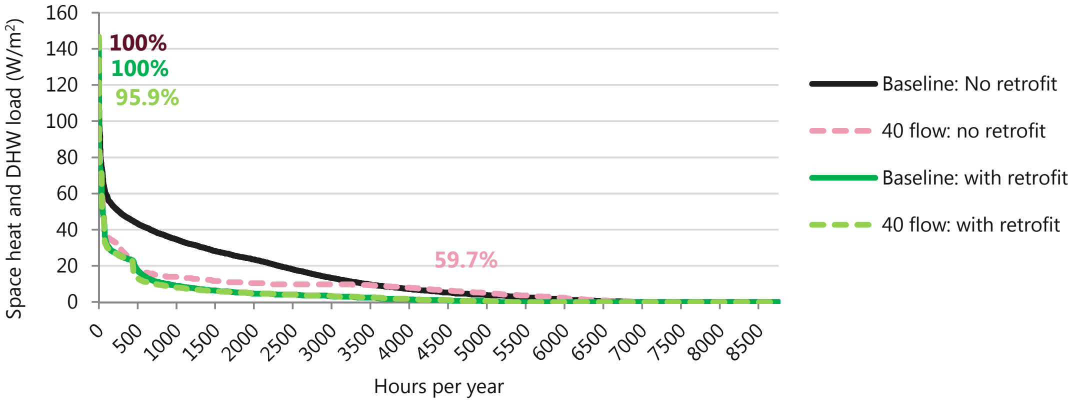

Figure 9-8 Low efficiency house - Load duration curve illustrating the annual percentage of heat demand met at a 40 °C supply temperature with no energy efficiency measures applied. The annual percentage of heat demand met at a 40 °C supply temperature is then re-baselined and analysed following energy efficiency retrofit to Building Regulations Part L2B, with infiltration halved.

Table 9-6 gives the annual heat demand results for each of the retrofit cases assessed for the low efficiency house typology. As shown, low/no cost works to improve air infiltration are found to increase the annual proportion of heat demand met at 40 °C supply temperatures to 68.7%. More extensive retrofit works to Building Regulations standards then increases this figure to between 86.4% - 94.6%. Deeper retrofits meeting Passivhaus U-values are found to allow a 40 °C supply temperature to be able to meet between 94.6% - 99.8% of the annual heat demand.

Table 9-6 Modelling results illustrating proportion of annual heat demand met after energy efficiency retrofit in low efficiency house model.

Low efficiency house	Percentage of annual heat demand	
	Baseline	40 flow
Baseline (no retrofit measures)	100%	59.70%
Half air infiltration	100%	68.70%
U-values to Part L1B	100%	86.40%
U-values to Part L1B + half infiltration	100%	95.90%
Passivhaus U-values	100%	94.60%
Passivhaus U-values + half infiltration	100%	99.80%

9.6 Non-domestic energy efficiency assessment

For non-domestic buildings, the extent of energy efficient fabric improvements is likely to be far more limited than in the domestic sector. Whilst it is possible to internally/externally insulate walls and replace entire facades, for the purposes of this retrofit study the main intervention assessed is the addition of new double glazing and improved air tightness on all previous cost effective typologies.

The ESP-r simulation models, mapped to non-domestic typologies found to be cost effective are given in Table 9-7 below, listed in order of cost effectiveness from high to medium. For all cases, a retrofit scenario has been assessed with new double glazing (U=1.4 W/m^2.K, G=0.68) with improved air tightness (0.5 ACH).

Table 9-7 Baseline characteristics of non-domestic office and retail models (prior to energy efficiency retrofit. U-values in W/m^2.K.

Load modelling geometry	Glazing	U-value	G-value	Glazing coverage	Wall type & U-value
Modern office, fully glazed	Double	2.0	0.72	Fully	Insulated 0.6
Modern office, partially glazed	Double	2.0	0.72	Partially (50% glazed)	Insulated 0.6
Retail large high street, no catering	Double	2.0	0.72	100% at front, 50% at back)	Solid, 2.1
Retail, small high street	Single	4.3	0.76	100% at front, 50% at back)	Solid, 2.1
Pre 1960 office, low efficiency	Single	4.3	0.76	Partially (50% glazed)	Solid, 2.1

Figure 9-9 illustrates the energy saving from this retrofit invention across the typologies. As shown, in all cases the primary energy savings are significant, being in the order of 61% to 74%, with the largest energy saving arising from the fully glazed office model with the largest glazing area. Slightly lower energy savings are observed on the other two office models, as they have larger expanses of exposed walls, which have not been upgraded as part of the works. The small retail high street model with single glazing illustrates a greater energy saving than the large retail high street model with double glazing as would be expected.

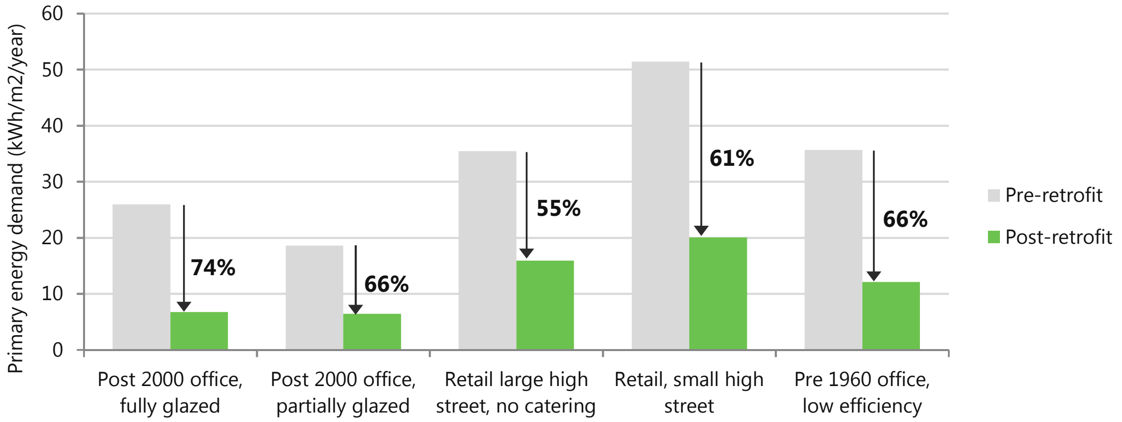

Figure 9-9 Primary energy savings (for heat) from installation of new double glazing with improved air tightness on the non-domestic models.

As per the analysis conducted for the domestic study, Figure 9-10 illustrates how the annual proportion of heat demand at a 40 °C supply temperature varies with and without the fabric retrofit for the pre 1960s office low efficiency model. As shown, with no retrofit applied, at a heating supply temperature of 40 °C, approximately 60% of the load can be met. By comparison, with the new double glazing and air tightness improvements applied, there is a marginal improvement on this figure to 71% against the revised baseline.

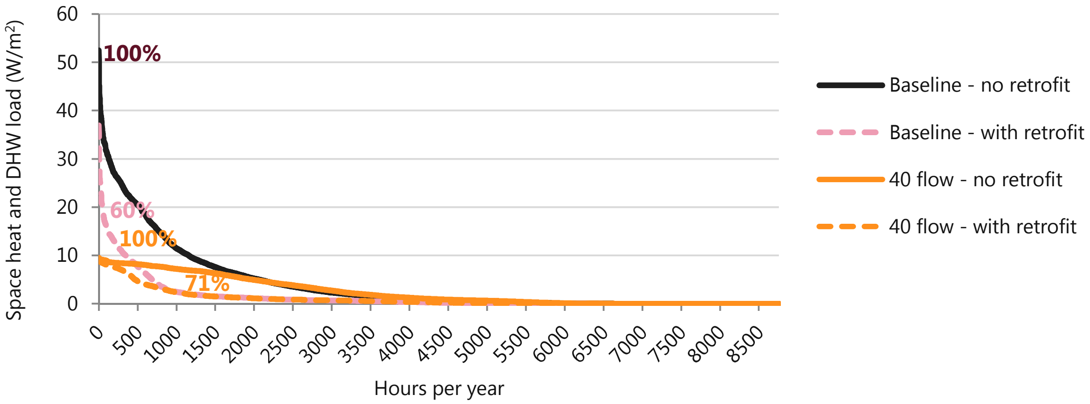

Figure 9-10 Pre 1960 office low efficiency - Load duration curve illustrating the annual percentage of heat demand met at a 40 °C supply temperature with no energy efficiency measures applied. The annual percentage of heat demand met at a 40 °C supply temperature is then re-baselined and analysed following energy efficiency retrofit with new double glazing and infiltration halved.

Table 9-8 contains the annual heat demand results for each of the non-domestic typologies assessed. As shown, the modern (now double glazed) offices, performs most favourably out of all the typologies, followed by the pre 1960s office. There is a marginal improvement of approximately 10% in the retail typologies, however the annual proportion of heat demand being met is still low, suggesting that these properties in particular would be challenging to get performing adequately from a thermal perspective at a supply temperature of 40 °C without more extensive retrofit works and/or the addition of much larger heat emitters.

Table 9-8 Modelling results illustrating proportion of annual heat demand met after energy efficiency retrofit in non-domestic models.

Non-domestic models (medium & high cost effectiveness)	Percentage of annual heat demand pre-retrofit		Percentage of annual heat demand post-retrofit	
	Baseline	40 flow	Baseline	40 flow
Modern office, fully glazed	100%	61%	100%	78%
Modern office, partially glazed	100%	63%	100%	76%
Retail large high street, no catering	100%	53%	100%	62%
Retail, small high street	100%	51%	100%	61%
Pre 1960 office, low efficiency	100%	60%	100%	71%

9.7 Capital costing of domestic energy efficiency measures

In order to assess the impact of additional energy efficiency investment on the overall cost effectiveness of 4th generation district heating at heating supply temperatures of 40 °C, high level capital costing has been carried out for the fabric measures discussed in this chapter to re-evaluate cost effectiveness as per Work Package 3A.

Domestic energy efficiency retrofit costing has been carried out for all typologies, using BuroHappold £/m^2 figures, as set out in Table 9-9, which have been internally benchmarked against BRE (Building Research Establishment) and EST (Energy Saving Trust) datasets to assess their validity.

Table 9-9 Domestic energy efficiency costs (BuroHappold figures).

ID			House	Low-rise flat, converted	Low-rise flat, purpose built	High rise flat
A	New double glazing	£/m^2 glazing	160	160	160	160
B	New triple glazing	£/m^2 glazing	350	350	350	350
C	60mm internal insulation	£/m^2 wall area	60	72	72	72
D	100mm internal insulation	£/m^2 wall area	80	96	96	96
E	150mm internal insulation	£/m^2 wall area	100	150	150	150
F	100mm external insulation	£/m^2 wall area	90	135	135	135
G	250mm external insulation	£/m^2 wall area	150	225	225	225
H	Cavity wall insulation	£/property	300	n/a	280	280
I	50-150 to 300mm loft insulation	£/property	240	n/a	n/a	n/a
J	150+ to 300mm loft insulation	£/property	230	n/a	n/a	n/a
K	Draft proofing	£/m perimeter	20	20	20	20
L	Builders works	% CapX	10%	10%	10%	10%
M	Preliminaries and overheads	% CapX	25%	25%	25%	25%

Table C-6 to C-8 in Appendix C show how the costing data above has been translated to each of the domestic typologies to determine retrofit package costs for each of the energy efficiency scenarios discussed. In these tables, the letters in the 'REF' column refer to the measures above. Note that builders works, preliminaries, overheads and additional labour allowance are not included in these figures, but are added afterwards.

Figure 6-6 illustrates the calculated total capital cost associated with retrofitting each domestic typology to Building Regulations Part L1B U-values and halved air infiltration. Here, the highest cost can be seen for the low efficiency house, which has undergone new double glazing, 60mm internal insulation, 50-150mm to 300mm loft insulation and draught proofing.

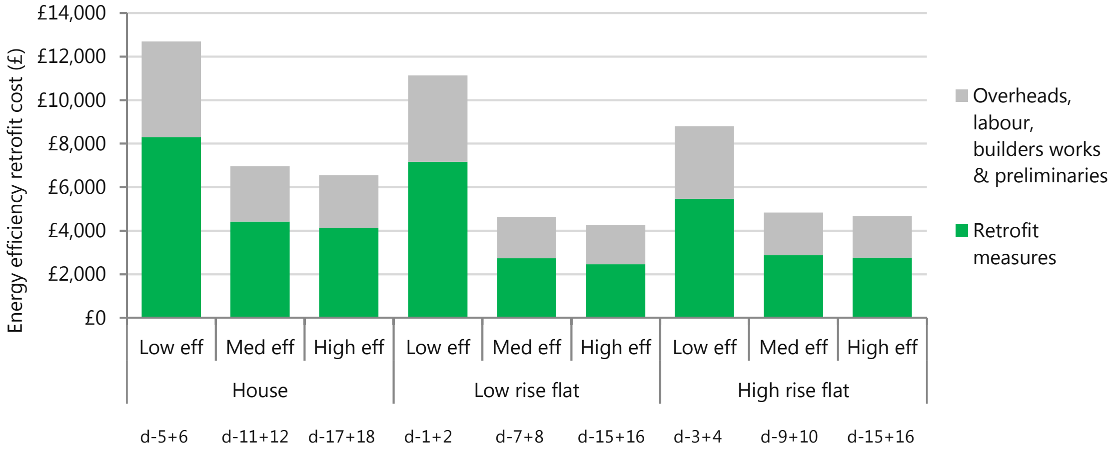

Figure 9-11 Capital costs for the domestic energy efficiency scenario of "U-values to Part L1B + half infiltration".

Capital costs per m^2 for this intervention are also given in Figure 9-12. As shown costs per m^2 range from £71 for the high rise low efficiency flat, to £161 for the low efficiency house. Note that values are in a similar order of magnitude to those for district heating retrofit costs presented in Work Package 2B.

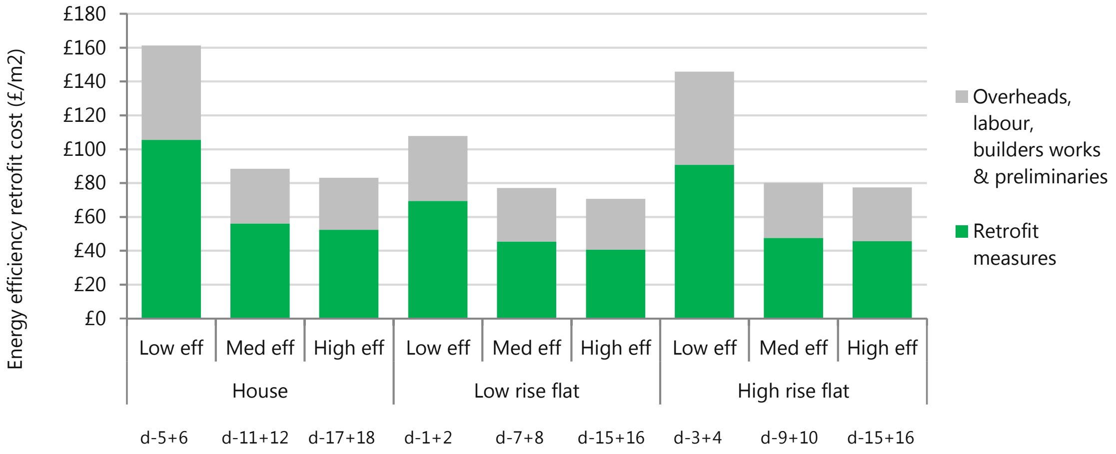

Figure 9-12 Capital costs per m^2 for the domestic energy efficiency scenario of "U-values to Part L1B + half infiltration".

Table C-9 to C-11 in Appendix C detail the cost for all packages in terms of the total cost and cost per m^2. In terms of costs for the improved air tightness scenario only, these are found to range from £312 to £342 in total, so represent a low-cost measure likely to improve the cost effectiveness of district heating retrofit.

Costs for the Passivhaus U-value scenarios are approximately 1.5 to 3 times larger than that of the Building Regulations scenarios, depending on the property type and level of baseline energy efficiency, with costs ranging from approximately £28,000 (£354/m^2) for the low efficiency house to £9,000 (£117/m^2) for the high efficiency high rise flat. These costs are likely to be prohibitive in terms of the cost effectiveness of district heating.

9.8 Capital costing of non-domestic energy efficiency measures

Table 9-10 summarises the estimated capital costs for new double glazing and halved air infiltration on the non-domestic typologies. Here, a unit cost of £120/m^2 of glazing area was assumed based on BuroHappold experience. Air tightness improvements are based on a cost of £20/m of perimeter, considering number of floors. Labour is taken as two labourers for three days on small units, and three labourers for five days on large units. A 10% and 25% allowance has been made for builders works, preliminaries and overheads.

Table 9-10 Capital costing for new double glazing and halved air infiltration on non-domestic typologies.

#	Geometry	Area (m^2)	Glazing area	Glazing	Infiltration	Labour	Total cost	Total (£/m^2)
nd-1	Pre 1960 office	100	33.3	£4,000	£400	£1,176	£7,527	£75.27
nd-2	Modern office	100	53.3	£6,400	£400	£1,176	£10,767	£107.67
nd-3	Retail, High street	100	60.0	£7,200	£400	£1,176	£11,847	£118.47
nd-4	Pre 1960 office	1000	52.7	£6,325	£632	£2,940	£13,360	£13.36
nd-5	Modern office	1000	84.3	£10,119	£632	£2,940	£18,483	£18.48
nd-6	Retail, large	1000	134.2	£16,100	£894	£2,940	£26,911	£26.91
nd-7	Modern office	100	53.3	£6,400	£400	£1,176	£10,767	£107.67
nd-8	Retail, High street	100	80.0	£9,600	£400	£1,176	£15,087	£150.87
nd-9	Modern office	100	33.3	£4,000	£400	£1,176	£7,527	£75.27
nd-10	Retail, High street	100	60.0	£7,200	£400	£1,176	£11,847	£118.47
nd-11	Pre 1960 office	1000	52.7	£6,325	£632	£2,940	£13,360	£13.36
nd-12	Retail, large	1000	134.2	£16,100	£894	£2,940	£26,911	£26.91
nd-13	Modern office	1000	52.7	£6,325	£632	£2,940	£13,360	£13.36
nd-14	Pre 1960 office	1000	42.2	£5,060	£632	£1,176	£9,272	£9.27

Figure 9-13 illustrates the capital costs determined per m^2. Again these energy efficiency costs are of a similar level of magnitude to the costs for connecting to district heating.

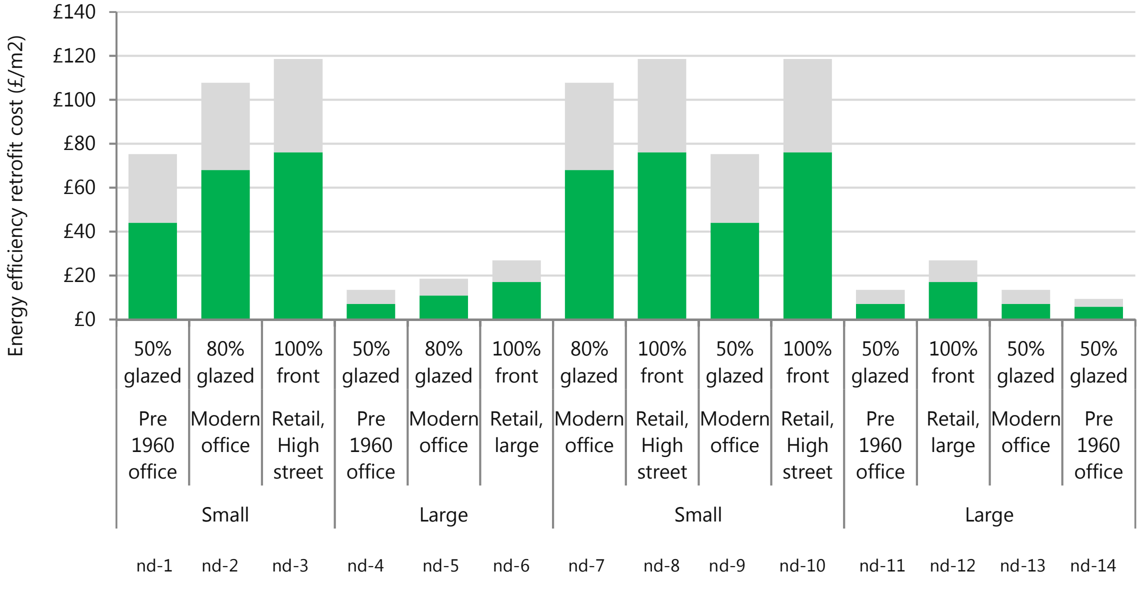

Figure 9-13 Capital costs per m^2 for new double glazing and halved air infiltration on non-domestic typologies.

9.9 Cost effectiveness of 4th generation district heating with energy efficiency measures

Using the capital cost figures generated, the cost effectiveness of district heating retrofit has been assessed for the 40 °C supply temperature scenario, with a series of energy efficiency retrofits applied. In this assessment, all five domestic fabric upgrade strategies were assessed, together with the single modelling iteration for non-domestic buildings looking at new double glazing and air tightness measures applied. In terms of the proportion of unmet annual heat demand that was unmet, (refer to Table 9-4 for the domestic examples, and Table 9-8 for non-domestic), interventions have been made to assess cost effectiveness with 100% of heating (and hot water) demand being met.

For domestic properties, across each scenario modelled, new larger radiators with TRVs have been modelled for the purpose of costing. In cases where the cost to connect to district heating has already allowed for the installation of new radiators (e.g. for the electric properties with a new wet-radiator system), these costs have been updated to reflect the new costs for large units, without double counting the figures. The radiator sizing is taken for the entire property and considers the number of heated rooms in the dwelling, the reduced room load following energy efficiency works, as well as the normal allowances for labour, overheads and installation.

For commercial properties, since the proportion of annual heat demand was generally found to be much lower than the domestic scenarios run, rather than costing larger radiators (likely to have been space prohibitive due to the Delta T associated with the 40 °C supply temperature), the unmet energy demand has been allocated to a secondary electric system, for which the supplementary energy use is charged at the commercial electricity rate.

For hot water production, (discussed in further detail in Appendix B) as the 40 °C district heating network would pose a potential Legionella risk, a solution to provide top-up heat electrically has been provided for each typology. Depending on the hot water use and system configuration it may be possible to install point-of-use heaters for sinks etc, which also allows centralised heating systems to be turned off in summer. This may be more economical if the use is low and inconsistent than the alternative of holding a large volume of water at 60 °C. An electric coil in the calorifier or hot water tank, if present, could also provide additional heat as necessary.

The proportion of annual heat demand supplied from the district heating network has been estimated at 55% based on a simple calculation assuming the district heating network provides a DHW pre-heat to 40 °C and the boiler provide the rest to 65 °C. For the high rise flats, rather than incorporating the centralised domestic hot water store option (e.g. for high rise flats, costed in Work Package 2B), the more economical point-of-use heaters for sinks etc has been costed, together with the associated electricity use.

9.10 Cost effectiveness results

Over the next three pages the cost effectiveness results for 4th generation district heating networks at heating supply temperatures of 40 °C are shown (following a similar approach to that described Work Package 3A).

On the first page, Table 9-11 gives the cost effectiveness results calculated for district heating at 40 °C on electric heated domestic properties, assessed against three building fabric upgrade strategies. Figures are compared to a counterfactual case which has had no fabric upgrade applied.

Table 9-12 then shows the same analysis for gas heated properties. Results for the two Passivhaus scenarios are not shown as in all cases results provided no payback (for either gas or electricity conversion scenarios).

Table 9-13 illustrates the cost effectiveness results for the non-domestic cases incorporating fabric energy efficiency. Here, the counterfactual cases are a combination of heat pump, VRF and gas boiler solutions with no building fabric measures applied.

Table 9-11 Domestic typology cost effectiveness calculation at heating supply temperature of 40°C with energy efficient retrofit in electric heated properties. Three tiers of payback results are shown representing three levels of energy efficiency applied alongside the 40 °C heating supply temperature. The counterfactual case has electric panel heaters and no building fabric upgrades applied.

		District heating heat price (£/MWh)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	Counterfactual cost (£/MWh)
Typology			Payback period (years) at different district heating unit prices																			
Fabric upgrade with half air infiltration																						
Electric conversion	d-2	House - Low eff. - Panel heaters	12	12	12	13	13	14	14	15	15	16	17	18	19	20	21	22	23	25	26	£180
	d-8	House - Med eff. - Panel heaters	17	17	18	18	19	20	21	22	23	24	25	26	28	29	31	33	36	39	42	£188
	d-14	House - High eff. - Panel heaters	33	34	36	38	40	42	44	47	50	54	59	65	73	86	n/a	n/a	n/a	n/a	n/a	£211
	d-4	Low rise flat - Low eff. - Panel heaters	14	15	15	16	16	17	18	18	19	20	21	22	23	25	26	28	30	32	35	£177
	d-10	Low rise flat - Med eff. - Panel heaters	17	18	19	19	20	21	22	23	24	25	26	27	29	30	32	34	37	40	43	£198
	d-16	Low rise flat - High eff. - Panel heaters	42	44	46	49	52	55	59	63	69	76	87	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£243
	d-6	High rise flat - Low eff. - Panel heaters	13	14	14	15	15	16	16	17	18	18	19	20	21	22	23	25	26	28	30	£191
	d-12	High rise flat - Med eff. - Panel heaters	18	19	20	20	21	22	23	24	25	26	27	29	30	32	34	36	39	42	46	£204
	d-18	High rise flat - High eff. - Panel heaters	32	34	35	36	38	40	42	44	47	50	53	57	62	69	78	92	n/a	n/a	n/a	£234
Fabric upgrade to Building Regulations Part L1B U-values																						
Electric conversion	d-2	House - Low eff. - Panel heaters	26	27	27	28	29	29	30	31	31	32	33	34	35	36	37	38	39	41	42	£180
	d-8	House - Med eff. - Panel heaters	26	26	27	27	28	29	29	30	31	32	32	33	34	35	36	38	39	40	42	£188
	d-14	House - High eff. - Panel heaters	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£211
	d-4	Low rise flat - Low eff. - Panel heaters	24	24	25	25	25	26	27	27	28	28	29	30	30	31	32	33	34	35	36	£177
	d-10	Low rise flat - Med eff. - Panel heaters	25	26	26	27	28	28	29	30	31	32	33	34	35	36	37	38	40	41	43	£198
	d-16	Low rise flat - High eff. - Panel heaters	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£243
	d-6	High rise flat - Low eff. - Panel heaters	28	29	29	30	31	31	32	33	34	35	36	37	38	40	41	42	44	46	48	£191
	d-12	High rise flat - Med eff. - Panel heaters	30	30	31	32	33	34	35	36	37	38	39	41	42	44	46	48	50	53	56	£204
	d-18	High rise flat - High eff. - Panel heaters	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£234
Fabric upgrade to Building Regulations Part L1B U-values + half air infiltration																						
Electric conversion	d-2	House - Low eff. - Panel heaters	25	25	25	26	26	26	27	27	27	28	28	28	29	29	30	30	30	31	31	£180
	d-8	House - Med eff. - Panel heaters	25	25	25	26	26	26	27	27	27	28	28	29	29	30	30	31	31	32	32	£188
	d-14	House - High eff. - Panel heaters	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£211
	d-4	Low rise flat - Low eff. - Panel heaters	22	22	23	23	23	23	24	24	24	24	25	25	25	25	26	26	26	27	27	£177
	d-10	Low rise flat - Med eff. - Panel heaters	25	25	26	26	26	27	27	28	28	29	29	30	30	31	32	32	33	34	34	£198
	d-16	Low rise flat - High eff. - Panel heaters	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£243
	d-6	High rise flat - Low eff. - Panel heaters	27	27	28	28	28	29	29	30	30	31	31	32	32	33	34	34	35	36	36	£191
	d-12	High rise flat - Med eff. - Panel heaters	29	30	30	31	31	32	33	33	34	35	36	37	37	38	39	40	41	43	44	£204
	d-18	High rise flat - High eff. - Panel heaters	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£234

Table 9-12 Domestic typology cost effectiveness calculation at heating supply temperature of 40°C with energy efficient retrofit in gas heated properties. Three tiers of payback results are shown representing three levels of energy efficiency applied alongside the 40 °C heating supply temperature. The counterfactual case has gas boilers and no building fabric upgrades applied.

		District heating heat price (£/MWh)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	Counterfactual cost (£/MWh)
		Typology	Payback period (years) at different district heating unit prices																			
Fabric upgrade with half air infiltration																						
Gas heating conversion	d-1	House - Low eff. - Gas boilers	31	35	40	47	59	87	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£66
	d-7	House - Med eff. - Gas boilers	35	39	45	54	68	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£74
	d-13	House - High eff. - Gas boilers	53	62	77	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£106
	d-3	Low rise flat - Low eff. - Gas boilers	39	45	55	73	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£63
	d-9	Low rise flat - Med eff. - Gas boilers	27	30	33	37	42	49	61	85	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£85
	d-15	Low rise flat - High eff. - Gas boilers	35	38	42	47	52	61	74	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£140
	d-5	High rise flat - Low eff. - Gas boilers	23	25	28	31	36	42	51	66	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£77
	d-11	High rise flat - Med eff. - Gas boilers	25	27	30	33	37	42	49	60	83	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£91
	d-17	High rise flat - High eff. - Gas boilers	30	32	35	39	43	49	57	70	97	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£130
Fabric upgrade to Building Regulations Part L1B U-values																						
Gas heating conversion	d-1	House - Low eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£66
	d-7	House - Med eff. - Gas boilers	91	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£74
	d-13	House - High eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£106
	d-3	Low rise flat - Low eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£63
	d-9	Low rise flat - Med eff. - Gas boilers	49	53	60	68	81	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£85
	d-15	Low rise flat - High eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£140
	d-5	High rise flat - Low eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£77
	d-11	High rise flat - Med eff. - Gas boilers	52	58	65	76	96	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£91
	d-17	High rise flat - High eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£130
Fabric upgrade to Building Regulations Part L1B U-values + half air infiltration																						
Gas heating conversion	d-1	House - Low eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£66
	d-7	House - Med eff. - Gas boilers	72	80	94	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£74
	d-13	House - High eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£106
	d-3	Low rise flat - Low eff. - Gas boilers	89	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£63
	d-9	Low rise flat - Med eff. - Gas boilers	46	49	53	57	63	71	82	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£85
	d-15	Low rise flat - High eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£140
	d-5	High rise flat - Low eff. - Gas boilers	89	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£77
	d-11	High rise flat - Med eff. - Gas boilers	50	54	59	66	74	88	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£91
	d-17	High rise flat - High eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£130

Table 9-13 Non-domestic typology cost effectiveness calculation at heating supply temperature of 40°C with energy efficient retrofit in electric heated properties. In all cases a building fabric upgrade consisting of new double glazing and increased air tightness has been applied alongside the 40 °C heating supply temperature. The counterfactual cases are a combination of heat pump, VRF and gas boiler solutions.

		District heating heat price (£/MWh)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	Counterfactual cost (£/MWh)
		Typology	Payback period (years) at different district heating unit prices																			
New double glazing + half air infiltration																						
Electric heating conversion	nd-2	Small office - Low eff. - Heat pump	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£559
	nd-5	Large Office - Low eff. - Heat pump	7	7	7	7	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	£521
	nd-3	Small retail - Low eff. - Heat pump	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£361
	nd-9	Small office - Med eff. - VRF	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£992
	nd-13	Large Office - Med eff. - VRF	15	15	15	15	16	16	16	16	16	16	16	16	16	16	16	16	17	17	17	£794
	nd-10	Small retail - Med eff. - VRF	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£477
	nd-6	Large retail - Low eff. - VRF	28	28	28	29	29	30	30	31	31	32	32	33	34	34	35	36	36	37	38	£472
Gas heating conversion	nd-7	Small office - Med eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£25
	nd-1	Small office - Low eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£100
	nd-14	Large Office - High eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£55
	nd-11	Large Office - Med eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£52
	nd-4	Large Office - Low eff. - Gas boilers	33	35	37	40	43	46	51	56	63	73	91	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£40
	nd-8	Small retail - Med eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£80
	nd-12	Large retail - Med eff. - Gas boilers	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	£37

9.11 Summary

The load modelling in this chapter estimates that in a district heating network with a supply temperature of 70 °C approximately 99% of annual energy demand can be met. At 60 °C this drops to between 96%-99%, and at 50 °C this drops further to between 86%-98%. At a supply temperature of 40 °C this can be as low as 50%-92% depending on the efficiency of the existing property to be supplied.

It was identified that through the use of larger radiators it was possible to meet 100% of space heating demand in a domestic property at heating supply temperatures from 70 to 50 °C with minimal impact on internal space due to the larger radiators. By comparison, with 40 °C supply temperatures larger radiators alone would be an impractical solution, because of the number and size of additional radiators required.

At this 40 °C supply temperature, low cost measures to improve air tightness alone were estimated to only increase the percentage of annual energy demand from approximately 60% to 70%. By comparison, an energy efficiency upgrade with insulation (equivalent to Building Regulations Part L1B standards for improved U-values), new windows and air tightness improvements, to deliver halved air infiltration rates, were shown to increase this to 95%. These additional energy efficiency works add further costs of £71/m^2 to £161/m^2 to the district heating retrofit, but they allow larger emitters (or variations in heat network temperature) to meet the remaining energy demand for the building.

For electrically heated domestic properties retrofitted with 4th generation district heating at 40 °C, the lowest cost intervention involving improving air tightness only was found to provide the highest level of cost effectiveness. It should be noted however, that for this scenario there was the highest number of unmet annual heating hours, meaning that significant disruptive works would be needed. For this fabric upgrade strategy, the high cost effective typologies were found to be the low efficiency house, high rise flat, then low-rise flat. Medium cost effectiveness can also be observed in the medium efficiency models. In terms of the two further cost effectiveness calculations meeting U-values within Building Regulations Part L1B, the combination of U-values with air-tightness upgrades is shown to provide the largest proportion of medium cost effective heat prices. None of the results here achieve high cost effectiveness, illustrating that the costs to retrofit existing buildings (i.e. involving glazing upgrade and wall insulation), would require subsidy to increase overall cost effectiveness.

For gas heated domestic properties, again the fabric intervention of halving infiltration provides the greatest increase in the cost effectiveness of 4th generation district heating. Properties that can achieve a medium level of cost effectiveness are shown to be the medium efficiency low rise flat, and all high rise flat scenarios. For the two fabric upgrade scenarios meeting Part L1B there are no medium or high cost effective typologies shown, illustrating that the counterfactual case (i.e. gas boiler with no fabric upgrade) provides the better whole life cost.

For the non-domestic 4th generation district heating cost effectiveness calculations with energy efficiency retrofits, the two high cost effective typologies are shown to be the conversion of large low efficiency offices served by heat pumps and large medium efficiency offices with VRF. The large low efficiency retail model was also found to be of medium cost effectiveness. Note that all three of these typologies, were also found to be of equivalent cost effectiveness in the baseline cost effectiveness assessment for Work Package 3A. No other cost effective cases were observed.

Maps illustrating the density of "high" and "high and medium" cost effective properties for 4th generation district heating retrofit are shown on the next two pages. As shown, the highest densities of "high" cost effective properties can be found in Tower Hamlets, Westminster, Islington, Sutton and Southwark. The highest densities of "high and medium" cost effective properties can be found in Tower Hamlets, Westminster, Southwark, Hammersmith & Fulham and Hounslow.

Density of high cost effective properties for 4th generation district heating retrofit – Domestic & non-domestic

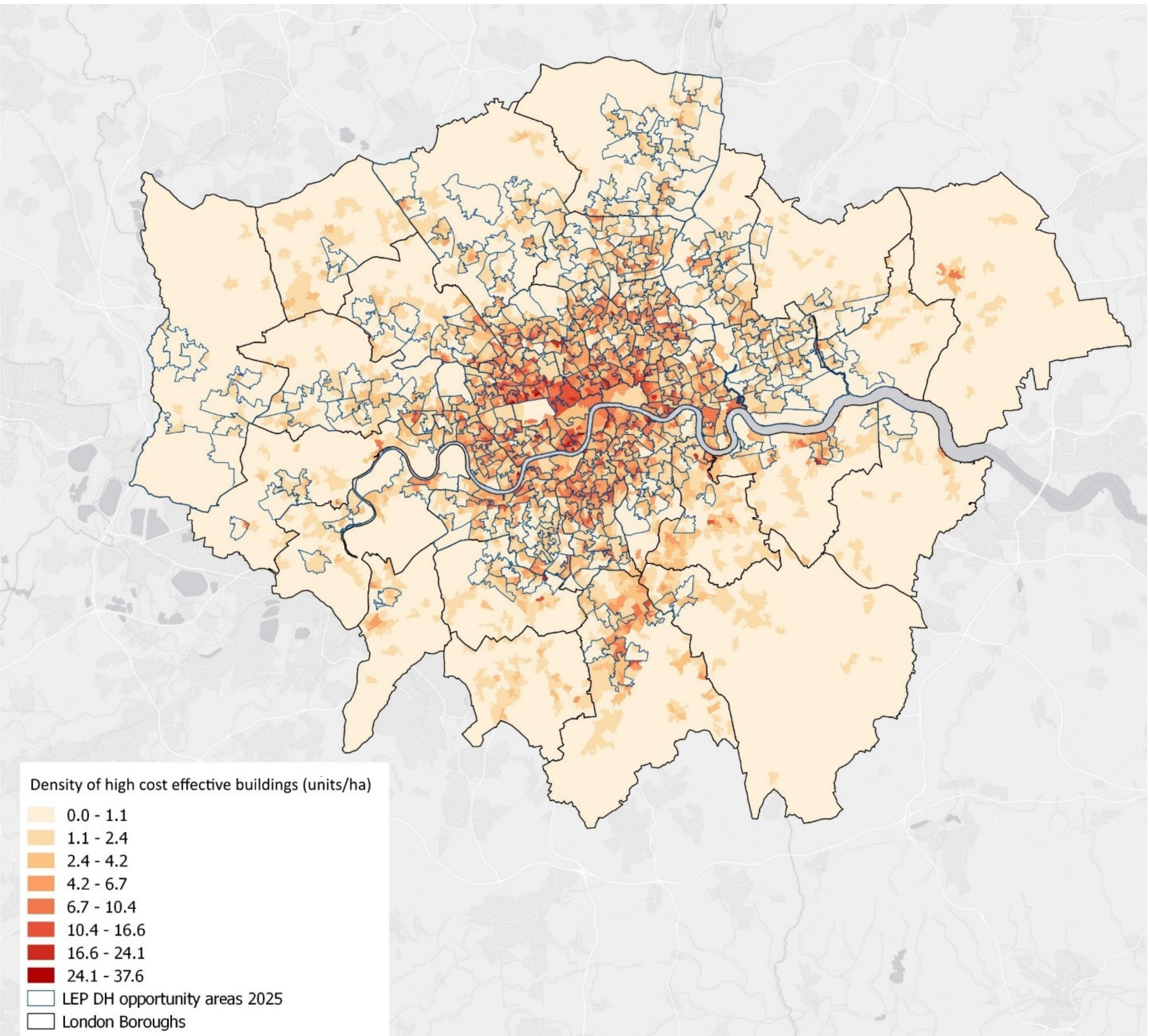

Figure 9-14 Density of high cost effective buildings for 4th generation district heating retrofit (domestic and non-domestic combined).

Table 9-14 LSOAs with the largest density of high cost effective properties for 4th generation district heating retrofit.

	High cost effectiveness – domestic	**#/ha**	**High cost effectiveness – non-dom.**	**#/ha**	**High cost effectiveness – combined**	**#/ha**
1	Tower Hamlets 028H	38	Brent 015A	18	Tower Hamlets 028H	34
2	Westminster 024E	34	Hackney 027G	12	Westminster 017C	35
3	Westminster 021B	30	Westminster 016B	11	Westminster 024E	34
4	Westminster 014F	30	Westminster 013E	11	Westminster 021B	32
5	Westminster 022D	30	Brent 022D	11	Westminster 014F	30
6	Westminster 015E	28	Westminster 013F	11	Westminster 022D	30
7	Islington 006F	28	Kensington and Chelsea 014E	9	Westminster 015E	29
8	Westminster 017C	27	Hillingdon 023B	9	Islington 006F	28
9	Sutton 008E	25	Tower Hamlets 033B	8	Sutton 008E	25
10	Southwark 003K	24	Westminster 017C	8	Southwark 003K	24

Density of high and medium cost effective properties for 4th generation retrofit – Domestic and non-domestic

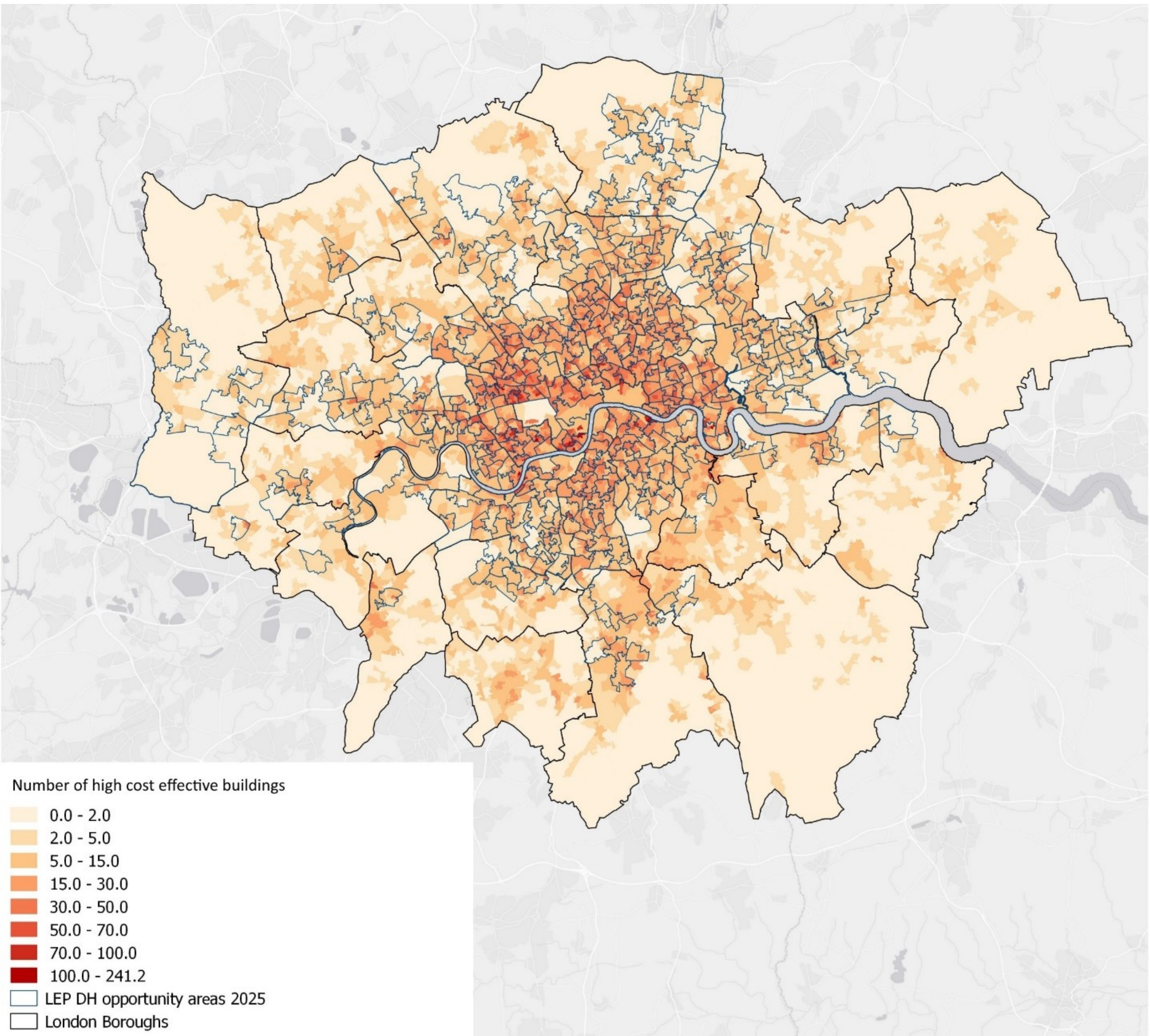

Figure 9-15 Density of high and medium cost effective buildings for 4th generation district heating retrofit (domestic and non-domestic).

Table 9-15 LSOAs with the largest density of high and medium cost effective properties for 4th generation district heating retrofit.

	High cost effectiveness – domestic	**#/ha**	**High cost effectiveness – non-dom.**	**#/ha**	**High cost effectiveness – combined**	**#/ha**
1	Tower Hamlets 032D	240	Westminster 013E	19	Tower Hamlets 032D	241
2	Westminster 024E	195	Brent 015A	18	Westminster 024E	196
3	Southwark 003K	165	Brent 028D	15	Southwark 003K	165
4	Hammersmith & Fulham 023E	163	Brent 022D	14	Hammersmith & Fulham 023E	163
5	Westminster 021B	141	Westminster 016B	13	Westminster 021B	142
6	Tower Hamlets 028H	136	Westminster 013F	12	Tower Hamlets 028H	136
7	Westminster 022D	133	Hackney 027G	12	Westminster 022D	133
8	Hounslow 010B	128	Brent 015F	10	Hounslow 010B	128
9	Hounslow 014B	119	Kensington and Chelsea 014E	9	Hounslow 014B	119
10	Tower Hamlets 031F	116	Westminster 011D	9	Tower Hamlets 031F	116

10 Conclusions

Typology assessment and spatial mapping

The London building stock has been represented by 32 typologies, covering houses, low rise flats, high rise flats, offices and retail buildings. The study captures 92.5% of all properties in London. These properties cover 95.4% of domestic properties (i.e. all buildings except those already with communal heating) and 72.1% of all non-domestic buildings, excluding district heating 'anchor loads', which are already suitable for connection to district heating networks. Due to the inherent diversity of non-domestic buildings it was decided that the typologies in the study should cover office and retail uses only.

Spatial mapping across London found that the most common typologies were low efficiency, gas heated houses, followed by low efficiency, low rise gas heated flats. For non-domestic buildings, the most common typologies were found to be small, medium efficiency electric heated retail buildings and large, medium efficiency gas heated offices.

The largest numbers of low efficiency domestic dwellings were found within the LSOAs for Westminster, Newham, Hammersmith & Fulham, Waltham Forest and Hillingdon. By comparison, the LSOAs with the highest numbers of low efficiency offices were within Westminster, Hackney, City of London and Brent, with the largest numbers of low efficiency retail buildings were in LSOAs in Westminster, Enfield, City of London and Brent.

In terms of medium efficiency dwellings, the highest numbers were found to be within LSOAs in Newham, Sutton, Hillingdon and Croydon. By comparison, the highest numbers of medium efficiency offices were within LSOAs in Westminster, Brent and Hackney, with the highest numbers of medium efficiency retail buildings being in LSOAs in the City of London, Newham, Westminster, Islington and Brent.

The results were interesting as they suggested that low-efficiency domestic typologies tend to coincide with high density areas with a mix of uses, particularly within Westminster, and also Newham, which also has a high density of medium efficiency offices.

If more building types were to be introduced in future and/or if more EPC data becomes available, the methodologies developed in the study are sufficiently flexible to accommodate these updates. Data was found to be of higher quality in the domestic sector, as for non-domestic stock, the thermal efficiency of buildings was reliant upon the available EPC data (which only covered approximately 20% of buildings), whereas for domestic buildings, information on wall construction was available for all dwellings.

For domestic buildings, further investment in expanding the typology study to cover more property type variations would be beneficial. For example, the low-rise low efficiency flat in particular has many possible variants and this study was limited to studying only a converted flat typology. In addition, all houses were represented by a 3-bedroom mid-terrace property, as compared to a semi-detached or detached house.

Typology retrofit – technical requirements and cost modelling

Indicative connection strategies were developed for retrofitting buildings to district heating including houses, low-rise flats (purpose built and converted) and high rise flats, as well as small and large office and retail buildings on the high street. The study identified connection strategies for the different building types, including the possibility of shared connections to multiple properties, likely to increase the economic feasibility of district heating retrofits. These economies of scale were not considered in the costing exercises however, given the likely mix of ownership across the London building stock and the difficulty envisaged in co-ordinating and getting agreements for shared connections.

For single dwellings, it was assumed that existing gas boilers and hot water cylinders would be removed, and instantaneous hot water provided by new heat interface units, thus providing space savings in properties. It was also assumed that the more expensive 'indirect' connection to district heating would be the preferred connection method. Though direct connections reduce losses in the system and can be considered more economical than the indirect connection, there is increased possibility for cross contamination and leakage. Where there are existing radiators in place these would be retained. Where there is an existing electric heating system in place, a new wet system would need to be installed, likely to cause additional cost, labour and disruption in properties.

For low-rise flats and high-rise flats, considerations were made for the different options available for routing pipework either internally or externally, feeding multiple units in the building. Issues around riser space, the degree of core drilling required, scaffolding, hydraulic separation, removal and re-instatement of any insulation or rain-screen systems etc, would all need consideration based on a site specific survey. There is potential to introduce centralised hot water stores, particular if it is envisaged that a low-temperature district heating network would be installed. However, this study has identified that the cost would be higher than a solution providing hot water through HIUs, due to the 4-pipe solution needed and the additional internal or external packaged hot water substation on the ground floor.

For non-domestic gas heated buildings, it was identified that the wet-system infrastructure could be retained. Where direct electric panel heaters are present connecting to district heating would require a new wet heating system. Connecting VRF systems to district heating would be challenging as it requires re-working the entire HVAC system. In some cases, a water-to-refrigerant central unit could be installed but these are not commonly used. Where existing heat pump systems supply a wet system that provides heating (and cooling) to a building, the district heating retrofit could be less disruptive as it would allow for the secondary circulation to be retained; a riser to bring the district heating connection to the roof level may however be required.

Works required to connect electric heated homes were found to be more expensive and intrusive than gas heated homes for all typologies, predominantly because a new wet radiator system would be needed.

For gas heated domestic buildings, the cost to retrofit was found to be £66/m^2 for low-rise low efficiency flats, £76/m^2 for high rise flat typologies, £84/m^2 for purpose built flats and £87/m^2 for houses. For electric heated domestic properties, cost varied based on typology and efficiency, given that these properties also had a new wet radiator system installed. Here, the cost range was £112/m^2 for low efficiency converted low-rise flats, £128-£132/m^2 for high to low efficiency high rise flats, £135-139/m^2 for high to medium efficiency low rise flats and £135-141/m^2 for high to low efficiency houses.

For non-domestic buildings, the cost difference per m^2 to retrofit a small (100m^2) building, compared to a large (1,000m^2) was found to be significant, with the large buildings having the lowest costs per m^2. The lowest cost per m^2 was found to be the conversion of the low efficiency large (1,000m^2) office with electric heat pumps at £30/m^2, where there is already a wet system in place. This was followed by the medium efficiency large retail typology's conversion from VRF at £61/m^2 and medium efficiency large office with VRF at £78/m^2. Higher costs per m^2 were observed in the conversion of non-domestic VRF typologies, compared to heat pump solutions. For small premises, both the low efficiency small office and small retail were found to have the highest costs at £132/m^2.

Typology retrofit – cost effectiveness and spatial mapping

The assessment of medium or high cost effectiveness for district heating retrofits was determined based upon whether a 30 or 15 year payback could be achieved, respectively, across a wide range of indicative heat retail prices (£25/MWh to £115/MWh) compared to the existing counterfactual case (e.g. gas boiler or electric heating).

The methodology used was selected because it allowed the costs of retrofitting the various typologies to be compared against each other and determine relative cost effectiveness of retrofit across the 32 identified typologies; it illustrates the attractiveness of district heating retrofit across all typologies rather than a detailed calculation of financial payback. The assessment is not meant to represent the detailed decision making of potential heat network operators or customers who will have varying requirements in terms of payback/discount rate, but rather to allow the most cost effective approaches to be identified. The intelligence gained is intended to inform pre-feasibility studies for new or expanding district heating networks about the cost and opportunity for retrofitting existing buildings for connection to local heat networks as part of a strategic decarbonisation plan.

Understanding the likely level of uptake is complex and requires more detailed study into consumer preferences and the type of proposition for heat customers, and not just the whole life cost of heat. Other issues such as affordability, carbon emissions, compatibility with local energy system, availability of grants and other financial sources, alternative investments, comfort, space take, disruption, tenure and opportunities for installing district heating alongside other works (e.g. kitchen replacement, home extension) would be some of the factors to be considered

The properties found to be the most cost effective for district heating retrofits were low and medium efficiency, electrically heated high-rise flats, low-rise flats and houses, as well as large electrically heated offices. These types of buildings represent up to 8.7% (330,000) of existing buildings in London. The LSOAs with the highest densities of these properties can be found in Tower Hamlets, Westminster, Hammersmith & Fulham and Southwark.

Properties found to be of medium cost effectiveness for district heating retrofits include low and medium efficiency, gas heated flats, houses and large retail buildings. Collectively the high and medium cost effective properties represent up to 81.7% of the total London building stock (3,100,000 buildings). Areas with the highest density of medium cost effective buildings include Tower Hamlets, Westminster, Hounslow, Southwark, Islington and Wandsworth.

Pilot study

In the pilot study, a methodology was developed to determine the relative cost effectiveness of district heating retrofit across the 32 typologies at a higher resolution of detail by using data for the number of buildings at Census output area, rather than at LSOA. It should be noted that information such as wall construction information at census output area was not available for the analysis, and EPC data was limited. As such, the outcomes should be taken as a proof of concept exercise, for which the reliability can be greatly increased through the use of more detailed datasets.

Based on the model-based analysis, the pilot study found that Islington and Enfield had the highest densities of buildings within the high cost effective category, whereas Sutton and Camden had lower densities of these building typologies. For Islington, mapping showed areas close to Citigen CHP plant, potentially contained high numbers of properties within the high cost effective category, together with the site to the north-west of Moorfield hospital, close to the Bunhill heat network. In the studied area of Enfield, the data indicated high numbers of high cost effective buildings close to the Silver Street train station, near to the proposed Upper Lee Valley network. For Sutton and Camden, the dominant typologies were found to be gas heated houses and low rise flats which have medium retrofit cost effectiveness.

The proof of concept model shows good potential for identifying architectures of high cost effectiveness, e.g. high rise flats and offices. More data on the thermal efficiency of properties would need to be gathered at Census output area to develop the pilot study mapping method further into a tool for feasibility studies, and at present it provides a useful tool for informing the work undertaken in pre-feasibility studies and providing intelligence that can be explored in greater detail in subsequent feasibility studies.

4th generation district heating networks

To assess the implications of third and fourth generation district heating, load modelling for each typology demonstrated that as district heating supply temperature reduces, so does the percentage of annual energy demand capable of being met through the heat network supply temperature.

In a district heating network with a supply temperature of 70 °C approximately 99% of annual energy demand can be met. At 60 °C this drops to between 96%-99%, and at 50 °C this drops further to between 86%-98%. At a supply temperature of 40 °C this can be as low as 50%-92% depending on the efficiency of the existing property to be supplied. Furthermore, as properties become more efficient, the percentage of annual energy demand was seen to increase, e.g. for a house with medium and high efficiency, the annual energy demand met by heating supplied at 40 °C was found to be approximately 66% and 81% respectively.

Importantly, district heating systems can operate with variable supply temperatures and during cold weather periods this strategy is often employed. Using low temperature, low carbon heat sources, such as waste or environmental heat with heat pumps, for the majority of the year, with peak loads then met by gaseous or liquid fuels, would be a possible strategy to maintain comfort levels for consumers while reducing the operational costs and overall carbon intensity of heat in the network

It was identified that through the use of larger radiators it was possible to meet 100% of space heating demand in a domestic property at heating supply temperatures from 70 to 50 °C with minimal implications on internal space. By comparison, under the 40 °C supply temperature scenario, larger radiators alone would be an impractical solution, because of the number of additional radiators required.

In the study to reduce unmet hours at the 40 °C heating supply temperature, a low cost air tightness improvement alone was found to increase the percentage of annual energy demand from approximately 60% to 70%, thus not significantly improving the practicality of radiator sizing.

By comparison, an upgrade to Building Regulations U-value standards and halved air tightness was shown to increase the proportion of annual energy demand being met by up to 95%, thus significantly increasing the practicality of installing larger radiators to meet the remaining load. These additional works may add further costs of £106/m^2 to £159/m^2 to the district heating retrofit, but they allow larger emitters to meet the remaining demand. Considering the high cost per dwelling of the building energy efficiency retrofit measures, varying the supply temperature in the heat network is likely to be more economical.

In terms of relative cost effectiveness, the updated payback calculations found that several typologies are still shown to be cost effective, at the lower end of the indicative heat retail price range, even considering the additional costs for fabric upgrades, larger radiators and DHW systems. Principally, these typologies were the large electrically heated offices, particularly those fed with heat pumps, as well as low efficiency domestic properties which are electrically heated.

From a cost perspective, the optimum level of energy efficiency was found to be the low cost air tightness improvements, however as discussed, this measure alone does not reduce unmet hours significantly. Some other rationale and funding for energy efficiency would therefore help improve the practicality of connection to heat networks in cases where deeper levels of retrofit are required in order to maintain comfort levels.

Regarding domestic hot water, depending on the hot water use and system configuration it may be possible to install point-of-use heaters for sinks etc, which also allows centralised heating systems to be turned off in summer. This may be more economical if the use is low and inconsistent than the alternative of holding a large volume of water at 60 °C. An electric coil in the calorifier or hot water tank, if present, could also provide additional heat as necessary. For high-rise flats it is possible to provide domestic hot water through a centralised approach, rather than having HIUs within each floor or flat. This approach was found to be more expensive than just providing HIUs, however it would facilitate the lower temperature 4th generation district heat networks by decoupling hot water supply and space heating, allowing the later to operate at lower temperatures where external weather conditions allow.

Wider interpretation and recommendations

This report has focused on technical issues, as well as capital and operational costs, compared to a counterfactual heating system to determine the relative cost effectiveness of district heating retrofits for a wide range of London's building stock. Fuel cost assumptions, wider operation and maintenance costs and capital equipment pricing were taken as 2015/16 prices. Carbon savings were not reported on as the scope of this study did not include the network and any district heating carbon factors would be dependent on assumptions for heat sources as well as plant make-up and capacities in bespoke energy centres. Other factors outside the scope of the report include comparison with other low carbon sources, such as heat pumps, and the associated electrical infrastructure investment to support greatly increased peak loads.

Electrically heated solid walled flats and houses, together with large electric offices were found to be the most cost effective of the 32 typologies to retrofit. On the domestic side, these properties currently represent 'hard-to-treat' homes for London, therefore this study has unlocked a potential solution for decarbonising this stock. For non-domestic buildings, it was those properties which already contain heat pumps and secondary wet systems that were found to be the most cost effective to retrofit, and as these typologies already have a route to decarbonise they would generally only be retrofitted to district heating if required to leverage a good mix of heat demand on a network and/or when a building/heating system is needing refurbishment or replacement.

The cost to retrofit a low efficiency electrically heated domestic property to district heating, including the installation of a new wet system was found to range from £112/m^2 to £140/m^2. For low efficiency gas heated domestic properties, the cost to retrofit to district heating was less, ranging from £76/m^2 to £87/m^2. By comparison, the cost to undertake an energy efficiency retrofit to these properties (including internal or external wall insulation, new double glazing and full draught proofing) to Part L insulation standards with halved air infiltration was £106/m^2 to £159/m^2.

Evidently, for electrically heated homes the cost to retrofit to district heating is of the same order of magnitude as the whole house retrofit. For gas heated homes however, the district heating connection is of lower capital cost. Carbon savings would be a function of the carbon intensity of the network and grid.

In terms of whole life costs compared to the counterfactual case, for gas heated flats it was found that high cost effectiveness can only be achieved up to district heating retail prices of £35/MWh, with medium cost effectiveness achieved up to £60/MWh. If gas prices increased by 20%, then high cost effectiveness can be achieved at district heating retail prices of £50/MWh, with medium cost effectiveness up to £70/MWh. If gas prices increased by 50%, then high cost effectiveness can be achieved at district heating retail prices of £65/MWh, with medium cost effectiveness up to £85/MWh. Further scenarios that can improve cost effectiveness include reductions in capital cost driven by the market, or through policy e.g. supported by grant funding which could be leveraged through Carbon offset payments, ECO or other grants.

In terms of subsidies for district heating retrofit, at a fixed district heating heat retail price of £60/MWh, it was shown that with capital grant funding set at a level of 20% to 40% all low and medium efficiency electric domestic properties can achieve high cost effectiveness at £60/MWh. With capital funding reaching 60% low and high rise gas heated flats can achieve high cost effectiveness. At this level of funding, low and medium efficiency houses can also achieve medium levels of cost effectiveness too. What this analysis therefore conveys is that with relatively small percentage grant subsidies the overall cost effectiveness of district heating retrofit in electric heated properties increases, and with relatively larger percentages of grant subsidies there is potential to unlock a greater proportion of the gas heated building stock.

To provide the greatest benefit, these grant subsidies (e.g. leveraged through Carbon offset taxes or other policy measures) should be available for district heating retrofit in areas with a high likelihood for developing district heating networks as a cost effective way to catalyse the decarbonisation of buildings. In areas where district heating networks are not as likely to be developed then whole house energy efficiency and building level decarbonisation of heating supply solutions should be considered.

For 4th generation district heating with heating supply temperatures at 40 °C, the analysis has shown that unmet heat demand can be significant unless an energy efficiency retrofit is carried out with the works, which can reduce cost effectiveness. By comparison, cost effectiveness at supply temperatures of 70 °C to 50 °C is higher as the additional unmet energy demand can be provided through minor radiator modifications. Either additional funding for retrofit measures would be required to increase cost effectiveness and/or the network temperature be increased at times of peak demand. In order to allow for variable network temperatures this would require some gas peaking plant at the energy centre, alongside the lower temperature heat pumps. The selection of district heating pipework material would also need to accommodate the temperature range.

In terms of the wider roll out of district heating in London, it is likely that network locations will still be dictated by new-build developments and district heating anchor loads. However, this study serves to identify an additional layer of existing buildings that can be connected to local heating networks as they expand and grow in their later phases. The LSOA mapping has allowed areas with higher cost effective typologies to be located. The methodology for pilot study mapping then allows greater levels of resolution for area-by-area strategies to be investigated in more detail for pre-feasibility studies. It is likely that local authority owned buildings would be the most straight-forward to retrofit initially. Conservation areas may also prove to be suitable for retrofitting buildings for district heating as they offer a solution for decarbonising where building fabric upgrade measures are restricted.

Where there are existing or planned district heating networks, retrofitting existing buildings to them offers a cost competitive solution for decarbonising their heat supply and creating low and zero carbon neighbourhoods. From a consumer point of view, owners of electrically heated properties may be more receptive to a district heating retrofit than those in properties heated by natural gas, due to the high costs of electricity compared to gas and the potential for improved comfort and convenience e.g. on-demand high pressure hot water for showering and free space in former hot water tank cupboards. In locations where district heating networks are not expected to be built, energy efficiency measures together with alternative low carbon heat supply solutions, such as heat pumps or green gas, will be required to decarbonise their heat supply.

The most optimal strategy for decarbonising heat supply will vary depending on the part of the city that is considered; it is likely to require a combination of heat network connections, energy efficiency measures and a mix of building level heat generation systems. Factors affecting the choice will depend on the nature of the building stock, the mix of property types, their heat demand density and what the local infrastructure can sustain, e.g. available electrical network capacity and heat network capacity.

Appendix A – CNCA Replicability Study

Overview

Using the knowledge gathered from this London based study, this appendix sets out step-by-step methodology for the processes undertaken to increase the replicability of this project for the CNCA partner cities. The intention is that this will allow other cities to undertake an initial review of their building stocks, so that they are able to make an initial high-level assessment of the cost effectiveness and opportunity for connecting its existing building stock to district heating networks. Supporting this process, a preliminary typology assessment is carried out based on initial datasets provided for Minneapolis, Seattle, Vancouver and Washington DC. An inventory of spatial datasets should be undertaken for each CNCA city prior to undertaking similar studies.

Generic typology assessment

A comparison has been made between the London building stock and four CNCA cities: Minneapolis, Seattle, Vancouver and Washington DC. Due to the availability of data, only the domestic stock has been compared. More investigation is therefore required to determine how the non-domestic building stock is formed.

For the domestic stock, data was found to be available for similar indices as used for the typology generation for London, suggesting that similar studies could be replicated. The trends in housing stock data relating to age, property type, fuel use and heating degree days are shown in Figure A-1 to Figure A-4.

Data for the CNCA cities is based on data from the following sources.

- U.S. Census Bureau, 2010-2014 American Community Survey 5-Year Estimates
- 2014 Canadian Housing Observer (Canada Mortgage and Housing Corporation)
- Statistics Canada (National Household Survey) for 2011.
- RETScreen software weather data (NASA Surface meteorology and Solar Energy)

Though most data was available for city authorities, averages for British Columbia have been used for heating fuel in Vancouver, due to lack of granular spatial data.

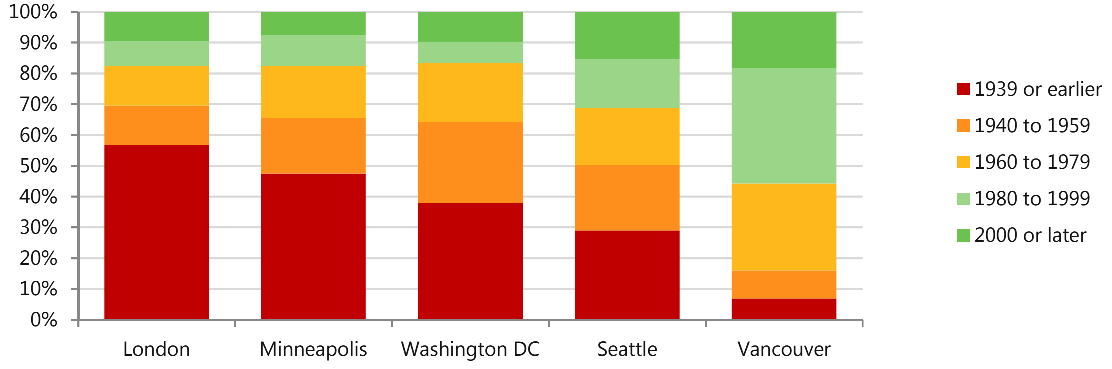

Figure A-1. Comparison of domestic building stock data by age. As shown, London has the oldest building stock and Vancouver is found to have the newest. In the London based study, those properties that were older were assumed to have solid walled construction and lower overall energy efficiency. In terms of cost effectiveness for district heating retrofit, the more inefficient properties were found to be most cost effective as the annual heating savings compared to the counterfactual case were greater.

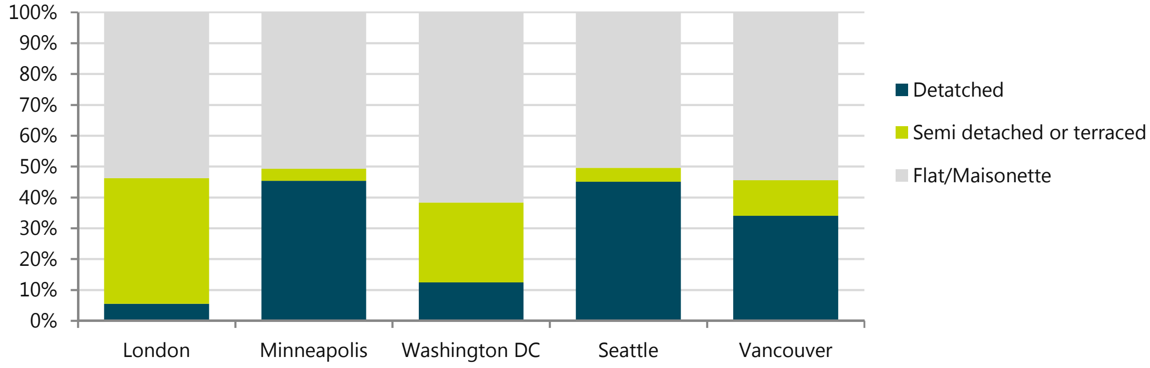

Figure A-2. Comparison of domestic building stock data by property type. As shown, flats/maisonettes make up at least 50% of the domestic stock for all cities. The biggest difference that can be observed is that all CNCA cities have a high proportion of detached houses compared to London. This may suggest that in generating the domestic typologies, a simple model for a 'house' could be a detached property for some cities and/or there is a stronger case introduce two different types e.g. detached and semi-detached, for example.

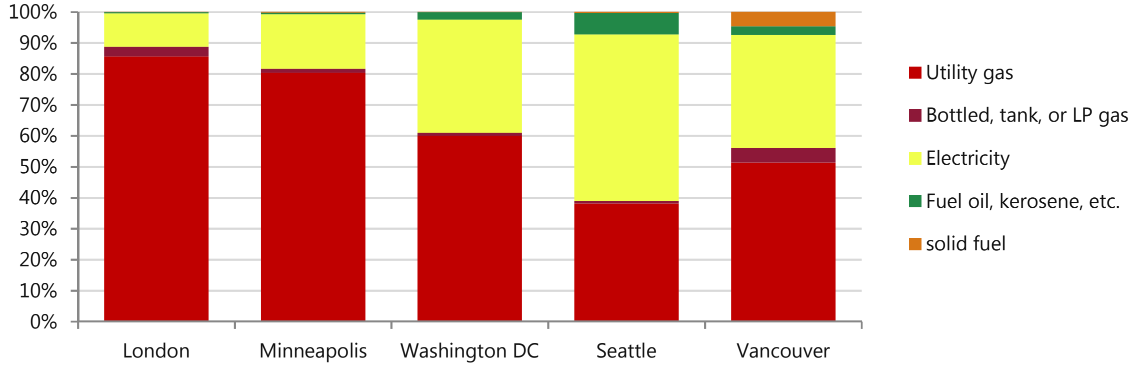

Figure A-3. Comparison of domestic building stock data by heating fuel. Gas and electricity are the two most common types of heating fuel across all cities. London and Minneapolis are shown to have a similar proportion of gas heated properties, where the remaining cities, particularly Seattle has a higher proportion of electrically heated dwellings. For the London based study, gas heated homes were less expensive to retrofit because the wet system could be retained. However, electric heated homes were more cost effective because the fuel cost was much higher. It is recommended that fuel cost data be gathered for each city. Note that this data should ideally be obtained for small and large commercial properties as rates will differ.

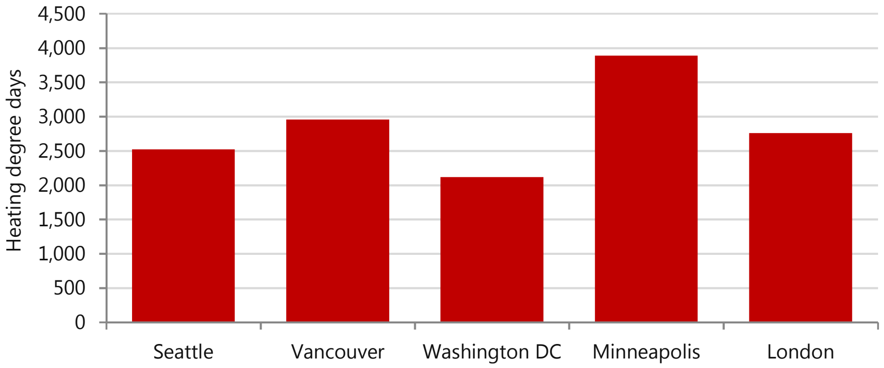

Figure A-4. Comparison of heating degree days. heating degree days are a measure of how much (in degrees), and for how long (in days), the outside air temperature was below a certain level. They are commonly used in calculations relating to the energy consumption required to heat buildings. The cost effectiveness of district heating retrofit would be expected to increase in cities that have a higher number of heating degree days (e.g. Minneapolis).

Replicability Method

Based on the approach adopted in the London based study, the following section gives a high level step-by-step methodology to assist the CNCA cities with scoping a similar piece of work to assess district heating retrofit cost effectiveness. Core activities, steps and rationale across the following stages are given:

	Activity	Steps	Rationale
Building stock analysis	[1a]. Generation of a domestic building stock dataset containing building type information and thermal attributes in a format suitable for spatial mapping	[1.1]. Review and collate available spatial datasets containing, as a minimum: • Number of buildings by type • Measure of thermal efficiency (e.g. wall construction) [1.2]. Determine most suitable way to overlay separate datasets (e.g. percentage distributions). [1.3]. Collate data on wider attributes for properties (e.g. fuel type, heating system, roof insulation and glazing type) [1.4]. Determine split of high and low rise buildings (e.g. number of floors, or building height data) [1.5]. Isolate and remove properties that are already connected to communal heat networks	The domestic building stock dataset forms the foundation for the study. Thermal efficiency is important to have intrinsically linked to building types so that thermal classes can be developed in Step 3. Factors such as height are important to include as this will impact on cost of district heating pipework.
	[1b]. Generation of a non-domestic building stock dataset containing building type information and thermal attributes in a format suitable for spatial mapping	[1.6]. Review and collate available spatial datasets containing, as a minimum: • Total number and/or floor area of non-domestic buildings by typology [1.7]. Remove typologies that may already be considered as district heating anchor loads. [1.8]. Use heat demand benchmarks and floor area estimates to determine the most significant non-domestic typologies to shortlist (e.g. office, retail).	There is a large number of different non-domestic building types. By stripping out anchor loads and undertaking simple heat demand estimates the important areas can be focussed on.
Develop set of thermal classes	[2a]. Development of generic thermal classes covering all domestic buildings	[2.1]. Develop matrix of simplified thermal classes by typology, thermal efficiency and existing heating system, e.g: • All houses, all low/high rise flats • Low, medium and high efficiency based on either age or wall construction • Gas heated or not gas heated [2.2]. Undertake spatial mapping of the number and density of low, medium and high efficiency properties [2.3]. For each typology, identify a typical property architecture and assign the most probabilistic attributes, by analysing available data, for: • Number of bedrooms • Floor area, glazing area • Glazing type and roof insulation • Heating system type	By developing a generic list of thermal classes it is possible to apply any of the results generated through this study to the whole domestic building stock. For these typologies to be useful, the underlying assumptions should be justifiable, based on an analysis of the available data.

		• Number of floors / number of units per floor and building if multi-dwelling building. [2.4]. Undertake location specific research to provide further detail to the above assumptions, e.g. heat transfer coefficient, heating system efficiencies	
	[2b]. Development of thermal classes for most prevalent non-domestic buildings	[2.5]. Collate and review available data on the energy performance rating of the shortlisted non-domestic typologies [2.6]. Group data into simplified energy efficiency bands to represent low, medium and high efficiency [2.7]. Determine suitable floor area for small and large sized buildings [2.8]. Develop matrix of simplified thermal classes by typology, thermal efficiency and existing heating system, e.g: • Office/retail – low, medium, high efficiency (e.g. by energy rating bandings or age) • Gas heated or not gas heated • Small or large [2.9]. Shortlist the most prevalent thermal typologies [2.10]. Extrapolate results based on total floor area to cover all shortlisted non-domestic building types [2.11]. Undertake spatial mapping of the number and density of low, medium and high efficiency properties [2.12]. For each typology, identify a typical property architecture and assign the most probabilistic attributes for: • Floor area, glazing area • Glazing type, wall construction • HVAC system type – centralised / mixed, (e.g. heat pump, VRF, gas boiler etc) • Number of floors [2.13]. Undertake location specific research to provide further detail to the above assumptions, e.g. HVAC system efficiencies, heat transfer coefficients.	As with the domestic stock, it is important to develop a set of thermal classes for the non-domestic typologies, so that the cost effectiveness of district heating can be better understood. By shortlisting the most prevalent typologies, this will allow a significant proportion of property types to be assessed. Classifying properties as having centralised or mixed gas/electrical HVAC systems will help to rationalise the large variation of heating system types.
Technical retrofit requirements	[3a]. Development of energy and load models for each typology	[3.1]. Develop a set of building simulation models to represent the baseline domestic and non-domestic typologies. Note: Some typologies may have identical architectures and/or fabric properties, providing time savings during the modelling process. HVAC efficiencies can be applied retrospectively. [3.2]. Undertake load and energy modelling results to obtain figures for heating and hot water in terms of: • Peak load • Primary energy demand • Fuel usage	Load modelling results help to inform capital costing of heat emitters. It also allows load duration curves to be produced, providing an indication of the hours of heat required throughout the year. Annual energy figures feed into the payback calculations for cost effectiveness.

		[3.3]. Extract half hourly energy consumption profiles from the above analysis, enabling load duration curves to be produced for each typology.	
	[3b]. Development of district heating retrofit connection strategies	[3.4]. For each of the typologies, diagrammatically illustrate the works required to retrofit the property to district heating, considering: • If direct or indirect connection is most applicable for building type and location. • What heating and DHW infrastructure can be retained and/or needs to be removed. • Where district heating pipework should be routed (e.g. internally or externally). • Number of heat interface units for building • Possible space provision for centralised DHW store [3.5]. Undertake district heating pipework sizing calculations for each typology, considering: • Pipework lengths and insulations thicknesses • Diversity factors in multi-dwelling buildings [3.6]. Undertake sizing of new heat emitters where applicable, using peak load figures.	By producing indicative retrofit strategies for each typology this enables the costing exercise to occur. The process will also serve to uncover different options for connectivity, and assists in visually communicating the works required.
Costing of retrofit requirements	[4]. Undertake capital costing of district heating retrofit strategies	[4.1]. Develop domestic and non-domestic capital costing models, and considering costs for: • District heating and secondary pipework and insulation • Costs of trenching to street main • Heat emitters, HIUs, pumps • Labour, preliminaries and overheads • Additional costs associated with 'retrofit' challenges [4.2]. Provide costing summary tables by typology, reviewing total cost by dwelling and building, in absolute terms and per m^2. [4.3]. Explicitly state unit costs assumed in study so that figures can be shared and compared against different CNCA cities.	Costing of retrofit works is important as this links directly into the district heating cost effectiveness calculations. Note that most costing data will not account for additional disruption of retrofit, so additional labour and overheads etc should be expected.
Cost effectiveness study	[5]. Undertake payback calculations to assess the whole life cost of the district heating retrofit to a counterfactual case	[5.1]. Determine the annualised counterfactual cost of heat for each typology, considering: • Capital cost of counterfactual system (e.g. gas boiler, panel heaters, heat pump etc). • Operation and maintenance costs • Plant replacement period • % of plant to be replaced • Labour, preliminaries and overheads [5.2]. Undertake a discounted interest calculation to determine the payback period for the district heating investment, considering: • District heating running costs (including O&M), vs. annualised counterfactual case costs [5.3]. Calculate payback at a range of district heating retail heat prices to determine, at which point the district heating payback period becomes cost effective.	By assessing the cost effectiveness of district heating compared to a counterfactual case, this provides an indication of the life time savings vs. business as usual. Running multiple retail heat prices allows the sensitivity of results across all typologies to be understood. The 30 year payback is based upon London Plan guidance for the economic evaluation of heat supplies.

		[5.4]. Categorise typologies in terms of cost effectiveness based on the payback period e.g. high: 0-15 years, medium: 15-30 and low cost effectiveness: 30 years+) [5.5]. Undertake spatial mapping of the number and density of "high" cost effective properties, as well as "high + medium" cost effective properties.	
Pilot study	[6]. Undertake pilot studies in areas prioritised for district heating to better understand the potential for existing building retrofit	[6.1]. Select pilot areas to undertake pre-feasibility district heating retrofit studies (e.g. based on areas with high cost effectiveness or with district energy investment). [6.2]. Review and collate available spatial datasets (as per Step 1.1 and 2.1) in level of detail appropriate for the pilot areas (e.g. Census output area). [6.3] Produce maps illustrating the number of "high" and "high + medium" cost effective properties. [6.4] Using the heat demand figures created in step 5.2, produce maps illustrating the heat demand per m^2 for "high" cost effective properties, as well as "high + medium" cost effective properties. [6.5] Overlay points of interest onto maps, e.g. existing and proposed heat networks, energy centres, incinerators etc.	The pilot studies give an indication into the level of detail that can be produced to aid project teams in pre-feasibility studies for district heating. By overlaying points of interest and highlight areas of high cost effectiveness and high heat demand, this will strengthen the case for investment in those areas.
4G energy efficiency study	[7] Investigate the technical feasibility and cost effectiveness of the retrofit of 4th generation district heating networks.	[7.1]. Undertake load modelling results at different heating supply temperature scenarios e.g. 70, 60, 50, 40 degrees Celsius (158, 140, 122, 104 degrees Fahrenheit). [7.2]. Produce load profiles for the temperature reduction strategies and determine the % of annual unmet energy demand for each typology. [7.3]. Undertake heat emitter sizing calculations to determine at which point fabric retrofits to improve energy efficiency are required. [7.4]. Develop energy simulations for a range of fabric efficiency strategies (e.g. new double glazing, wall insulation improved air tightness) [7.5]. Re-run load modelling for selected low temperature scenarios to understand remaining unmet energy demand. [7.6]. Undertake further heat emitter sizing calculations for post-retrofit scenarios, including costing for hot water generation provision. [7.7]. Re-assess cost effectiveness, as per steps 8.1 to 8.4, based on the reduced temperature scenario with additional investment costs included. [7.8]. Provide summary and recommendations for implementation of 4th generation networks.	Lower temperature heat networks enable a transition away from fossil fuels to a future heat supply that makes an ever increasing use of renewable energy alongside local secondary heat sources. With respect to existing buildings it is important to understand what interventions are required to allow this solution to be technically feasible. How this impacts on overall cost effectiveness should be better understood, as it may be more cost effective to simply refurbish the property to a high standard and not connect to district energy.
End of methodology – Interpretation of results and policy implications for CNCA member cities.			

Appendix B – DHW and secondary network design guidance

Overview

The following section gives a summary of approaches for domestic hot water design, together with recommendations for secondary system and circuit design. The information has is based on the GLA "London's Zero Carbon Energy Resource: Secondary Heat" study, phase 2 report (2013), for which BuroHappold was the lead consultant.

Approaches for domestic hot water design

Networks with a low supply temperature can give rise to potential issues of Legionella growth within the hot water systems, particularly where there is any storage. This can be controlled either by limiting the amount of water held in the system at any one time or preventing the growth of Legionella by heating the water to over 65°C.

Legionella regulations require any domestic hot water storage to be disinfected on a regular basis by raising temperatures to a minimum of 65°C26. Domestic hot water is required to reach 50 °C after 1 minute of operating a tap. In practice however, temperatures higher than this can cause scalding and are rarely required in domestic and most non-domestic buildings.

For new buildings with no storage disinfection requirements it is possible to operate the heat network at 55°C and maintain a 50 °C DHW outlet temperature. This does raise potential health concerns as after a tap or shower is stopped, water in the system would then cool to below 50 °C and hence be at risk of Legionella growth before being drawn off for subsequent usage. As this water would never have been heated above disinfection temperature it could lead to a higher risk of bacterial growth.

In new flats in Denmark they operate their systems at 50 °C and deliver hot water at 45°C, minimising health risk by having negligible storage of hot water in their systems. Storage is limited to 0.5 litres in the plate heat exchanger and 3 litres in the domestic hot water pipework to the outlet. Achieving the latter requires careful location of outlets relative to heat exchangers. The Danish approach is illustrated in Figure B-1.

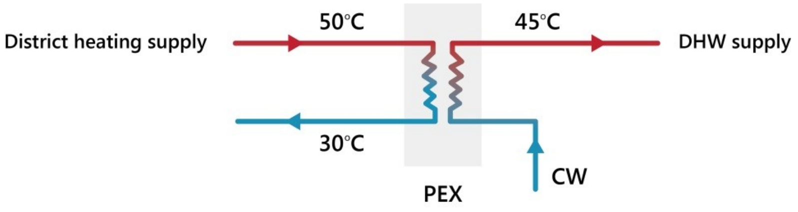

Figure B-1 Danish heat network temperatures in new buildings for domestic hot water supply. Note that in the UK this approach would be subject to approval by public health authorities.

An alternative solution is to use chemical dosing with chlorine dioxide to disinfect the lower temperature water. In UK health and safety policy, the Approved Code of Practice on Legionnaires' disease (ACoP L8) lists this as an appropriate method of legionella control, and recommends levels of 0.5 mg/l for it to be effective.

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

The location of the dosing would be dependent on the property. This dosing could take place in a cold water storage tank; however, this introduces a management activity, making the approach less resilient. If it is a block of flats with a shared cold water storage, both the hot and cold systems tanks should be dosed, cost permitting. If they are single dwellings fed direct from the mains, an in-line dosing unit could be fitted to the block of flats or after the 'tee' from the main on a housing estate.

The alternative of controlling Legionella growth is to heat the water in the system to 65°C. This may be necessary in some buildings that are to be retrofitted to a district heating system where it is not viable to change the internal hot water system to meet the above requirements. The extra cost of the additional heating required will depend on the amount of water to be heated and the supply temperature from the district heating system.

In some cases, an electric coil in the calorifier or hot water tank could provide additional heat as necessary. In other cases, (e.g. large office buildings or low/high rise flats) where there is already a gas connection, a very small (domestic sized) gas boiler could also be used to provide the necessary top up, or a centralised boiler could be used serving multiple dwellings. Depending on the hot water use and configuration within the building it may also be possible to install point-of-use heaters, which also allows heat systems to be turned off in summer. This may be more economical if the use is low and inconsistent than the alternative of holding a large volume of water at or around 60 °C.

Approaches for secondary system design

For the purposes of this report, the term 'secondary system' design is used to refer to all elements within the building that enable it to utilise heat from heat networks. Two aspects of secondary system design are considered in particular, the terminal design and controls and the secondary circuit design. The following sections set out a recommended approach for connections to low temperature heat networks, however, in practice these principles should also be followed for connections to all district heating systems.

Recommendations for terminal design and controls

The design of the final heating systems and the control of that system is important for effective utilisation of lower temperature heat sources, and particularly for ensuring low return temperatures to the heat network. Key design issues and their pros and cons are outlined in Table B-1 overleaf.

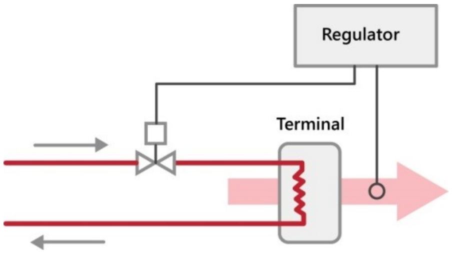

Figure B-2. Principle of two port control for heat emitter devices.

Figure B-2 shows the principle of two port control, referred to in Table B-1. The regulator can also be placed in the return air to a heat emitter (e.g. a radiator or fan coil unit) to sense when additional heat is required in the space, but maintain cooling on the network water flow.

Table B-1. Recommendations for design of building heating systems for connections to low temperature heat networks.

Recommended principle	**Advantages**	**Constraints**
2-port control. Regulates flow to control heat output	Using 2-port control ensures heating water passes through heat emitters at only at the rate required to heat the space. This means that heating water is cooled as much as possible, reducing the return temperature. This is as opposed to 3-port control where a significant part of the heating water flow bypasses the heat emitters returning at close to the flow temperature.	Bypasses are sometimes required to maintain temperatures on main branches of heating systems with low demand. However, these should be minimised to main branches only and use temperature controlled bypass valves. Variable flow pumps will also be required to control load.
Underfloor heating (Central heating system)	Operating temperatures are typically around 30 - 45°C and so well suited to low temperature supply without the need for extensive modifications.	Delayed response time and low flow temperatures may not suit all occupants and building types. Output typically limited to 60 W/m^2. Require a relatively efficient building fabric
TRVs (Thermostatic radiator valves)	Valves automatically control the temperature of the room by changing the flow to the radiator. Temperature is based on user control	TRVs are less discreet than manual radiator valves and do not allow as much user control as programmable thermostats
Programmable room thermostats for dynamic control of room temperatures	Allows heating for individual rooms to be restricted to certain periods and temperatures to reduce heat wastage and to avoid overheating	Room thermostats usually control boiler operations, this level of functionality is also available from a district network
Weather compensation controls. Adjusts the flow temperature based on ambient temperature	The network and systems can be operated at lower temperatures allowing lower temperature sources to be used. Only on cold days are flow temperatures increased. Can be effectively combined with TRVs to ensure low return flow temperatures	Temperatures need to be increased either locally or centrally to meet peak loads. For former additional plant is required, for latter network must be designed to meet this requirement
Large Radiators to meet heat demand with lower flow temperature	Can be retrofitted to allow low temperature heat supply to conventional buildings	Increased capital costs due to need to replace radiators. Restrictions in space and increased visual impact of large radiators
Use of hot water storage tank (calorifier)	Reduces peak load on the heat network, allowing pipe sizes to be minimised Hot water supply is more resilient to heat network failure as typically 0.5-1 day storage provided and an auxiliary heating source can be provided (e.g. electric immersion heater). Easy to integrate with solar water heating	Tend to result in high return temperatures as most water in the tank is at around 60 °C. Return water cooling of as little as 5°C possible Standing losses from calorifier. Space take - in many cases people have removed hot water tanks and for new build unlikely that additional space take is welcome
Use of plate heat exchangers for hot water provision. Plate heat exchangers are used to generate domestic hot water 'on-demand' drawing heat from the secondary heating network	Instantaneous hot water performance, which does not run out, similar to a natural gas combi-boiler. Also delivers mains pressure water for showers etc. Low space take. Excellent cooling of return water (down to 15-20 °C)	Large instantaneous demands means plant and pipework have to be sized accordingly. No storage and not as resilient as a calorifier based solution

Use of hot water storage tanks with plate heat exchangers	When temperature in the calorifier drops below a certain value a small shunt pump draws off water and pumps it through plate heat exchanger connected to the heat network. The hot water enters the calorifier at the top, re-charging the contents As per the use of hot water storage tanks. Excellent cooling of return water (down to 15-20 °C)	Standing losses from calorifier Space take - in many cases people have removed hot water tanks and for new build unlikely that additional space take is welcome

Recommendations for circuit design

Figure B-3 shows the recommended configuration of a secondary heating system for connection to a heat network. This includes the use of true variable flow pumping whereby flow can be reduced to very low (almost zero) levels during low load conditions. Low loss headers and primary circuits with separate pumping are avoided due to the large bypass flows which pass to the return of the primary heat network side, increasing return temperature.

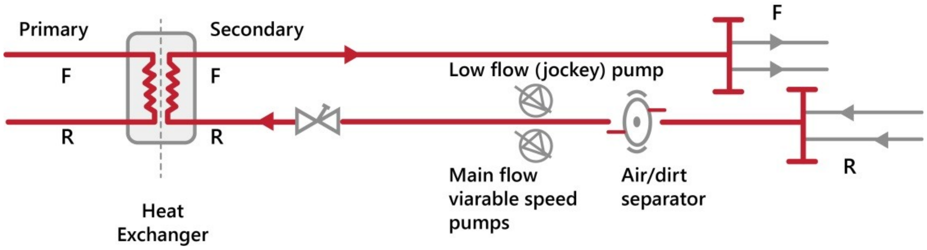

Figure B-3. Principle of recommended approach for secondary side heating system design to minimise heat network return temperatures.

Table B-2 sets out the recommended design approach for connection to lower temperature heat networks, linking the external network to the end use heating system.

Table B-2. Recommendations for design of building heating systems for connections to low temperature heat networks.

Recommended principle	Advantages	Constraints
Variable speed Pumping. Use of pumps which operate at variable speed and are controlled to maintain a fixed minimum differential pressure at a reference point (the index point or longest run or across control valves at terminal units) on the secondary heating system side. Terminal units make use of 2-port control approaches. Variable speed pumps have lower running costs that fixed rate pumps	Variable speed pumping ensures that return temperatures are kept to a minimum even when low loads are present at the district heating connection. Significant energy savings can be achieved compared to constant speed pumping. The savings are most marked during low load conditions, when even small reductions in pump speed provide significant energy savings. There is some evidence to suggest that throttling flow may be a more effective way of reducing return temperatures than using temperature compensation however practical evidence was not available.	Controls and system commissioning of secondary systems may be considered more complex. However, variable speed pumping is considered common practice in building heating system design. Check (non-return) valves should be used to prevent reverse flow in low flow conditions. Variable speed pumps typically have higher capital costs than fixed rate pipes.
Use of direct Connections. Connections between building heating systems and the primary	Direct connections minimise costs and enable the lowest possible supply temperatures to be used. They are most	They are not suitable for connections to taller buildings due to static pressure, or in areas with large variations in topography.

district heating network should not use a heat exchanger, with space heating being provided via direct connection	appropriately used on smaller scale heat networks where pressures are lower (<6 bar) and building systems can be designed to accommodate the operating pressure in the network Leakage concerns can be addressed through use of automatic leak detection valves on flow and return.	They should only be used provided heating system on secondary and primary side are both in good condition. They potentially raise the possibility of disputes between system owners where poor water quality causes performance issues
One circuit. Heating systems should be comprised of one circuit without use of separate primary and secondary circuits (branches are still permitted). No use of low loss headers	Using a single circuit means that heating water passes through the full heating system, maximising the opportunities to cool the water, reducing return temperature. Costs are lower as there is less fluid circulating and fewer pumps in the system. Using low loss headers means a significant portion of the flow in the primary circuit does not go through the terminal units and so is not cooled. This approach is widely used with gas boilers where maintaining flow through the heating appliance is important but is not suitable for use with district heating systems.	Building system designers may not be familiar with this approach. The control of pressure within heating systems may be considered more complex, though this is not the case in practice.
Multi-stage Pumping. Use multiple pumps in parallel to give good variation of flow over the whole range of load conditions. This could include use of very small capacity 'jockey' pump for low load conditions (e.g. where domestic hot water load is the only requirement).	Variable speed pumps are not able to turn down to zero flow, and so where there are large variations in heat demand (e.g. peak winter space heating load vs. summer hot water load) a single set of variable speed pumps may not provide adequate turn down to provide good cooling of return water. A pump selection of several pumps in parallel including a jockey pump should be used to give good turndown performance, down to a few per cent of peak load demand. Further energy savings are possible as motor efficiency is reduced on pumps operating at high turndown ratios. By having a smaller pump and motor operating closer to their full load, efficiencies are greater and energy savings are maximised.	More pumps are required potentially adding some additional capital cost Control of the pumps needs to be undertaken by a building management system or pump controller but these are commonly found in most modern building services systems.
Plate heat exchanger sizing. Plate heat exchangers sized to give good approach temperatures and controlled with differential pressure control valves.	Using correctly sized plate heat exchangers means that close approach temperatures can occur (e.g. return temperatures on the primary side can approach the return temperature on the secondary side), maximising the cooling of the district heating return water.	None.
Strainers. Where plate heat exchangers are used strainers should be used to protect the heat exchanger. A flushing loop should be installed on the	Plate heat exchangers have relatively small clearances and can become partially or fully blocked by debris. This is particularly true where new buildings are connected without adequate system flushing, or where old	Pressure drop across the strainer marginally increases pumping energy.

secondary side to bypass the heat exchanger.	buildings with dirty systems are connected to heat exchangers.	
Pumps on return leg of heating circuit. The secondary system pumps should be installed on the return of the heating circuit, prior to the heat exchanger / connection point.	This arrangement reduces cavitation on the pump, though this should not be a problem for low temperature systems.	None.
Connect circuits in series. High temperature circuits such as radiators and calorifiers should be connected in series with lower temperature requirements such as underfloor heating. The return from the higher temperature system becomes the flow to the lower temperature system, maximising the cooling of the heating water. The return water from space heating can be used to pre-heat the domestic hot water supply, by using a pre-heat heat exchanger (also termed a 2-stage connection)	Increases cooling of the heating water, further reducing return temperature.	Not always possible where one circuit demands heat at a different time from others. Increase in complexity may not be suitable for smaller consumers or connections where domestic hot water is not a significant load.

Appendix C – Full page data tables

Table C-1 Domestic building typology characteristics. Units for U-values are W/m^2.K.

#	Type	Load modelling geometry	Size	Fabric Eff	Wall type	Wall U-value	Glazing type	Glazing U-value	Heating fuel	System	Heat Emitters (All radiators after district heating conversion)	Remove existing boiler	Remove existing heat emitter	Remove existing cooling system	Install wet secondary system	Install heat exchanger to connect to DE supply
DOMESTIC TYPOLOGIES																
d-1	Flat	Converted flat	2 bed	Low	Solid walls	2.1	Single	4.8	Gas	Gas boilers	Radiators	Y	N	n/a	N	N
d-2	Flat	Converted flat	2 bed	Low	Solid walls	2.1	Single	4.8	Electricity	Electric	Panel heaters	N	Y	n/a	Y	N
d-3	Flat	High rise flat	2 bed	Low	Solid walls	2.0	Single	4.8	Gas	Gas boilers	Radiators	Y	N	n/a	N	N
d-4	Flat	High rise flat	2 bed	Low	Solid walls	2.0	Single	4.8	Electricity	Electric	Panel heaters	N	Y	n/a	Y	Y
d-5	House	Mid-terrace house	3 bed	Low	Solid walls	2.1	Single	4.8	Gas	Gas boilers	Radiators	Y	N	n/a	N	N
d-6	House	Mid-terrace house	3 bed	Low	Solid walls	2.1	Single	4.8	Electricity	Electric	Panel heaters	N	Y	n/a	Y	N
d-7	Flat	Purpose built flat	2 bed	Medium	Un-insulated cavity	1.6	Double	2.8	Gas	Gas boilers	Radiators	Y	N	n/a	N	N
d-8	Flat	Purpose built flat	2 bed	Medium	Un-insulated cavity	1.6	Double	2.8	Electricity	Electric	Panel heaters	N	Y	n/a	Y	N
d-9	Flat	High rise flat	2 bed	Medium	Un-insulated cavity	1.6	Double	2.8	Gas	Gas boilers	Radiators	Y	N	n/a	N	N
d-10	Flat	High rise flat	2 bed	Medium	Un-insulated cavity	1.6	Double	2.8	Electricity	Electric	Panel heaters	N	Y	n/a	Y	Y
d-11	House	Mid-terrace house	3 bed	Medium	Un-insulated cavity	1.6	Double	2.8	Gas	Gas boilers	Radiators	Y	N	n/a	N	N
d-12	House	Mid-terrace house	3 bed	Medium	Un-insulated cavity	1.6	Double	2.8	Electricity	Electric	Panel heaters	N	Y	n/a	Y	N
d-13	Flat	Purpose built flat	2 bed	High	Insulated	0.35	Double	2.0	Gas	Gas boilers	Radiators	Y	N	n/a	N	N
d-14	Flat	Purpose built flat	2 bed	High	Insulated	0.35	Double	2.0	Electricity	Electric	Panel heaters	N	Y	n/a	Y	N
d-15	Flat	High rise flat	2 bed	High	Insulated	0.35	Double	2.0	Gas	Gas boilers	Radiators	Y	N	n/a	N	N
d-16	Flat	High rise flat	2 bed	High	Insulated	0.35	Double	2.0	Electricity	Electric	Panel heaters	N	Y	n/a	Y	Y
d-17	House	Mid-terrace house	3 bed	High	Insulated	0.35	Double	2.0	Gas	Gas boilers	Radiators	Y	N	n/a	N	N
d-18	House	Mid-terrace house	3 bed	High	Insulated	0.35	Double	2.0	Electricity	Electric	Panel heaters	N	Y	n/a	Y	N

Table C-2 Non-domestic building typology characteristics. Units for U-values are W/m^2.K.

#	Type	Load modelling geometry	Size	EPC rating	Glazing type	Glazing coverage	Wall type & U-value	Heating fuel	System	Heat Emitters (All radiators after district heating conversion)	Remove existing boiler	Remove existing heat emitter	Remove existing cooling system	Install wet secondary system	Install heat exchanger to connect to DE supply
NON-DOMESTIC TYPOLOGIES															
nd-1	Office	Pre 1960 office, solid wall	Small	E-G	Single	Partially (50% glazed)	Solid, 2.1	Gas	Gas boilers + ad hoc cooling	Radiators	Y	N	N	N	Y
nd-2	Office	Modern office, fully glazed	Small	E-G	Double	Fully (80% glazed)	Insulated 0.6	Electric	Heat pump	Radiator + AHU	N	N	N	N	Y
nd-3	Retail	Retail, small, high street	Small	E-G	Single	Full at front (100% at front, 50% at back)	Solid, 2.1	Electric	Heat pump	Overhead	N	N	N	N	Y
nd-4	Office	Pre 1960 office, solid wall	Large	E-G	Single	Partially (50% glazed)	Solid, 2.1	Gas	Gas boilers + ad hoc cooling	Radiators	Y	N	N	N	Y
nd-5	Office	Modern office, fully glazed	Large	E-G	Double	Fully (80% glazed)	Insulated 0.6	Electric	Heat pump	Radiator + AHU	N	N	N	N	Y
nd-6	Retail	Retail, large, no catering	Large	E-G	Double	Full at front (100% at front, 50% at back)	Solid, 2.1	Electric	VRF	Overhead	N	N	N	Y	Y
nd-7	Office	Modern office, fully glazed	Small	C-D	Double	Fully (80% glazed)	Insulated 0.6	Gas	Gas, AHU, FCU + perimeter heating	Radiator + AHU	Y	N	N	N	Y
nd-8	Retail	Retail, small, high street	Small	C-D	Single	Full at front (100% at front, 50% at back)	Solid, 2.1	Gas	Gas boiler, no cooling	Overhead	Y	N	N	N	Y
nd-9	Office	Modern office, partially glazed	Small	C-D	Double	Partially (50% glazed)	Insulated 0.6	Electric	VRF	Radiator + AHU	N	N	N	Y	Y
nd-10	Retail	Retail, small, high street	Small	C-D	Single	Full at front (100% at front, 50% at back)	Solid, 2.1	Electric	VRF	Overhead	N	N	N	Y	Y
nd-11	Office	Pre 1960 office, insulated cavity	Large	C-D	Double	Partially (50% glazed)	Insulated 0.6	Gas	Gas, AHU, FCU + perimeter heating	Radiator + AHU	Y	N	N	N	Y
nd-12	Retail	Retail, large, catering	Large	C-D	Double	Full at front (100% at front, 50% at back)	Solid, 2.1	Gas	Gas boilers, AHU, FCU	Overhead + AHU	Y	N	N	N	Y
nd-13	Office	Modern office, partially glazed	Large	C-D	Double	Partially (50% glazed)	Insulated 0.6	Electric	VRF	Radiator + AHU	N	N	N	Y	Y
nd-14	Office	Pre 1960 office, insulated cavity	Large	A-B	Double	Partially (50% glazed)	Insulated 0.6	Gas	Gas, AHU, FCU	Radiator + AHU	Y	N	N	N	Y

Table C-3 Building typology retrofit costs per dwelling and building – total cost figures.

Typology				Existing heating system	Number of units / dwellings	Floor area (m^2)	Capital cost breakdown per unit / dwelling (£)					Cost per dwelling	Cost per building
							Insulation & DH pipework	Heat emitters	HIU	Pumps	Overheads, prelims & labour		
Electric heating conversion	nd-2	Small office	Low eff	Heat pump	1	100	£ 2,752	-	£ 2,557	£ 3,500	£ 4,407	-	£ 13,216
	nd-5	Large office	Low eff	Heat pump	1	1,000	£ 6,757	-	£ 7,576	£ 6,000	£ 9,765	-	£ 30,098
	nd-3	Small retail	Low eff	Heat pump	1	100	£ 2,752	-	£ 2,557	£ 3,500	£ 4,407	-	£ 13,216
	nd-9	Small office	Med eff	VRF	1	100	£ 4,824	£ 562	£ 2,557	£ 3,500	£ 5,329	-	£ 16,772
	nd-13	Large office	Med eff	VRF	1	1,000	£ 34,495	£ 5,621	£ 7,576	£ 6,000	£ 24,090	-	£ 77,782
	nd-10	Small retail	Med eff	VRF	1	100	£ 4,824	£ 1,334	£ 2,557	£ 3,500	£ 6,924	-	£ 19,139
	nd-6	Large retail	Low eff	VRF	1	1,000	£ 23,804	£ 10,085	£ 3,788	£ 3,500	£ 19,709	-	£ 60,886
	d-2	House	Low eff	Panel heaters	1	78.7	£ 1,788	£ 2,750	£ 2,500	-	£ 4,053	£ 11,092	£ 11,092
	d-8	House	Med eff	Panel heaters	1	78.7	£ 1,788	£ 2,614	£ 2,500	-	£ 4,005	£ 10,908	£ 10,908
	d-14	House	High eff	Panel heaters	1	78.7	£ 1,788	£ 2,411	£ 2,500	-	£ 3,934	£ 10,633	£ 10,633
	d-4	Low rise flat	Low eff	Panel heaters	8	103.3	£ 1,738	£ 3,202	£ 2,500	-	£ 4,193	£ 11,633	£ 93,065
	d-10	Low rise flat	Med eff	Panel heaters	32	60.3	£ 680	£ 2,152	£ 2,500	-	£ 3,058	£ 8,390	£ 268,480
	d-16	Low rise flat	High eff	Panel heaters	32	60.3	£ 680	£ 2,006	£ 2,500	-	£ 3,007	£ 8,193	£ 262,188
	d-6	High rise flat	Low eff	Panel heaters	40	60.3	£ 320	£ 2,210	£ 2,500	-	£ 2,953	£ 7,983	£ 319,316
	d-12	High rise flat	Med eff	Panel heaters	40	60.3	£ 320	£ 2,094	£ 2,500	-	£ 2,912	£ 7,826	£ 313,024
	d-18	High rise flat	High eff	Panel heaters	40	60.3	£ 320	£ 2,006	£ 2,500	-	£ 2,881	£ 7,708	£ 308,304
Gas heating conversion	nd-7	Small office	Med eff	Gas boilers	1	100	£ 2,752	-	£ 2,557	-	£ 2,917	-	£ 8,226
	nd-1	Small office	Low eff	Gas boilers	1	100	£ 2,752	-	£ 2,557	-	£ 2,917	-	£ 8,226
	nd-14	Large office	High eff	Gas boilers	1	1,000	£ 5,503	-	£ 7,576	-	£ 6,697	-	£ 19,776
	nd-11	Large office	Med eff	Gas boilers	1	1,000	£ 5,503	-	£ 7,576	-	£ 6,697	-	£ 19,776
	nd-4	Large office	Low eff	Gas boilers	1	1,000	£ 5,503	-	£ 7,576	-	£ 6,697	-	£ 19,776
	nd-8	Small retail	Med eff	Gas boilers	1	100	£ 2,752	-	£ 2,557	-	£ 2,917	-	£ 8,226
	nd-12	Large retail	Med eff	Gas boilers	1	1,000	£ 5,503	-	£ 3,788	-	£ 5,371	-	£ 14,662
	d-1	House	Low eff	Gas boilers	1	78.7	£ 1,788	-	£ 2,500	-	£ 2,560	£ 6,849	£ 6,849
	d-7	House	Med eff	Gas boilers	1	78.7	£ 1,788	-	£ 2,500	-	£ 2,560	£ 6,849	£ 6,849
	d-13	House	High eff	Gas boilers	1	78.7	£ 1,788	-	£ 2,500	-	£ 2,560	£ 6,849	£ 6,849
	d-3	Low rise flat	Low eff	Gas boilers	8	103.3	£ 1,738	-	£ 2,500	-	£ 2,543	£ 6,781	£ 54,248
	d-9	Low rise flat	Med eff	Gas boilers	32	60.3	£ 680	-	£ 2,500	-	£ 1,908	£ 5,088	£ 162,802
	d-15	Low rise flat	High eff	Gas boilers	32	60.3	£ 680	-	£ 2,500	-	£ 1,908	£ 5,088	£ 162,802
	d-5	High rise flat	Low eff	Gas boilers	40	60.3	£ 320	-	£ 2,500	-	£ 1,782	£ 4,602	£ 184,072
	d-11	High rise flat	Med eff	Gas boilers	40	60.3	£ 320	-	£ 2,500	-	£ 1,782	£ 4,602	£ 184,072
	d-17	High rise flat	High eff	Gas boilers	40	60.3	£ 320	-	£ 2,500	-	£ 1,782	£ 4,602	£ 184,072

Table C-4 Building typology retrofit costs per dwelling and building – cost per m^2.

Typology				Existing heating system	Number of units / dwellings	Floor area (m^2)	Capital cost breakdown per unit / dwelling (£/m^2)					Cost per dwelling	Cost per building
							Insulation & DH pipework	Heat emitters	HIU	Pumps	Overheads, prelims & labour		
Electric heating conversion	nd-2	Small office	Low eff	Heat pump	1	100	£ 27.5	-	£ 25.6	£ 35.0	£ 44.1	-	£ 132.2
	nd-5	Large office	Low eff	Heat pump	1	1,000	£ 6.8	-	£ 7.6	£ 6.0	£ 9.8	-	£ 30.1
	nd-3	Small retail	Low eff	Heat pump	1	100	£ 27.5	-	£ 25.6	£ 35.0	£ 44.1	-	£ 132.2
	nd-9	Small office	Med eff	VRF	1	100	£ 48.2	£ 5.6	£ 25.6	£ 35.0	£ 53.3	-	£ 167.7
	nd-13	Large office	Med eff	VRF	1	1,000	£ 34.5	£ 5.6	£ 7.6	£ 6.0	£ 24.1	-	£ 77.8
	nd-10	Small retail	Med eff	VRF	1	100	£ 48.2	£ 13.3	£ 25.6	£ 35.0	£ 69.2	-	£ 191.4
	nd-6	Large retail	Low eff	VRF	1	1,000	£ 23.8	£ 10.1	£ 3.8	£ 3.5	£ 19.7	-	£ 60.9
	d-2	House	Low eff	Panel heaters	1	78.7	£ 22.7	£ 34.9	£ 31.8	-	£ 51.5	£ 140.9	£ 140.9
	d-8	House	Med eff	Panel heaters	1	78.7	£ 22.7	£ 33.2	£ 31.8	-	£ 50.9	£ 138.6	£ 138.6
	d-14	House	High eff	Panel heaters	1	78.7	£ 22.7	£ 30.6	£ 31.8	-	£ 50.0	£ 135.1	£ 135.1
	d-4	Low rise flat	Low eff	Panel heaters	8	103.3	£ 16.8	£ 31.0	£ 24.2	-	£ 40.6	£ 112.6	£ 900.9
	d-10	Low rise flat	Med eff	Panel heaters	32	60.3	£ 11.3	£ 35.7	£ 41.5	-	£ 50.7	£ 139.1	£ 4,452.4
	d-16	Low rise flat	High eff	Panel heaters	32	60.3	£ 11.3	£ 33.3	£ 41.5	-	£ 49.9	£ 135.9	£ 4,348.1
	d-6	High rise flat	Low eff	Panel heaters	40	60.3	£ 5.3	£ 36.7	£ 41.5	-	£ 49.0	£ 132.4	£ 5,295.5
	d-12	High rise flat	Med eff	Panel heaters	40	60.3	£ 5.3	£ 34.7	£ 41.5	-	£ 48.3	£ 129.8	£ 5,191.1
	d-18	High rise flat	High eff	Panel heaters	40	60.3	£ 5.3	£ 33.3	£ 41.5	-	£ 47.8	£ 127.8	£ 5,112.8
Gas heating conversion	nd-7	Small office	Med eff	Gas boilers	1	100	£ 27.5	-	£ 25.6	-	£ 29.2	-	£ 82.3
	nd-1	Small office	Low eff	Gas boilers	1	100	£ 27.5	-	£ 25.6	-	£ 29.2	-	£ 82.3
	nd-14	Large office	High eff	Gas boilers	1	1,000	£ 5.5	-	£ 7.6	-	£ 6.7	-	£ 19.8
	nd-11	Large office	Med eff	Gas boilers	1	1,000	£ 5.5	-	£ 7.6	-	£ 6.7	-	£ 19.8
	nd-4	Large office	Low eff	Gas boilers	1	1,000	£ 5.5	-	£ 7.6	-	£ 6.7	-	£ 19.8
	nd-8	Small retail	Med eff	Gas boilers	1	100	£ 27.5	-	£ 25.6	-	£ 29.2	-	£ 82.3
	nd-12	Large retail	Med eff	Gas boilers	1	1,000	£ 5.5	-	£ 3.8	-	£ 5.4	-	£ 14.7
	d-1	House	Low eff	Gas boilers	1	78.7	£ 22.7	-	£ 31.8	-	£ 32.5	£ 87.0	£ 87.0
	d-7	House	Med eff	Gas boilers	1	78.7	£ 22.7	-	£ 31.8	-	£ 32.5	£ 87.0	£ 87.0
	d-13	House	High eff	Gas boilers	1	78.7	£ 22.7	-	£ 31.8	-	£ 32.5	£ 87.0	£ 87.0
	d-3	Low rise flat	Low eff	Gas boilers	8	103.3	£ 16.8	-	£ 24.2	-	£ 24.6	£ 65.6	£ 525.2
	d-9	Low rise flat	Med eff	Gas boilers	32	60.3	£ 11.3	-	£ 41.5	-	£ 31.6	£ 84.4	£ 2,699.9
	d-15	Low rise flat	High eff	Gas boilers	32	60.3	£ 11.3	-	£ 41.5	-	£ 31.6	£ 84.4	£ 2,699.9
	d-5	High rise flat	Low eff	Gas boilers	40	60.3	£ 5.3	-	£ 41.5	-	£ 29.6	£ 76.3	£ 3,052.6
	d-11	High rise flat	Med eff	Gas boilers	40	60.3	£ 5.3	-	£ 41.5	-	£ 29.6	£ 76.3	£ 3,052.6
	d-17	High rise flat	High eff	Gas boilers	40	60.3	£ 5.3	-	£ 41.5	-	£ 29.6	£ 76.3	£ 3,052.6

Table C-5 Baseline primary energy demand and fuel usage figures.

Typology				Counterfactual heating system	Floor area (m^2)	Primary energy demand (kWh/yr)			System efficiency		Annual fuel usage (kWh/yr)		
						Heating	DHW	Total	Heating	DHW	Heating	DHW	Total
Electric heating conversion	nd-2	Small office	Low eff	Heat pump	100	2,386	206	2,592	220%	160%	1,084	129	1,213
	nd-5	Large office	Low eff	Heat pump	1,000	23,856	2,064	25,921	220%	160%	10,844	1,290	12,134
	nd-3	Small retail	Low eff	Heat pump	100	5,042	99	5,141	220%	160%	2,292	62	2,354
	nd-9	Small office	Med eff	VRF	100	1,655	206	1,861	260%	180%	636	115	751
	nd-13	Large office	Med eff	VRF	1,000	16,548	2,064	18,612	260%	180%	6,365	1,147	7,512
	nd-10	Small retail	Med eff	VRF	100	5,042	99	5,141	260%	180%	1,939	55	1,994
	nd-6	Large retail	Low eff	VRF	1,000	34,554	875	35,429	260%	180%	13,290	486	13,776
	d-2	House	Low eff	Panel heaters	78.7	6,731	2064	8,796	100%	100%	6,731	2064	8,796
	d-8	House	Med eff	Panel heaters	78.7	4,573	2064	6,637	100%	100%	4,573	2064	6,637
	d-14	House	High eff	Panel heaters	78.7	1,788	2064	3,853	100%	100%	1,788	2064	3,853
	d-4	Low rise flat	Low eff	Panel heaters	103.3	8,412	2064	10,476	100%	100%	8,412	2064	10,476
	d-10	Low rise flat	Med eff	Panel heaters	60.3	2,899	2064	4,963	100%	100%	2,899	2064	4,963
	d-16	Low rise flat	High eff	Panel heaters	60.3	469	2064	2,533	100%	100%	469	2064	2,533
	d-6	High rise flat	Low eff	Panel heaters	60.3	4,017	2064	6,082	100%	100%	4,017	2064	6,082
	d-12	High rise flat	Med eff	Panel heaters	60.3	2,351	2064	4,415	100%	100%	2,351	2064	4,415
	d-18	High rise flat	High eff	Panel heaters	60.3	735	2064	2,799	100%	100%	735	2064	2,799
Gas heating conversion	nd-7	Small office	Med eff	Gas boilers	100	2,386	206	2,592	80%	80%	2,982	258	3,240
	nd-1	Small office	Low eff	Gas boilers	100	3,358	206	3,564	80%	80%	4,197	258	4,455
	nd-14	Large office	High eff	Gas boilers	1,000	13,711	2,064	15,775	90%	90%	15,234	2,294	17,528
	nd-11	Large office	Med eff	Gas boilers	1,000	13,711	2,064	15,775	80%	80%	17,138	2,581	19,719
	nd-4	Large office	Low eff	Gas boilers	1,000	33,579	2,064	35,644	80%	80%	41,974	2,581	44,555
	nd-8	Small retail	Med eff	Gas boilers	100	5,042	99	5,141	80%	80%	6,302	124	6,426
	nd-12	Large retail	Med eff	Gas boilers	1,000	32,559	4,854	37,413	80%	80%	40,699	6,067	46,766
	d-1	House	Low eff	Gas boilers	78.7	6,731	2064	8,796	74%	74%	9,096	2,789	11,885
	d-7	House	Med eff	Gas boilers	78.7	4,573	2064	6,637	74%	74%	6,180	2,789	8,969
	d-13	House	High eff	Gas boilers	78.7	1,788	2064	3,853	84%	84%	2,129	2,457	4,586
	d-3	Low rise flat	Low eff	Gas boilers	103.3	8,412	2064	10,476	74%	74%	11,368	2,789	14,157
	d-9	Low rise flat	Med eff	Gas boilers	60.3	2,899	2064	4,963	74%	74%	3,918	2,789	6,707
	d-15	Low rise flat	High eff	Gas boilers	60.3	469	2064	2,533	84%	84%	558	2,457	3,015
	d-5	High rise flat	Low eff	Gas boilers	60.3	4,017	2064	6,082	74%	74%	5,428	2,789	8,218
	d-11	High rise flat	Med eff	Gas boilers	60.3	2,351	2064	4,415	74%	74%	3,177	2,789	5,966
	d-17	High rise flat	High eff	Gas boilers	60.3	735	2064	2,799	84%	84%	875	2,457	3,332

Table C-6 House building typologies – calculated total cost of different scenarios for energy efficiency works in £ and £/m^2.

House	Retrofit costs (£)			Overheads, labour etc (£)			Retrofit costs (£/m^2)			Overheads, labour etc (£/m^2)		
	Low eff	Med eff	High eff	Low eff	Med eff	High eff	Low eff	Med eff	High eff	Low eff	Med eff	High eff
Half air infiltration	£ 177	£ 177	£ 177	£ 342	£ 342	£ 342	£ 2.30	£ 2.30	£ 2.30	£ 4.30	£ 4.30	£ 4.30
U-values to Part L1B	£ 8,122	£ 4,239	£ 3,939	£ 12,343	£ 6,613	£ 6,200	£ 103.20	£ 53.90	£ 50.10	£ 156.80	£ 84.00	£ 78.80
U-values to Part L1B + 0.5 ach	£ 8,299	£ 4,417	£ 4,117	£ 12,685	£ 6,955	£ 6,542	£ 105.50	£ 56.10	£ 52.30	£ 161.20	£ 88.40	£ 83.10
Passivhaus U-values	£ 18,785	£ 15,598	£ 13,907	£ 27,594	£ 22,623	£ 20,298	£ 238.70	£ 198.20	£ 176.70	£ 350.60	£ 287.50	£ 257.90
Passivhaus U-values + 0.5 ach	£ 18,963	£ 15,776	£ 14,085	£ 27,838	£ 22,867	£ 20,542	£ 241.00	£ 200.50	£ 179.00	£ 353.70	£ 290.60	£ 261.00

Table C-7 Low rise flat building typologies – calculated total cost of different scenarios for energy efficiency works in £ and £/m^2.

Low rise flat	Retrofit costs (£)			Overheads, labour etc (£)			Retrofit costs (£/m^2)			Overheads, labour etc (£/m^2)		
	Low eff	Med eff	High eff	Low eff	Med eff	High eff	Low eff	Med eff	High eff	Low eff	Med eff	High eff
Half air infiltration	£ 203	£ 155	£ 155	£ 377	£ 312	£ 312	£ 2.00	£ 2.60	£ 2.60	£ 6.30	£ 5.20	£ 5.20
U-values to Part L1B	£ 6,960	£ 2,579	£ 2,299	£ 10,746	£ 4,330	£ 3,945	£ 67.40	£ 42.80	£ 38.10	£ 178.20	£ 71.80	£ 65.40
U-values to Part L1B + 0.5 ach	£ 7,163	£ 2,734	£ 2,454	£ 11,123	£ 4,641	£ 4,256	£ 69.40	£ 45.30	£ 40.70	£ 184.50	£ 77.00	£ 70.60
Passivhaus U-values	£ 18,076	£ 11,033	£ 8,631	£ 26,618	£ 16,346	£ 13,044	£ 175.20	£ 183.00	£ 143.10	£ 441.40	£ 271.10	£ 216.30
Passivhaus U-values + 0.5 ach	£ 18,279	£ 11,188	£ 8,786	£ 26,898	£ 16,559	£ 13,257	£ 177.10	£ 185.50	£ 145.70	£ 446.10	£ 274.60	£ 219.90

Table C-8 High rise flat building typologies – calculated total cost of different scenarios for energy efficiency works in £ and £/m^2.

High rise flat	Retrofit costs (£)			Overheads, labour etc (£)			Retrofit costs (£/m^2)			Overheads, labour etc (£/m^2)		
	Low eff	Med eff	High eff	Low eff	Med eff	High eff	Low eff	Med eff	High eff	Low eff	Med eff	High eff
Half air infiltration	£ 155	£ 155	£ 155	£ 312	£ 312	£ 312	£ 2.60	£ 2.60	£ 2.60	£ 5.20	£ 5.20	£ 5.20
U-values to Part L1B	£ 5,311	£ 2,714	£ 2,598	£ 8,479	£ 4,515	£ 4,356	£ 88.10	£ 45.00	£ 43.10	£ 140.60	£ 74.90	£ 72.20
U-values to Part L1B + 0.5 ach	£ 5,467	£ 2,869	£ 2,753	£ 8,791	£ 4,827	£ 4,667	£ 90.70	£ 47.60	£ 45.70	£ 145.80	£ 80.00	£ 77.40
Passivhaus U-values	£ 12,467	£ 6,784	£ 5,683	£ 18,906	£ 10,504	£ 8,989	£ 206.70	£ 112.50	£ 94.20	£ 313.50	£ 174.20	£ 149.10
Passivhaus U-values + 0.5 ach	£ 12,622	£ 6,940	£ 5,838	£ 19,119	£ 10,718	£ 9,203	£ 209.30	£ 115.10	£ 96.80	£ 317.10	£ 177.70	£ 152.60

Table C-9 House building typologies – calculated energy efficiency costs (excluding builders works, preliminaries, overheads & labour).

House	**Low efficiency**					**Medium efficiency**					**High efficiency**				
	REF	Glazing	Walls	Roof	Ach	REF	Glazing	Walls	Roof	Ach	REF	Glazing	Walls	Roof	Ach
Half air infiltration	K	-	-	-	£177	K	-	-	-	£177	K	-	-	-	£177
U-values to Part L1B	ACI	£3,709	£4,173	£240	-	AHJ	£3,709	£300	£230	-	AJ	£3,709	-	£230	-
U-values to Part L1B + 0.5 ach	ACIK	£3,709	£4,173	£240	£177	AHJK	£3,709	£300	£230	£177	AJK	£3,709	-	£230	£177
Passivhaus U-values	BFI	£8,114	£10,432	£240	-	BEHJ	£8,114	£7,255	£230	-	BDJ	£8,114	£5,564	£230	-
Passivhaus U-values + 0.5 ach	BFIK	£8,114	£10,432	£240	£177	BEHJK	£8,114	£7,255	£230	£177	BDJK	£8,114	£5,564	£230	£177

Table C-10 Low rise flat building typologies – calculated energy efficiency costs (excluding builders works, preliminaries, overheads & labour).

Low rise flat	**Low efficiency**					**Medium efficiency**					**High efficiency**				
	REF	Glazing	Walls	Roof	Ach	REF	Glazing	Walls	Roof	Ach	REF	Glazing	Walls	Roof	Ach
Half air infiltration	K	-	-	-	£203	K	-	-	-	£155	K	-	-	-	£155
U-values to Part L1B	AD	£2,799	£2,339	-	-	AH	£2,299	£280	-	-	A	£2,299	-	-	-
U-values to Part L1B + 0.5 ach	ADK	£2,799	£2,339	-	£203	AHK	£2,299	£280	-	£155	AK	£2,299	-	-	£155
Passivhaus U-values	BG	£6,123	£7,310	-	-	BG	£5,029	£6,004	-	-	BF	£5,029	£3,602	-	-
Passivhaus U-values + 0.5 ach	BGK	£6,123	£7,310	-	£203	BGK	£5,029	£6,004	-	£155	BFK	£5,029	£3,602	-	£155

Table C-11 High rise flat building typologies – calculated energy efficiency costs (excluding builders works, preliminaries, overheads & labour).

High rise flat	**Low efficiency**					**Medium efficiency**					**High efficiency**				
	REF	Glazing	Walls	Roof	Ach	REF	Glazing	Walls	Roof	Ach	REF	Glazing	Walls	Roof	Ach
Half air infiltration	K	-	-	-	£155	K	-	-	-	£155	K	-	-	-	£155
U-values to Part L1B	AF	£3,247	£3,392	-	-	AH	£3,247	£280	-	-	A	£3,247	-	-	-
U-values to Part L1B + 0.5 ach	AFK	£3,247	£3,392	-	£155	AHK	£3,247	£280	-	£155	AK	£3,247	-	-	£155
Passivhaus U-values	BG	£7,103	£8,480	-	-	B	£7,103	£8,480	-	-	BF	£7,103	£5,088	-	-
Passivhaus U-values + 0.5 ach	BGK	£7,103	£8,480	-	£155	BK	£7,103	£8,480	-	£155	BFK	£7,103	£5,088	-	£155

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