CONNECTING EXISTING BUILDINGS TO DISTRICT HEATING NETWORKS

BUROHAPPOLD ENGINEERING

Summary Report - 14 Dec 2016

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date	**14 Dec 2016**
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signature	
date	**14 Dec 2016**

Connecting Existing Buildings to District Heating Networks

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INTRODUCTION

- **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 **retrofitting existing buildings in London so they can be connected 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.
- This reduction in temperature enables the integration of renewable and secondary (environmental & waste) heat sources in order to decarbonise heat supply (also termed **fourth generation (4G) district heating** networks).
- The project will look at **two fundamental aspects of this transition**, covering:
  - The technical feasibility and cost effectiveness of retrofitting existing buildings so they can be connected to district heating;
  - And, to what extent the existing building stock and its secondary heating systems need to be retrofitted to allow heating networks to reduce their supply temperatures.

OBJECTIVES

- 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** programme and emerging work from the **London Energy Plan**, specifically the heat element of this. The core objectives of the project are to:
  1. **Understand the spatial opportunity as well as the technical and financial issues** 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.
  2. **Understand the optimum level of building energy performance and secondary heating system design** that is required in existing buildings to allow lower temperature, 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.
  3. **Develop a generic methodology and approach 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.

HEADLINE FINDINGS: RETROFITTING COSTS FOR BUILDING TYPOLOGIES

- Indicative connection strategies were developed for **32 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** ranged from **£66/m^2** to **£87/m^2**, equivalent to **£4,600** to **£6,800** per unit based on the models assessed.
- The cost to connect the existing **gas centrally heated commercial buildings** assessed varied for typologies from **£15/m^2** to **£82/m^2**.
- The cost to connect the existing **electrically heated domestic buildings** is higher than for gas heated domestic buildings and ranged from **£112/m^2** to **£141/m^2**, equivalent **£7,700** to **£11,000** per unit based on the models assessed.
- The cost to connect the existing electrically heated commercial buildings assessed varied for typologies from **£30/m^2** to **£191/m^2**.

HEADLINE FINDINGS: RETROFITTING COSTS FOR BUILDING TYPOLOGIES: 4TH GENERATION DISTRICT HEATING NETWORKS

- **4G district heating involves lowering the supply temperature of the heat network to between 70 °C and 40 °C**, this reduces the energy requirement of the network and enables the cost effective use of low grade heat.
- **At heating supply temperatures of 70 °C approximately 99% of annual heat demand can be met, at 60 °C between 96%-99%, at 50 °C between 86%-98% and at 40 °C this can be as low as 50%-92%**. The ranges are dictated by the energy efficiency of the property being supplied.
- Larger heat emitters/radiators alone were only sufficient to meet 100% of the projected heat demand at heat supply temperatures from 70 °C down to 50 °C. For heat supply temperatures of 40 °C investment in **energy efficiency** and **supplementary domestic hot water** (DHW) heating is required to meet 100% of the projected heat demand.
- A domestic retrofit meeting Building Regulation U-values including halving air infiltration can reduce unmet heat demand from **40%** to **5%** in 4G DH retrofit. These additional works add further costs of **£106/m^2** to **£159/m^2**, equivalent to **£4,200** to **£12,500** to the DH retrofit, but they allow larger emitters (or variable heat network supply temperatures) to meet the remaining space heating demand.
- For non-domestic buildings, investment in new double glazing and measures to halve air infiltration can reduce unmet heat demand from **40%** to **30%** in 4G DH retrofit. These additional works add further costs of **£10/m^2** to **£118/m^2** but a supplementary energy source (e.g. back up boiler, secondary electric system) is still required.

HEADLINE FINDINGS: COST EFFECTIVENESS OF DISTRICT HEATING RETROFIT

- **Up to 8.7% (330,000) of existing buildings in London fall into the high cost effectiveness category for connecting to district heating**
  - These properties are predominantly low and medium efficiency electrically heated high-rise flats, low-rise flats and houses, as well as large electric offices. The highest densities of these properties can be found in Tower Hamlets, Westminster, Hammersmith & Fulham and Southwark.

- **Up to 81.7% (3,100,000) of existing buildings in London fall into the high or medium cost effectiveness categories for connecting to district heating**
  - The medium cost effectiveness buildings are predominantly gas heated low and medium efficiency flats, houses and large retail buildings. The highest densities of these properties can be found in Tower Hamlets, Westminster, Hounslow, Southwark, Islington and Wandsworth.

Note: The total number of domestic buildings in London was found to be 3,455,750 based upon LSOA datasets for 'Property type and bedroom count' from Office for National Statistics (ONS) neighbourhood statistics, 2014. The total number of non-domestic buildings in London was taken as 331,511 based upon Ordnance Survey Address-Base-Plus, Nov 2015 and 2011 Census Lower Super Output Areas; of these buildings, 206,193 are office and retail buildings.

HEADLINE FINDINGS: COST EFFECTIVENESS OF DISTRICT HEATING RETROFIT: 4TH GENERATION DH + ENERGY EFFICIENCY RETROFIT

- **Up to 4.8% (180,000) of existing buildings in London fall into the <u>high</u> cost effectiveness category for connecting to district heating**
  - These properties are predominantly low efficiency electrically heated high-rise flats, low-rise flats and houses, as well as large electric offices. The highest densities of these properties can be found in Tower Hamlets, Westminster, Islington, Sutton and Southwark.

- **Up to 21.4% (810,000) of existing buildings in London fall into the <u>high or medium</u> cost effectiveness category for connecting to district heating**
  - These additional medium cost effective properties are predominantly medium efficiency electrically heated high-rise flats, low-rise flats and houses, and low efficiency gas heated high rise flats and large electric retail buildings. The highest densities of these properties can be found in Tower Hamlets, Westminster, Southwark, Hammersmith & Fulham and Hounslow.

<u>Note</u>: The total number of domestic buildings in London was found to be 3,455,750 based upon LSOA datasets for 'Property type and bedroom count' from Office for National Statistics (ONS) neighbourhood statistics, 2014. The total number of non-domestic buildings in London was taken as 331,511 based upon Ordnance Survey Address-Base-Plus, Nov 2015 and 2011 Census Lower Super Output Areas; of these buildings, 206,193 are office and retail buildings.

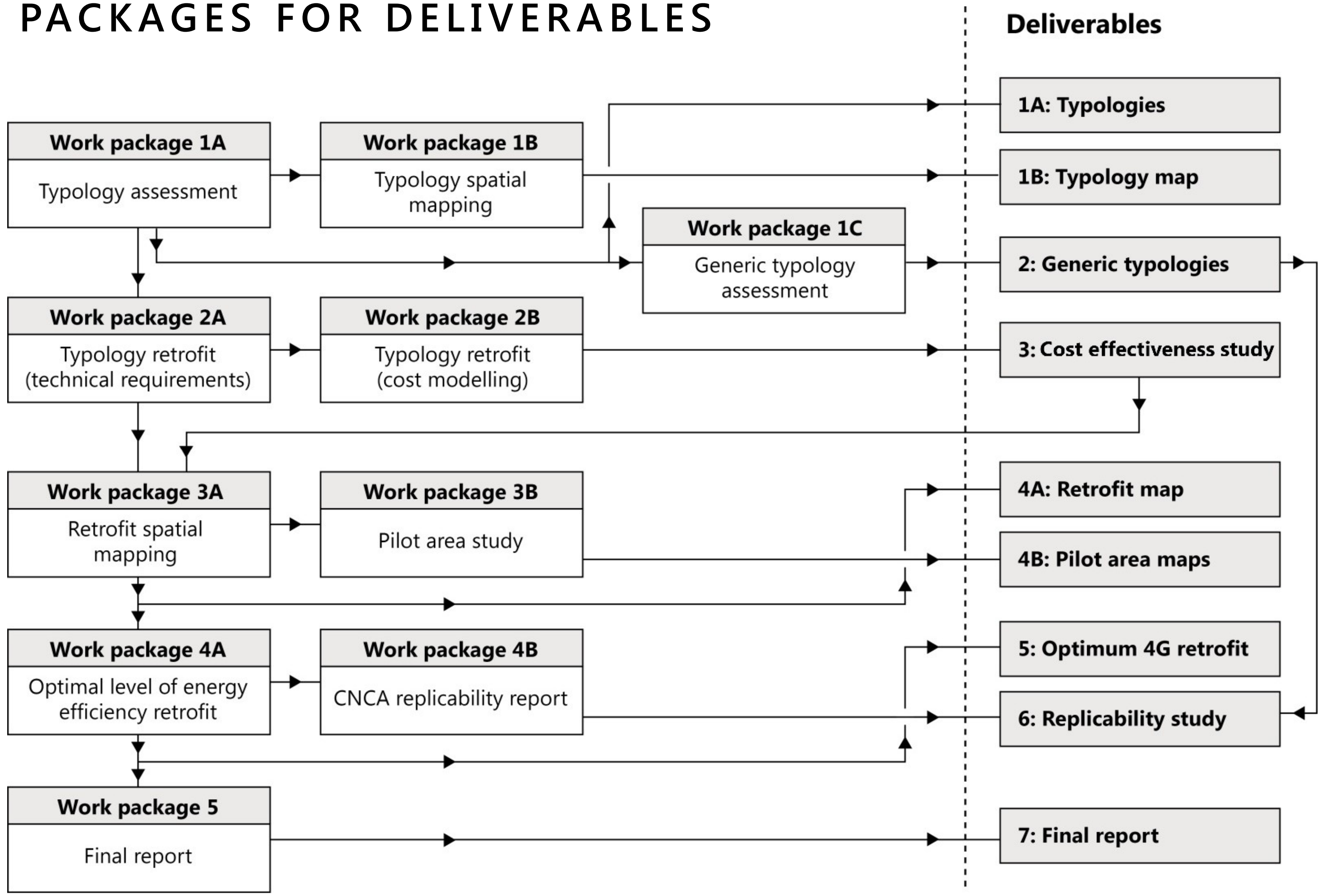
PROJECT PARTNERS

Greater London Authority	Carbon Neutral Cities Alliance	BuroHappold	Strathclyde University	University College London
Simon Wyke Peter North Chris Grainger Cassie Sutherland Agnieszka Griffin	Gayle Prest (Minneapolis) Christie Baumel (Seattle) Bill Updike (Washington DC) Alex Charpentier & Micah Lang (Vancouver)	Alasdair Young Mark Dowson Angeliki Gkogka Trevor Keeling Justin Etherington Kyriaki Alexiou	Joseph Clarke Nicolas Kelly Jon Hand Andrew Cowie	Francis Li

DELIVERABLES

- **Output 1a**: Generic list of existing residential and non-residential building typologies and assessment of requirements for how these buildings could be retrofitted to have their heat supplied by a district heating network.
- **Output 1b**: Spatial representations using GIS identifying these building typologies 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 allowing an initial high-level assessment to be discussed.
- **Output 3**: Cost effectiveness study looking at the technical requirements and financial costs associated with retrofitting each of London's commonest building typologies for connection to a district heating network.
- **Outputs 4a & 4b**: A map illustrating the prioritised areas in London for district heating networks. Further mapping of four neighbourhoods as potential pilot projects.
- **Output 5**: Assessment of 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°.
- **Output 6 & 7**: A replicability methodology that can be used by CNCA cities and 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.

WORK PACKAGES FOR DELIVERABLES



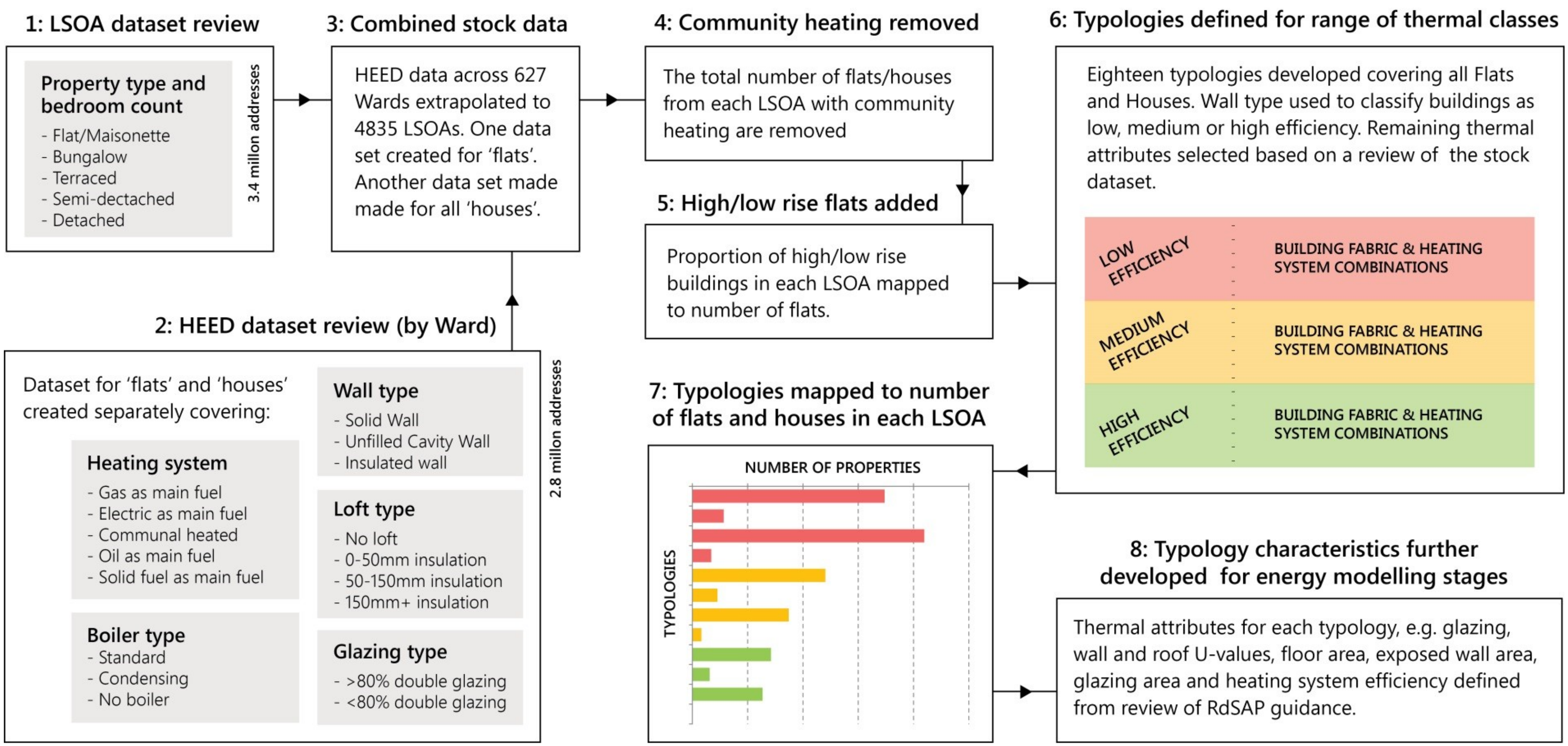
WORK PACKAGE 1A

BUILDING TYPOLOGY ASSESSMENT

OVERVIEW

- The London building stock was categorised into **32 typologies**; with **18** typologies representing **domestic buildings** and a further **14** typologies representing **non-domestic buildings**.
- In total, the selected typologies are considered to represent:
  - **3,298,000** domestic addresses: **95.4%** of the stock (existing communally heated blocks removed)
  - **206,000** 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 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.
- For domestic buildings, thermal efficiency was based on wall construction data from the HEED Home Energy Efficiency Database for Greater London, 2012. This data could be specifically mapped to all flats, and all houses separately.
- For non-domestic buildings, thermal efficiency was based on EPC data where directly available, or matched to similar building type. Remaining allocations to all buildings were extrapolated based on total floor area data.

DOMESTIC METHODOLOGY

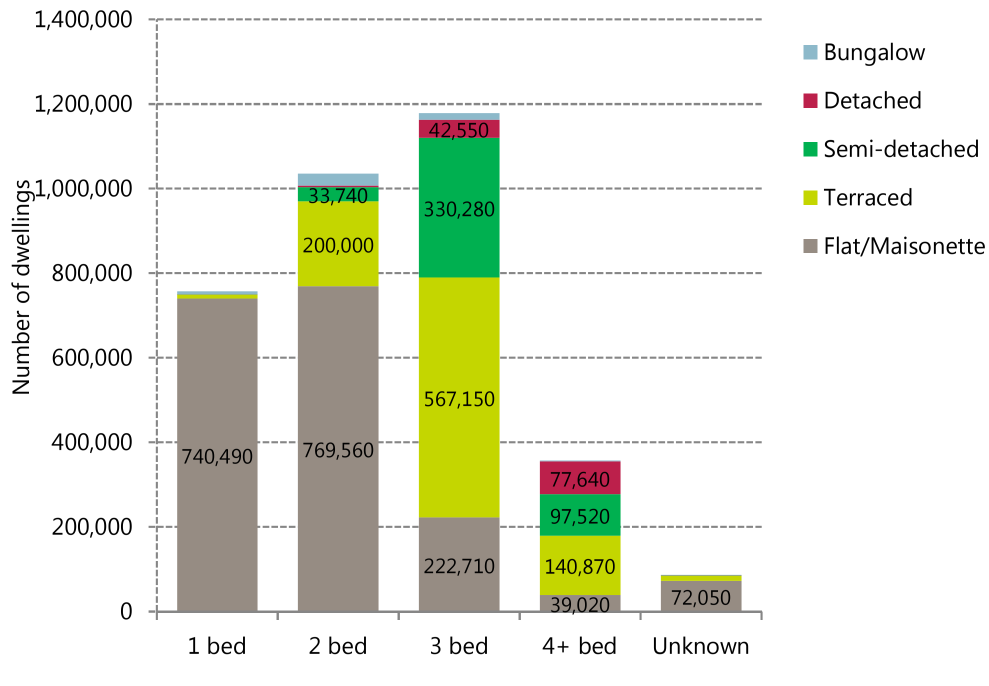


DOMESTIC TYPOLOGIES

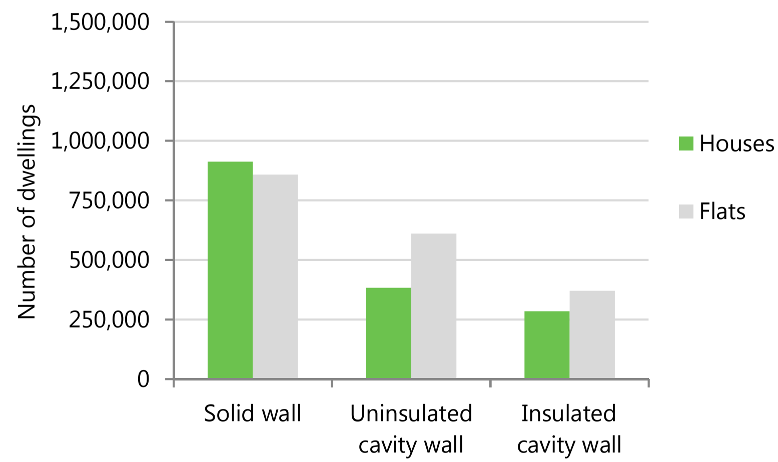
	Dwelling type	Efficiency	Wall type	Glazing type	Loft insulation	Heating fuel
d-1	Flat - low rise	Low	Solid wall	Less than 80% double glazed	No loft	Gas
d-2	Flat - low rise	Low	Solid wall	Less than 80% double glazed	No loft	Electricity
d-3	Flat - high rise	Low	Solid wall	Less than 80% double glazed	No 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 cavity wall	More than 80% double glazed	No loft	Gas
d-8	Flat - low rise	Medium	Un-insulated cavity wall	More than 80% double glazed	No loft	Electricity
d-9	Flat - high rise	Medium	Un-insulated cavity wall	More than 80% double glazed	No loft	Gas
d-10	Flat - high rise	Medium	Un-insulated cavity wall	More than 80% double glazed	No loft	Electricity
d-11	House	Medium	Un-insulated cavity wall	More than 80% double glazed	50-150mm	Gas
d-12	House	Medium	Un-insulated cavity 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

DOMESTIC PRIORITISATION

LSOA data for London shows that 1-2 bed flats and 3 bed mid terraces are the most common type of ‘flats’ and ‘houses’.



HEED data by ward extrapolated to LSOAs to show how wall construction is split between all flats and all houses separately.



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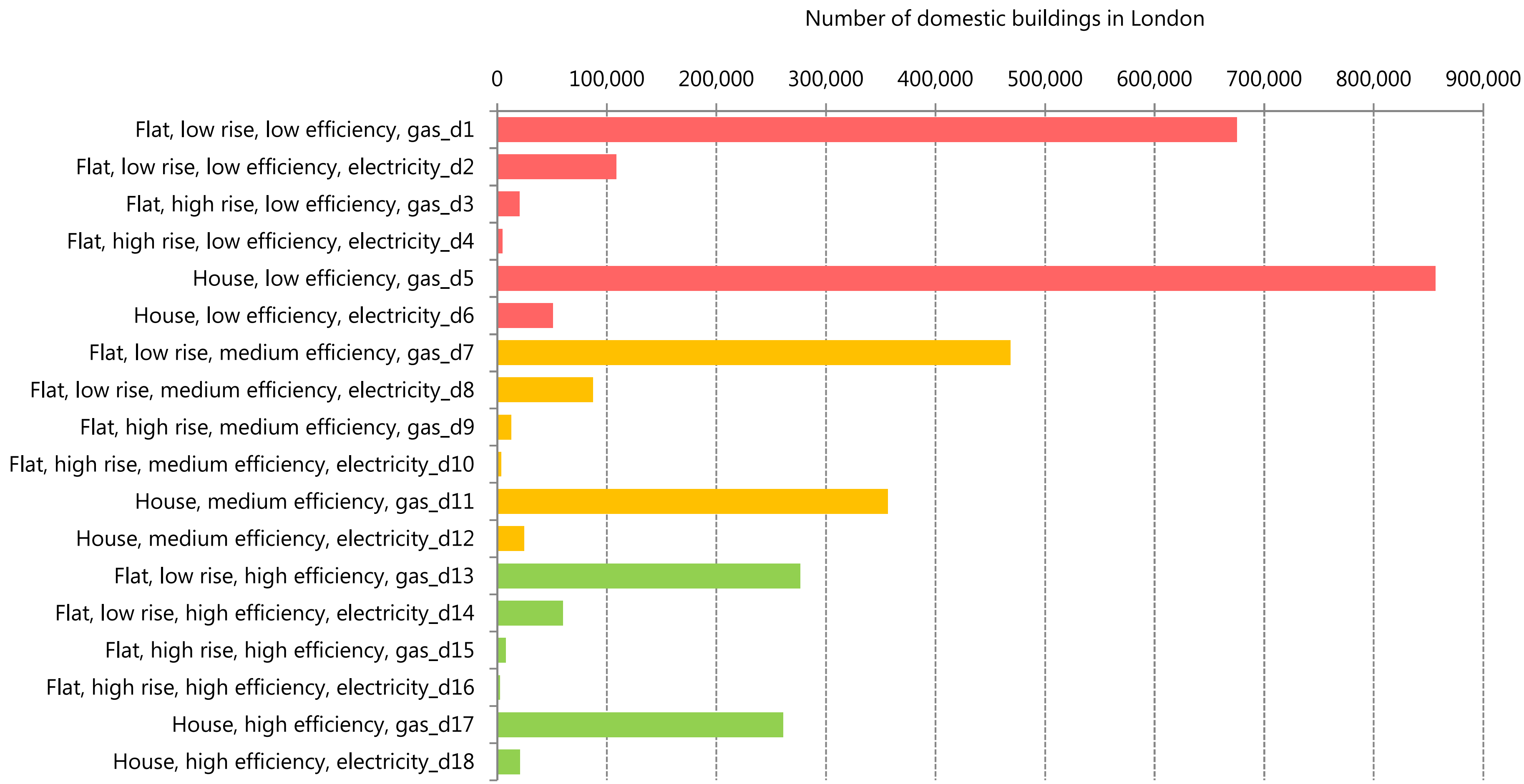
DOMESTIC STOCK DISTRIBUTION



NON-DOMESTIC METHODOLOGY

1: Review of non-domestic datasets

Number of non-domestic buildings

OS data 787,479 addresses
565 address classes
Full coverage of London

VOA data 205,797 addresses
Floor area split by typology

ONS data 461,020 addresses
Total number of businesses

OS data (reduced) 332,511 addresses

Reduced dataset removing:
- Non building addresses
- Overlap of residential datasets
- Unheated buildings

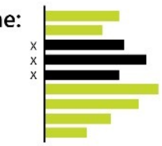
Allocate unallocated commercial based on VOA split between office and retail

Group by OS non-domestic typologies.
Identify most prevalent building types

2: Removal of district heating anchor loads

Removal of anchor loads identified in the DEMaP programme:

- Sport & Leisure facilities
- Central government estate
- Education facilities
- Fire and police stations
- Hotels (>99 units or 4,999 m²)
- Local government estate
- Multi-address buildings
- Museums & Art Galleries
- NHS buildings
- Other public buildings
- Private commercial (> 9,999 m²)
- Private residential (> 149 units or 9,999 m²)
- Buildings currently connected to district heating schemes or supplied by waste heat.



3: Shortlisting of building types using heat demand estimate

EPC data
Average floor area by building typology

CIBSE Guide F
Gas demand benchmarks per m by typology

DUKES
Demand by end use to remove catering loads

4: Development of thermal typologies from selected EPC records

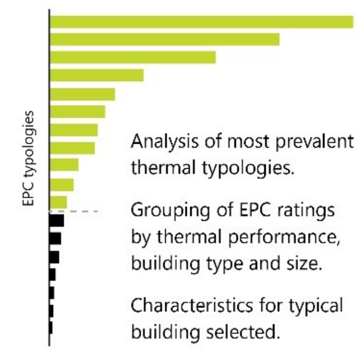
EPC data 60,239 addresses

Heating system
Grid Supplied Electricity (48%)
Natural Gas (47%)
All other (5%)

Property Type
52 property types

EPC rating

Floor area



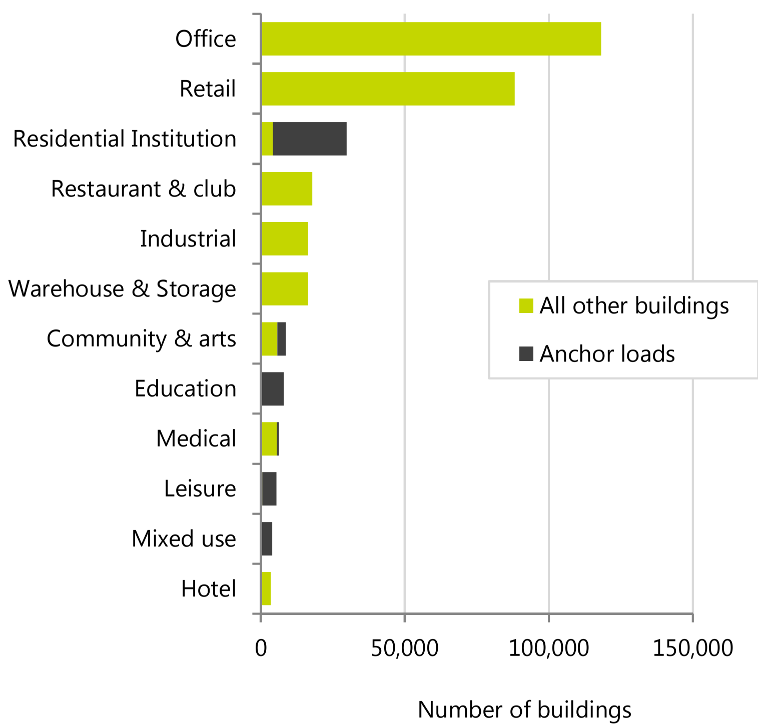
Analysis of most prevalent thermal typologies.

Grouping of EPC ratings by thermal performance, building type and size.

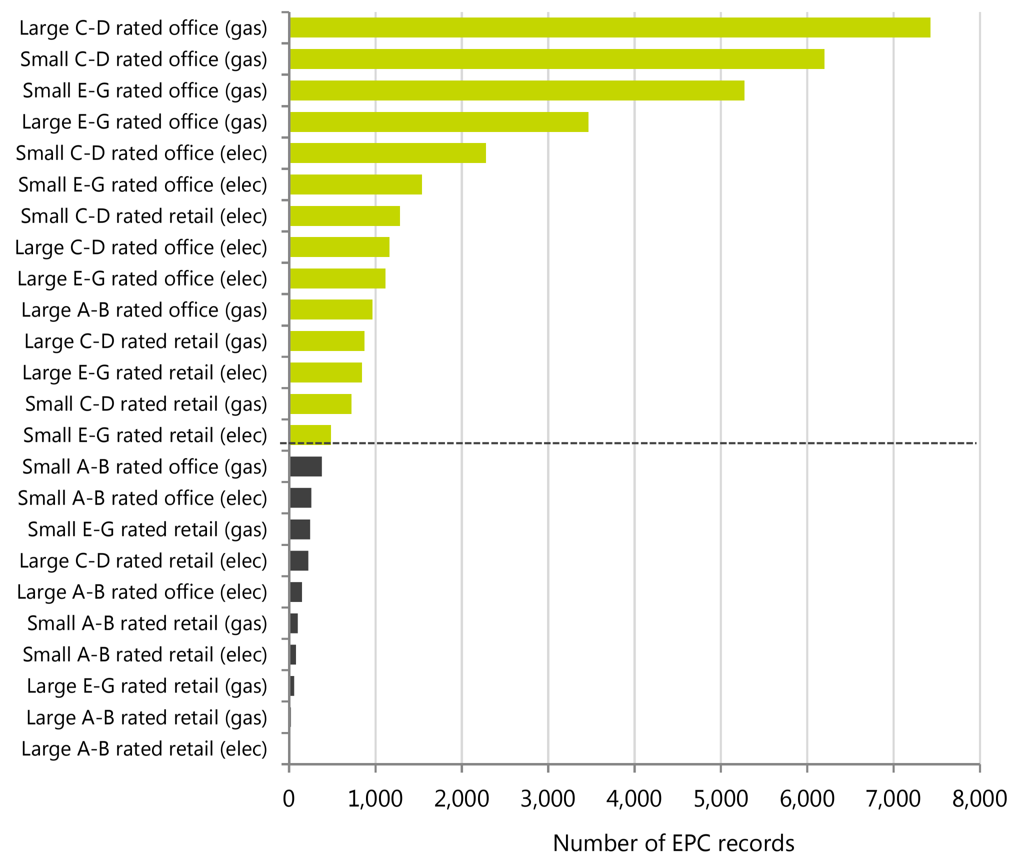
Characteristics for typical building selected.

NON-DOMESTIC PRIORITISATION

Office and retail buildings found to be most significant typologies after removal of district heating anchor loads.



14 typologies found to cover 95% of all office and retail EPC groups



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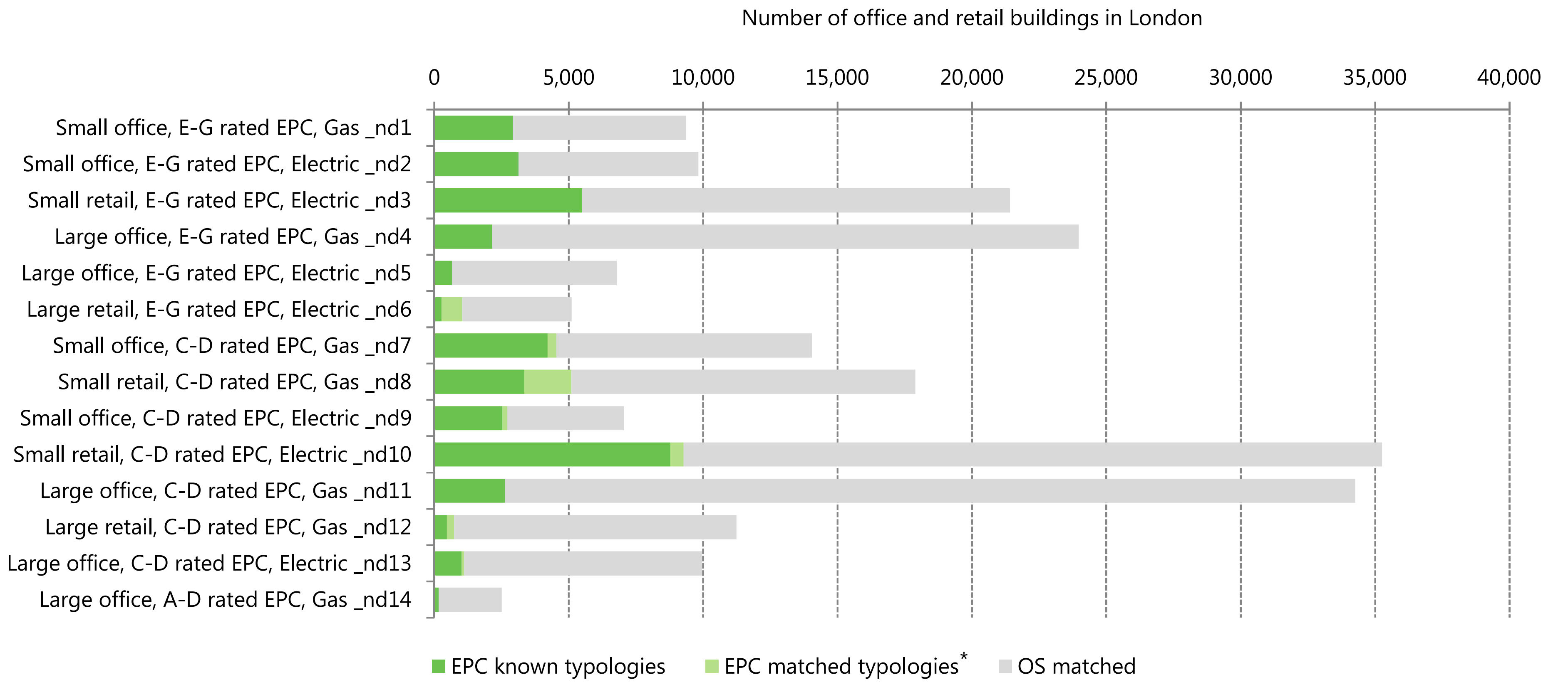
NON-DOMESTIC TYPOLOGIES

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

NON-DOMESTIC STOCK DISTRIBUTION



*Note: 2% of further EPC records were allocated to typologies, based on a review of wider non-domestic EPC records with similar floor areas, ages and heating fuels.

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WORK PACKAGE 1B

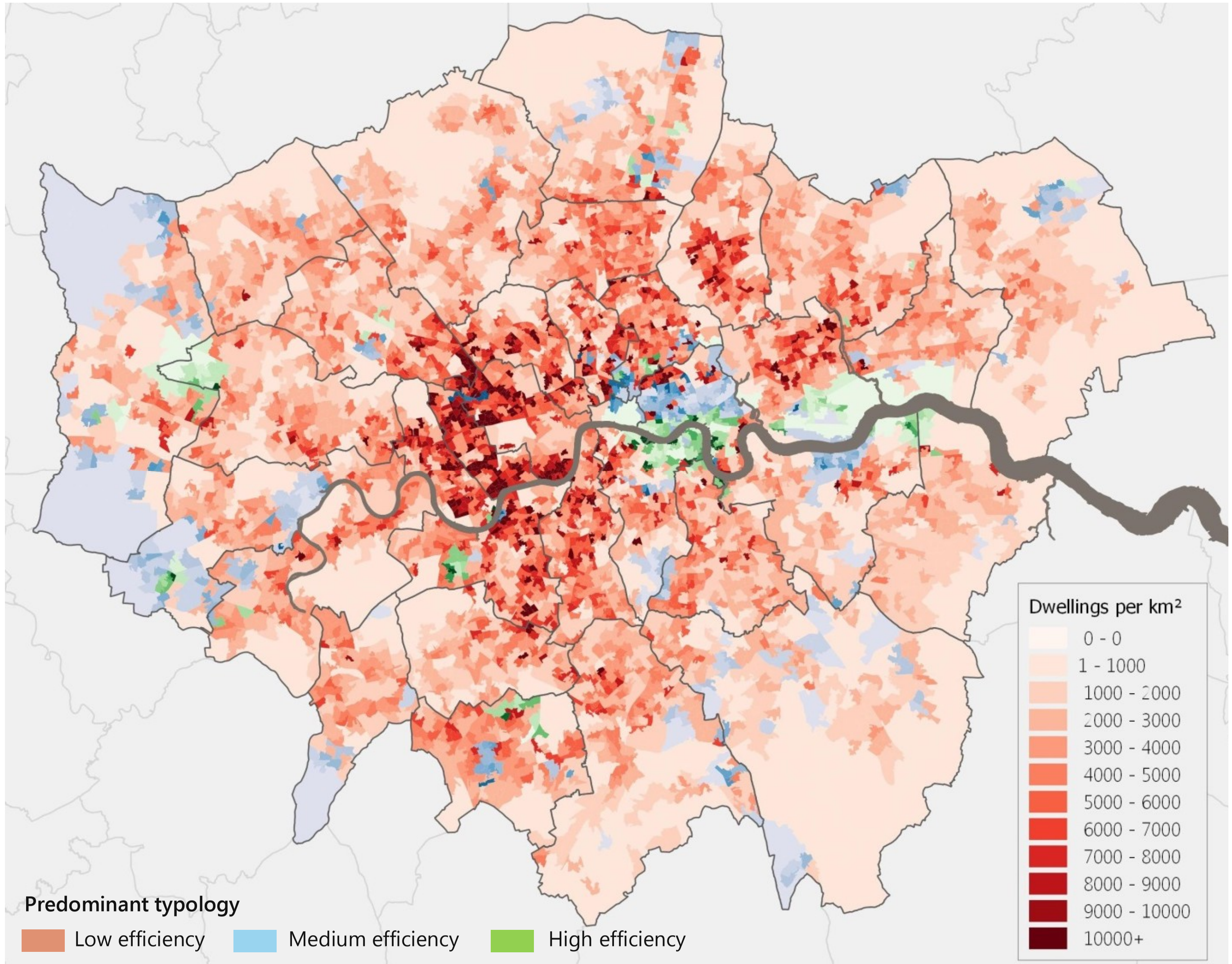
BUILDING TYPOLOGY SPATIAL MAPPING

DOMESTIC SPATIAL MAP

	Low efficiency	#
1	Westminster 011E	1580
2	Newham 013G	1244
3	Hammersmith & Fulham 021C	1224
4	Waltham Forest 018B	1194
5	Hillingdon 027E	1126

	Medium efficiency	#
1	Newham 013G	909
2	Sutton 001D	791
3	Sutton 022B	669
4	Hillingdon 027E	666
5	Croydon 030C	650

	High efficiency	#
1	Sutton 001D	946
2	Tower Hamlets 033C	754
3	Tower Hamlets 032D	725
4	City of London 001F	691
5	Greenwich 002B	665



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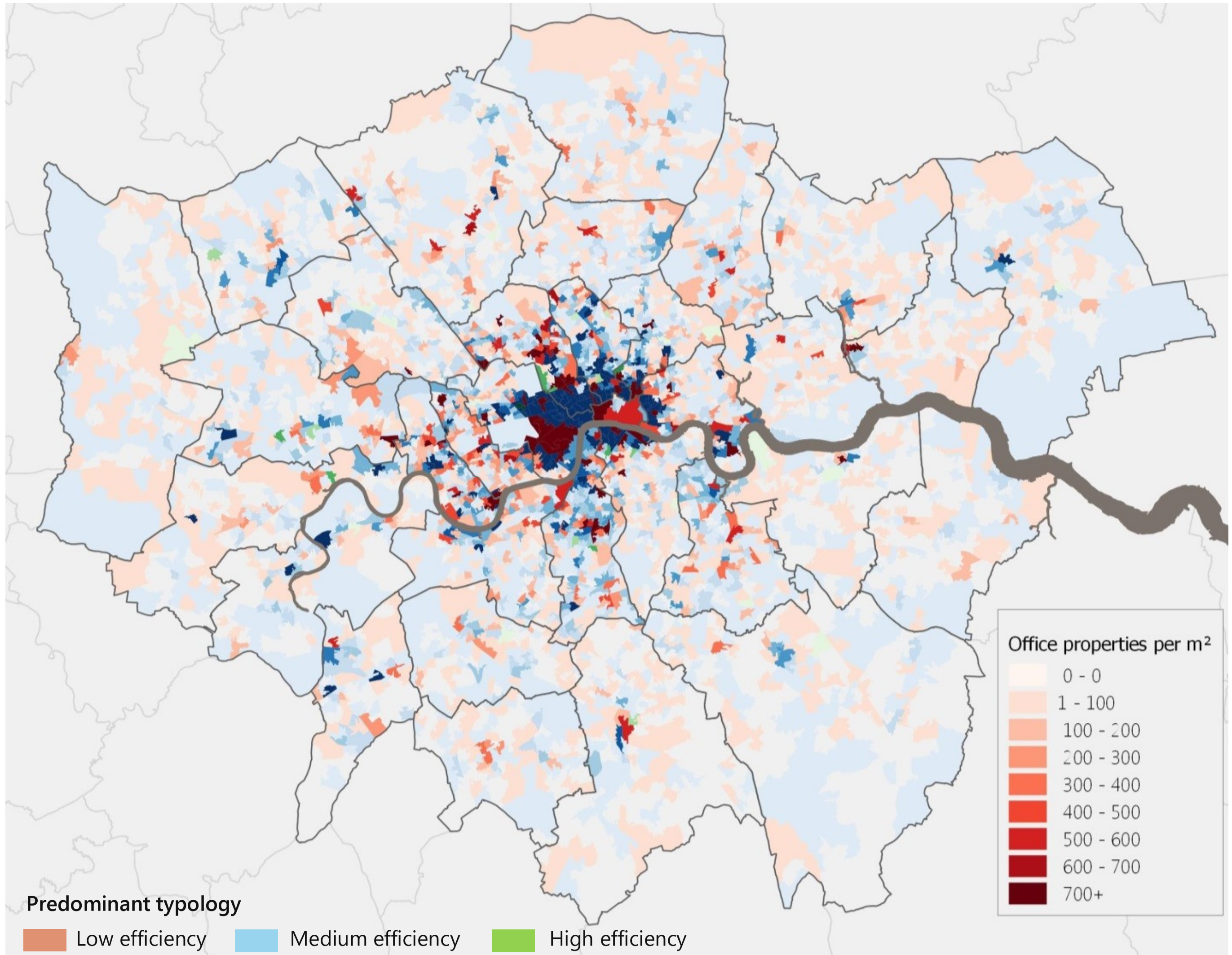
NON-DOMESTIC SPATIAL MAP
(OFFICES)

	Low efficiency	#
1	Westminster 013E	1734
2	Westminster 018D	1203
3	Westminster 018C	1068
4	Westminster 013B	671
5	Hackney 027G	645

	Medium efficiency	#
1	Westminster 013E	1915
2	Westminster 018C	918
3	Westminster 018D	884
4	Westminster 013D	882
5	Brent 022D	882

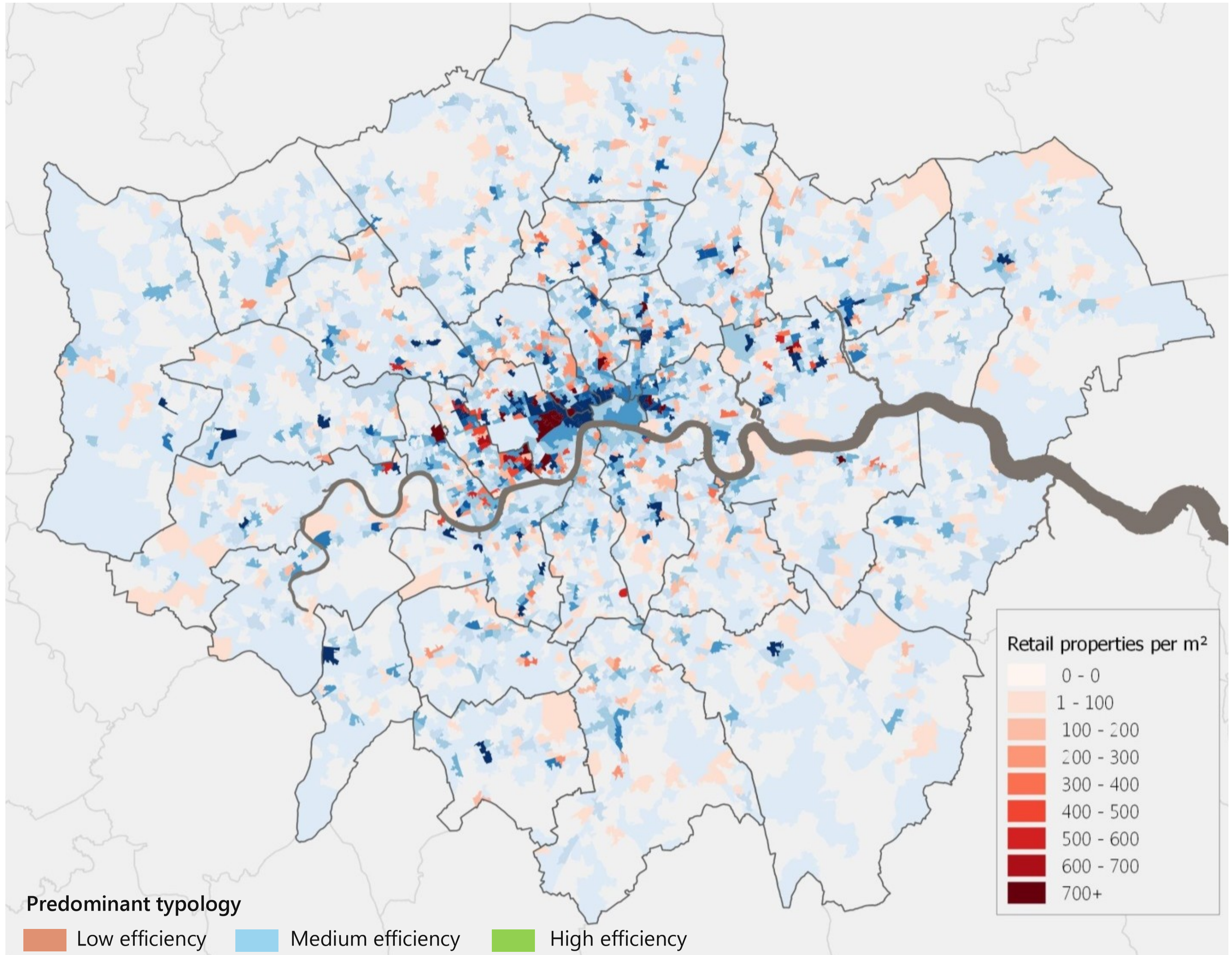
	High efficiency	#
1	Hillingdon 001E	137
2	Bromley 007A	131
3	Westminster 011E	92
4	Bromley 011B	83
5	Wandsworth 027C	81



NON-DOMESTIC SPATIAL MAP
(RETAIL)

	Low efficiency	#
1	Westminster 013E	694
2	Enfield 033C	277
3	Westminster 018D	250
4	Westminster 018C	221
5	Westminster 013D	177

	Medium efficiency	#
1	City of London 001F	538
2	Newham 013G	406
3	Westminster 013E	375
4	Islington 014F	369
5	Brent 024B	346



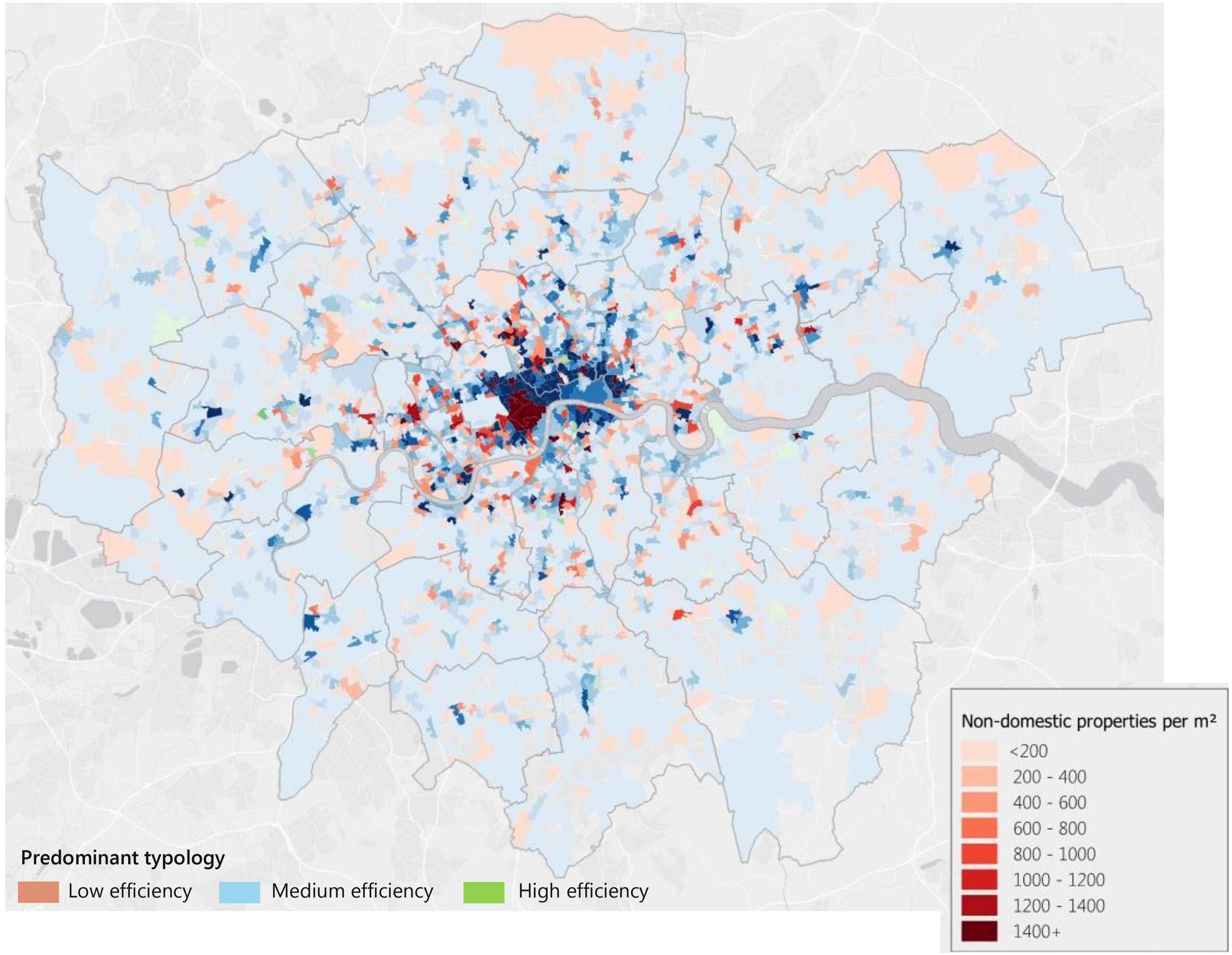
* Note: High efficiency retail was not within the top 95% of office and retail EPCS, so did not form a typology.

NON-DOMESTIC SPATIAL MAP
(OFFICE & RETAIL)

	Low efficiency	#
1	Westminster 013E	2428
2	Westminster 018D	1453
3	Westminster 018C	1289
4	Westminster 013B	785
5	Hackney 027G	710

	Medium efficiency	#
1	Westminster 013E	2290
2	Brent 024B	1223
3	Westminster 018C	1181
4	Westminster 013B	1169
5	Westminster 013D	1163

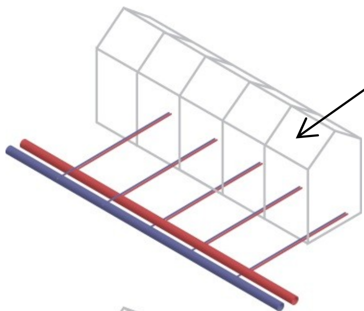
	High efficiency (office only)	#
1	Hillingdon 001E	137
2	Bromley 007A	131
3	Westminster 011E	92
4	Bromley 011B	83
5	Wandsworth 027C	81



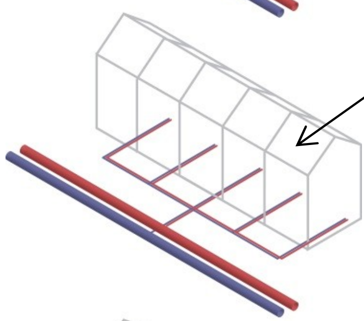
WORK PACKAGE 2A

BUILDING TYPOLOGY RETROFIT REQUIREMENTS

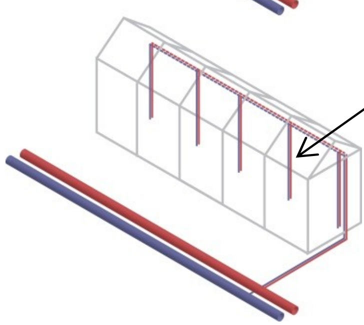
GAS CENTRAL HEATED HOUSE
CONNECTION STRATEGIES



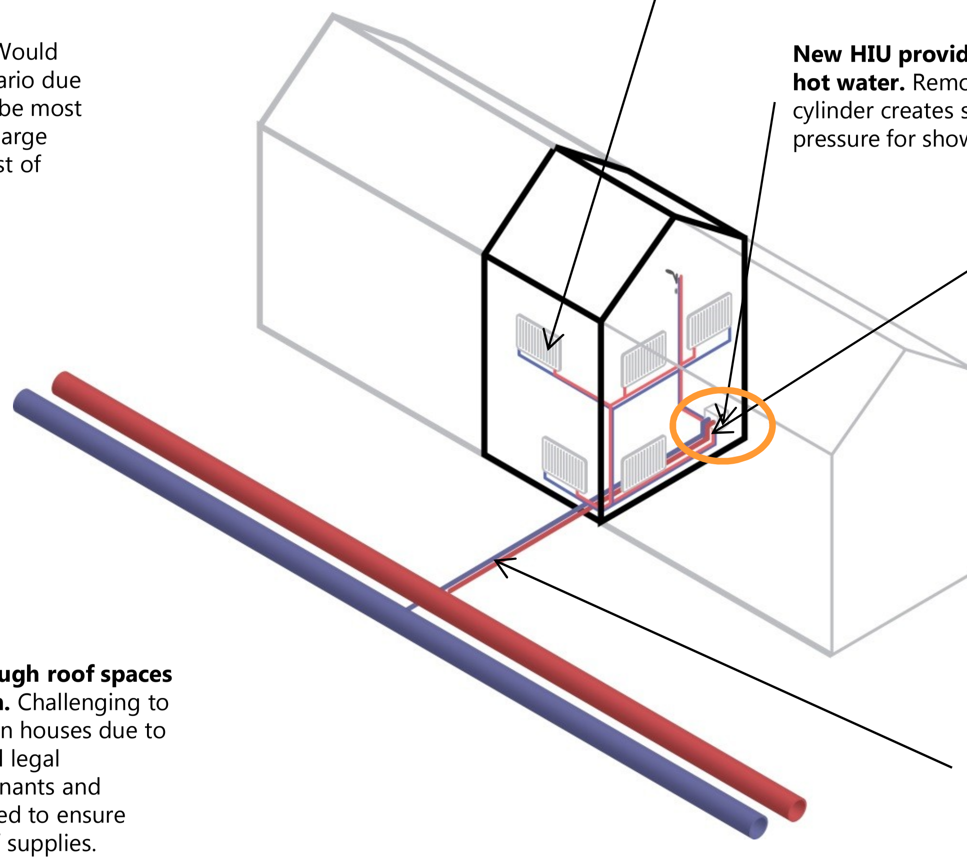
Individual connections. Would represent most likely scenario due to practicality. Unlikely to be most economical solution on a large scale due to additional cost of excavation.



Shared connection to reduce number of main branches. Feasibility likely to increase when multiple houses connect. Possible cross boundary and coordination issues.



Installing pipework through roof spaces to avoid road excavation. Challenging to share connections between houses due to technical, institutional and legal limitations. e.g. legal covenants and wayleaves would be needed to ensure neighbours cannot cut off supplies.



Existing radiators retained. Consideration would need to be given to the radiator sizes in lower temperature networks.

New HIU provides instantaneous hot water. Removing hot water cylinder creates space and provides pressure for shower.

Gas boiler replaced with HIU. Packaged unit with new secondary pump, control valves and heat meter on primary side. Indirect connection to reduce risk of contamination and leakage.

Connection to district network. Pipe rises up and enters into house. Excavation of trench, back-filling and re-instatement of surfaces required.

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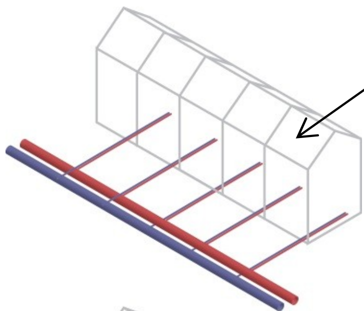
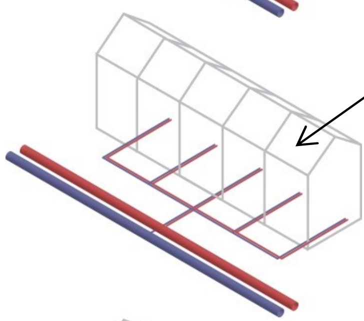
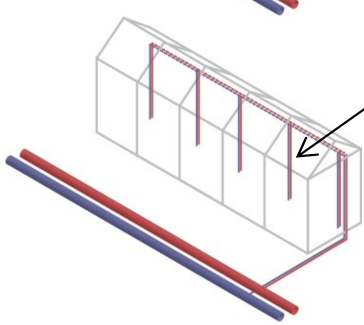
ELECTRICALLY HEATED HOUSE
CONNECTION STRATEGIES



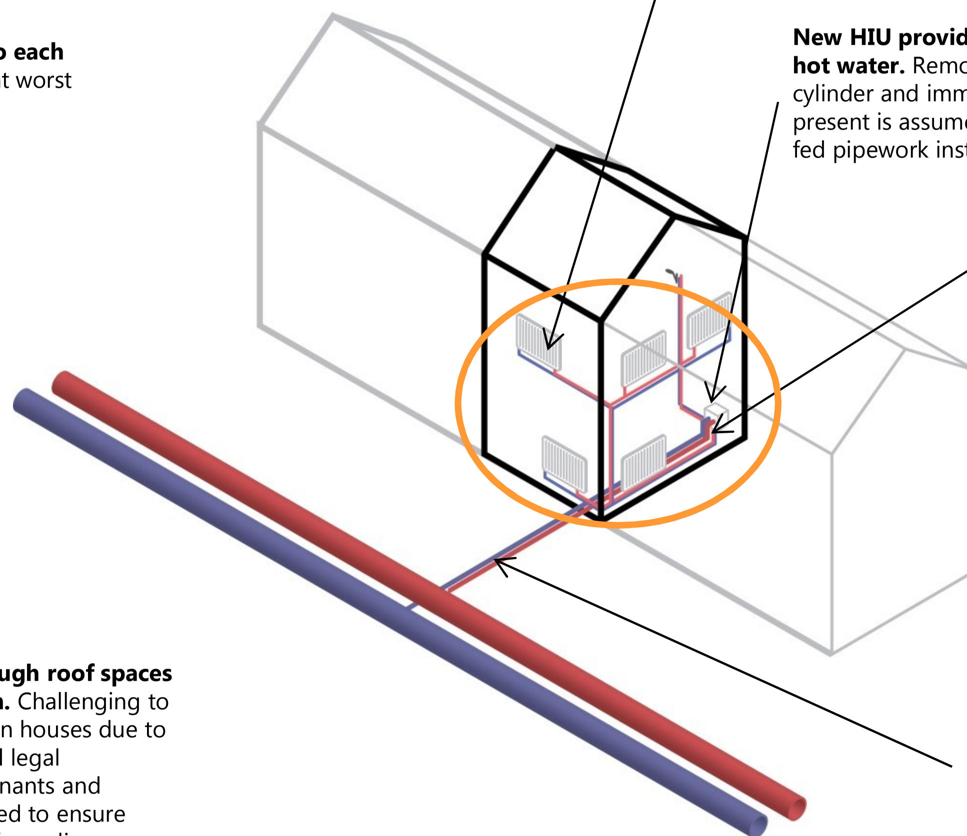
Individual connections to each property. Would represent worst case scenario.



Shared connection to reduce number of main branches. Feasibility likely to increase when multiple houses connect. Possible cross boundary and coordination issues.



Installing pipework through roof spaces to avoid road excavation. Challenging to share connections between houses due to technical, institutional and legal limitations. e.g. legal covenants and wayleaves would be needed to ensure neighbours cannot cut off supplies.



New wet radiator system installed. Heating controls including TRV (thermostatic radiator valves), timer and a central thermostat provided.

New HIU provides instantaneous hot water. Removal of the DHW cylinder and immersion heater if present is assumed, with new mains fed pipework installed to the HIU.

New HIU installed. Packaged unit with new secondary pump, control valves and heat meter on primary side. Indirect connection to reduce risk of contamination and leakage.

Connection to district network. Pipe rises up and enters into house. Excavation of trench, back-filling and re-instatement of surfaces required.

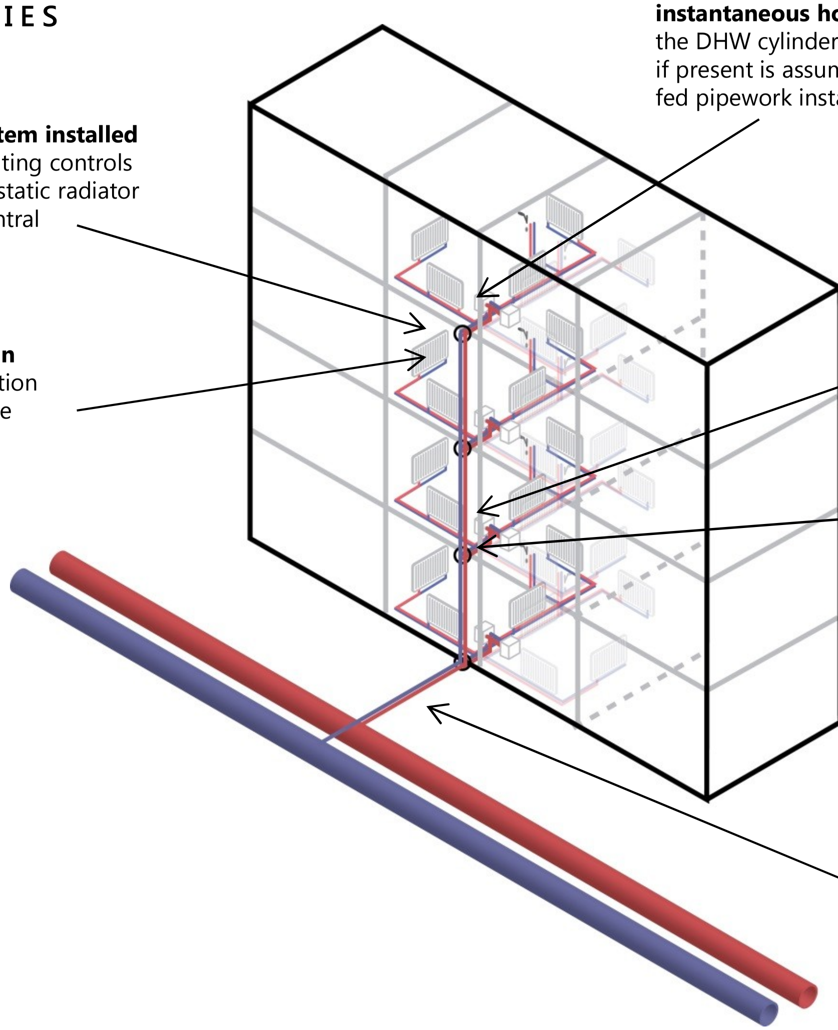
BUROHAPPOLD ENGINEERING

LOW RISE CONVERTED FLATS

CONNECTION STRATEGIES

New wet radiator system installed in ELECTRIC flats. Heating controls including TRV (thermostatic radiator valves), timer and a central thermostat provided.

Existing radiators retained in GAS heated flats. Consideration would need to be given to the radiator sizes in lower temperature networks.



New HIU in each flat provides instantaneous hot water. Removal of the DHW cylinder and immersion heater if present is assumed, with new mains fed pipework installed to the HIU.

Pre-insulated pipework mounted externally to façade.

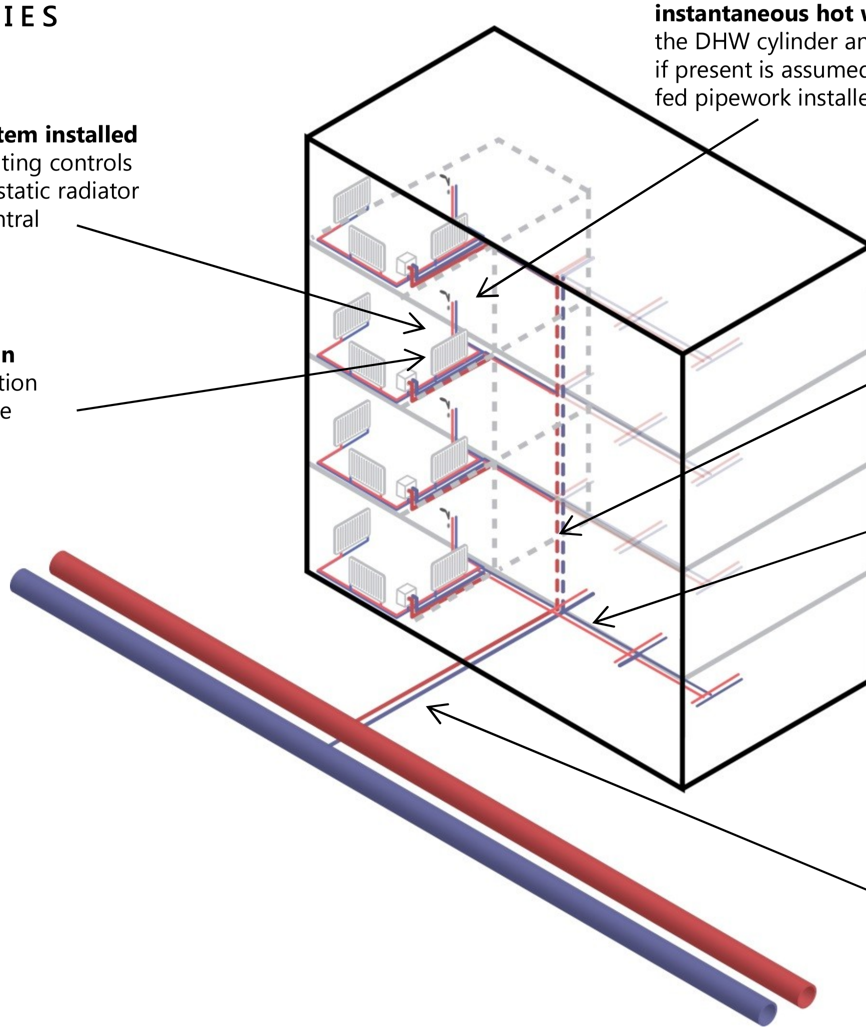
Penetrations per level. Enter into building floor plates. Two adjacent flats served together to reduce pipework.

Connection to district network. Pipe rises up and enters into flat Excavation of trench, back-filling and re-instatement of surfaces required.

BUROHAPPOLD ENGINEERING

LOW RISE PURPOSE BUILT FLATS

CONNECTION STRATEGIES



New HIU in each flat provides instantaneous hot water. Removal of the DHW cylinder and immersion heater if present is assumed, with new mains fed pipework installed to the HIU.

New wet radiator system installed in ELECTRIC flats. Heating controls including TRV (thermostatic radiator valves), timer and a central thermostat provided.

Existing radiators retained in GAS heated flats. Consideration would need to be given to the radiator sizes in lower temperature networks.

Internal riser. Core drilling required.

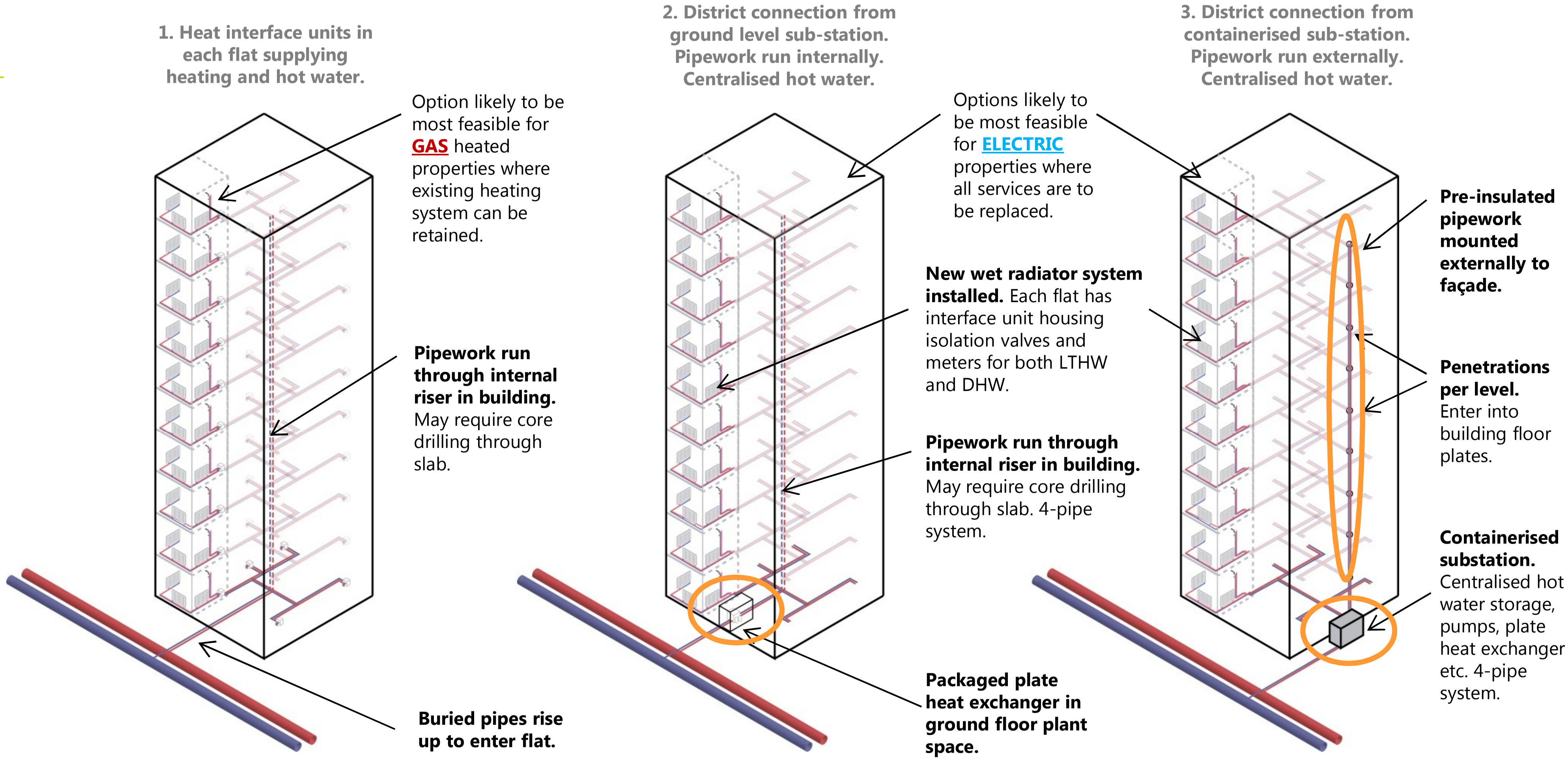
Pipework routed internally. Insulated pipework runs internally and along corridors.

Connection to district network. Pipe rises up and enters into flat Excavation of trench, back-filling and re-instatement of surfaces required.

BUROHAPPOLD ENGINEERING

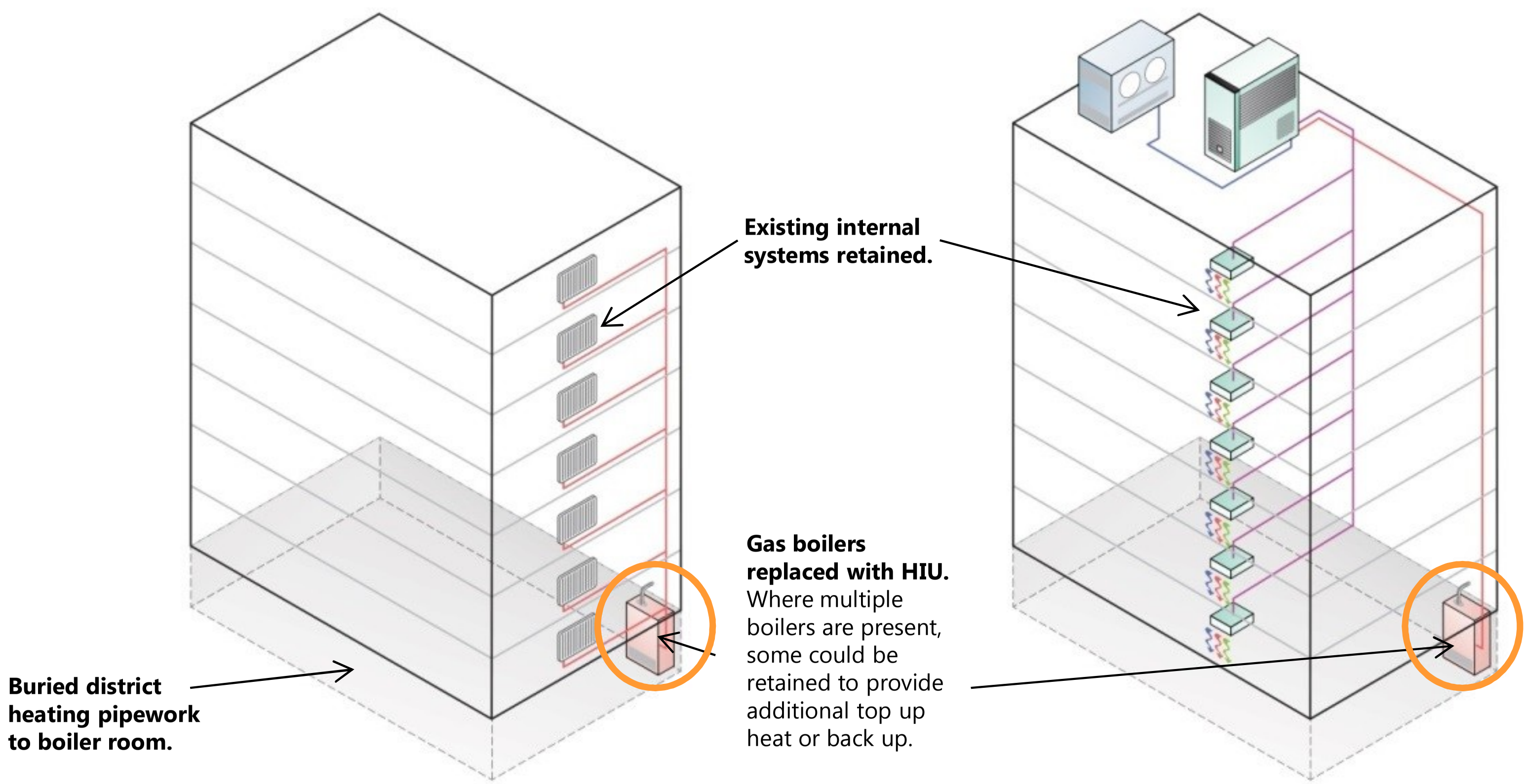
HIGH RISE FLATS
CONNECTION STRATEGIES

Every 60-80m would require hydraulic separation



BUROHAPPOLD ENGINEERING

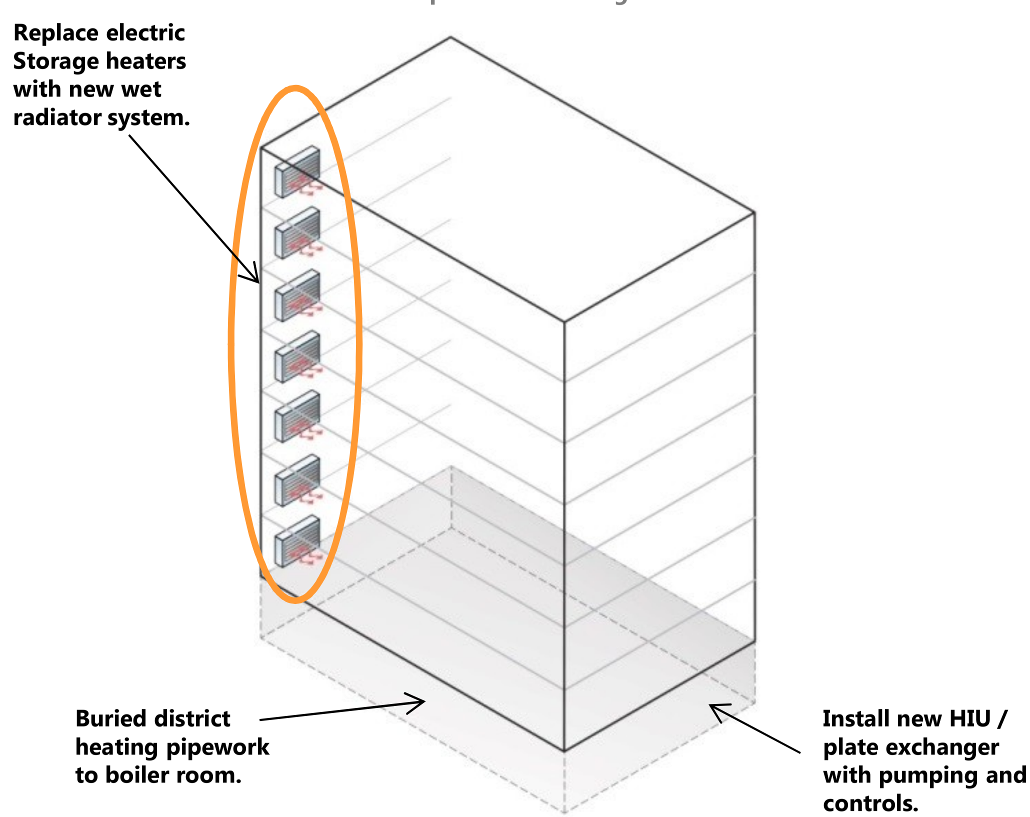
NON-DOMESTIC BUILDINGS
WITH CENTRAL GAS BOILER

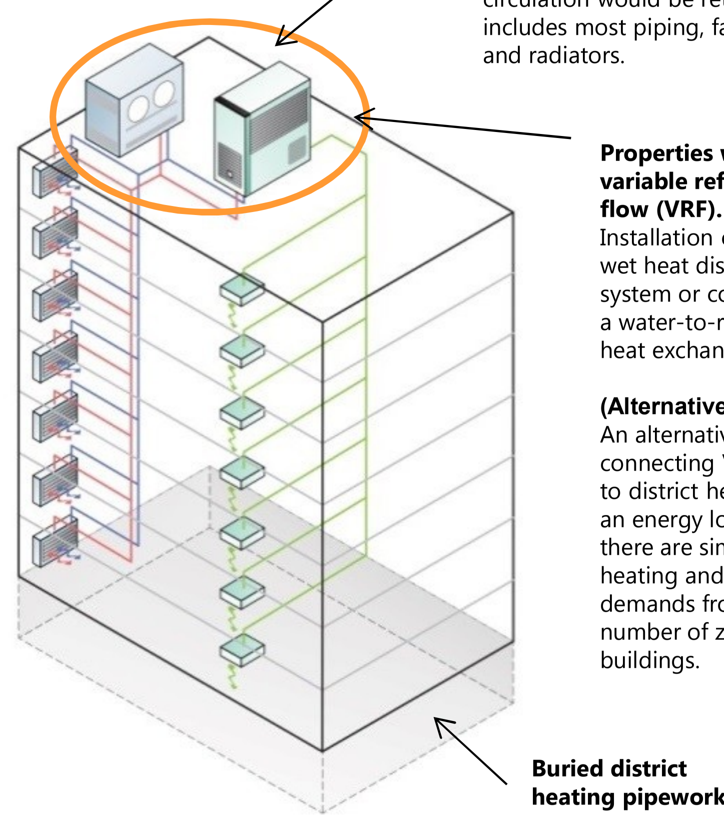


BUROHAPPOLD ENGINEERING

NON-DOMESTIC BUILDINGS

WITH ELECTRIC HEATING SYSTEMS





Properties with electric heat pumps. District heating will most likely require a riser to bring the connection to heat pumps (typically at roof level). Existing secondary circulation would be retained. This includes most piping, fan coil units and radiators.

Properties with variable refrigerant flow (VRF).
Installation of a parallel wet heat distribution system or connection of a water-to-refrigerant heat exchanger.

(Alternative approach)
An alternative option for connecting VRF systems to district heating is via an energy loop , where there are simultaneous heating and cooling demands from a number of zones within buildings.

BUROHAPPOLD ENGINEERING

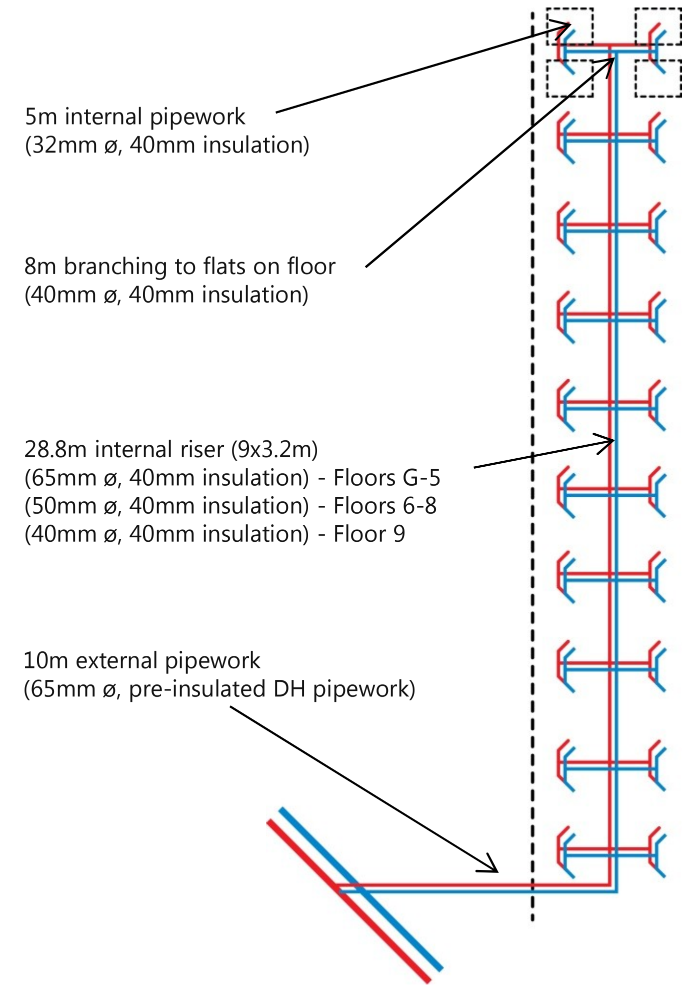
WORK PACKAGE 2B

BUILDING TYPOLOGY COST MODELLING

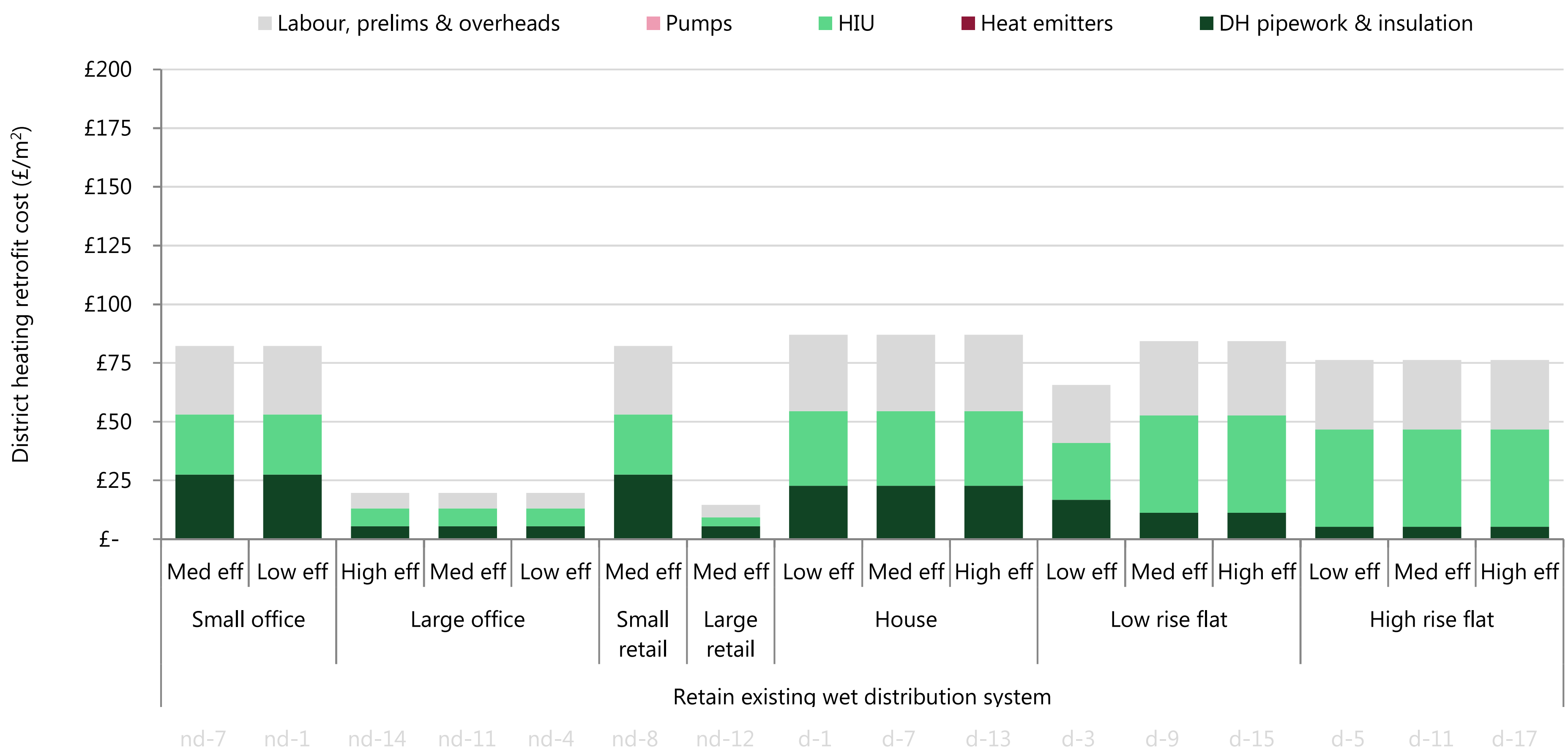
OVERVIEW

- For each typology, the cost to connect to district heating was calculated, using reference values and BuroHappold experience.
- In order to support the capital costing exercise, indicative district heating pipework layouts were produced for each typology together with pipe sizing calculations (see example to the right).
- The scope of the costing exercise only includes costs from the property boundary, and excludes the wider DH network infrastructure.
- Traffic management costs have been excluded from the costing exercise. Furthermore, efficiency savings from shared district heating connections are not included, so as to provide conservative cost estimates. Value Added Tax (VAT) is excluded.
- Costs for builders' works, contractor preliminaries and overheads and labour are included. This includes the removal of existing systems and making good of surfaces etc.

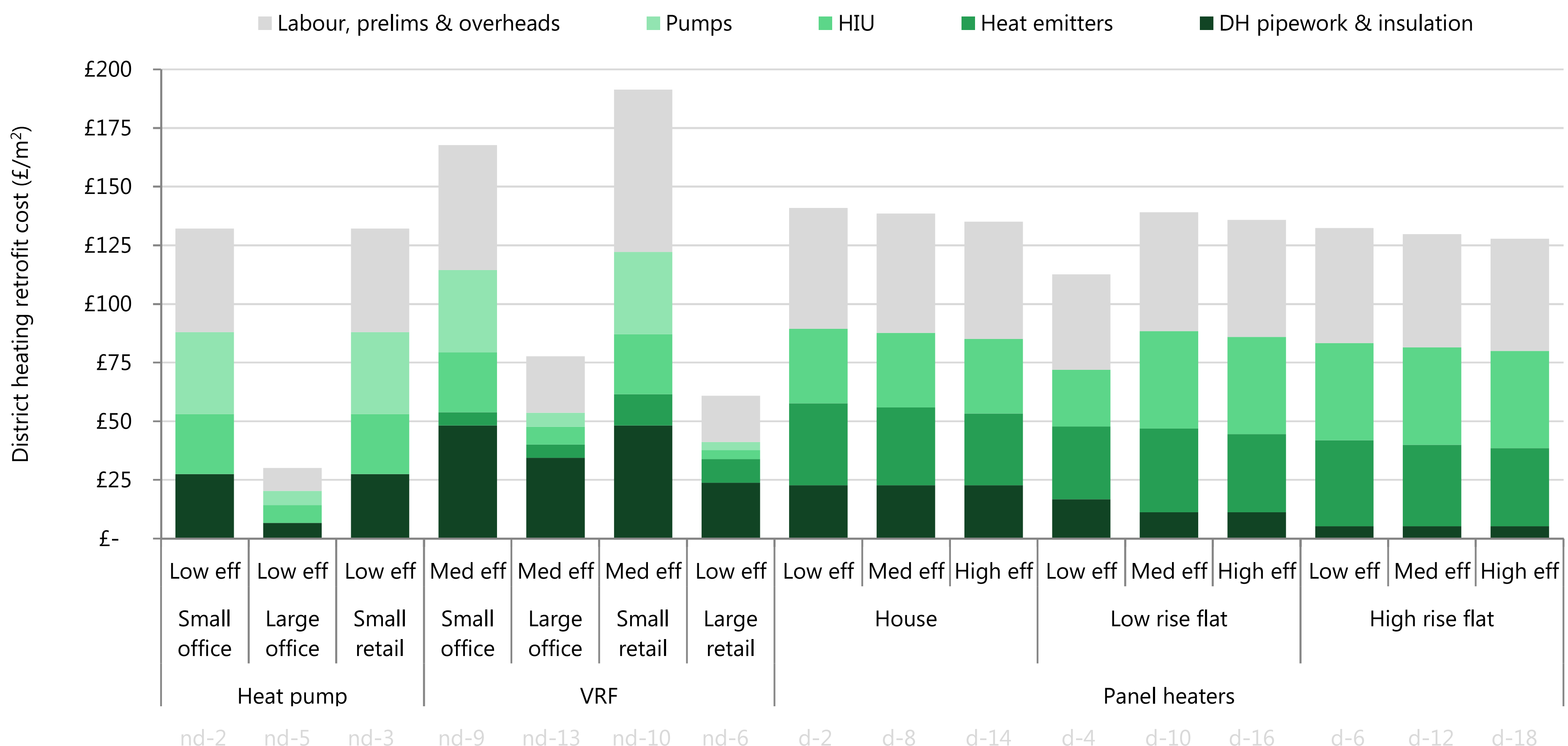
District heating pipework and insulation sizing
High rise flat – heating provided by HIU)



CAPITAL COSTING
GAS CONVERSION



CAPITAL COSTING
ELECTRIC CONVERSION



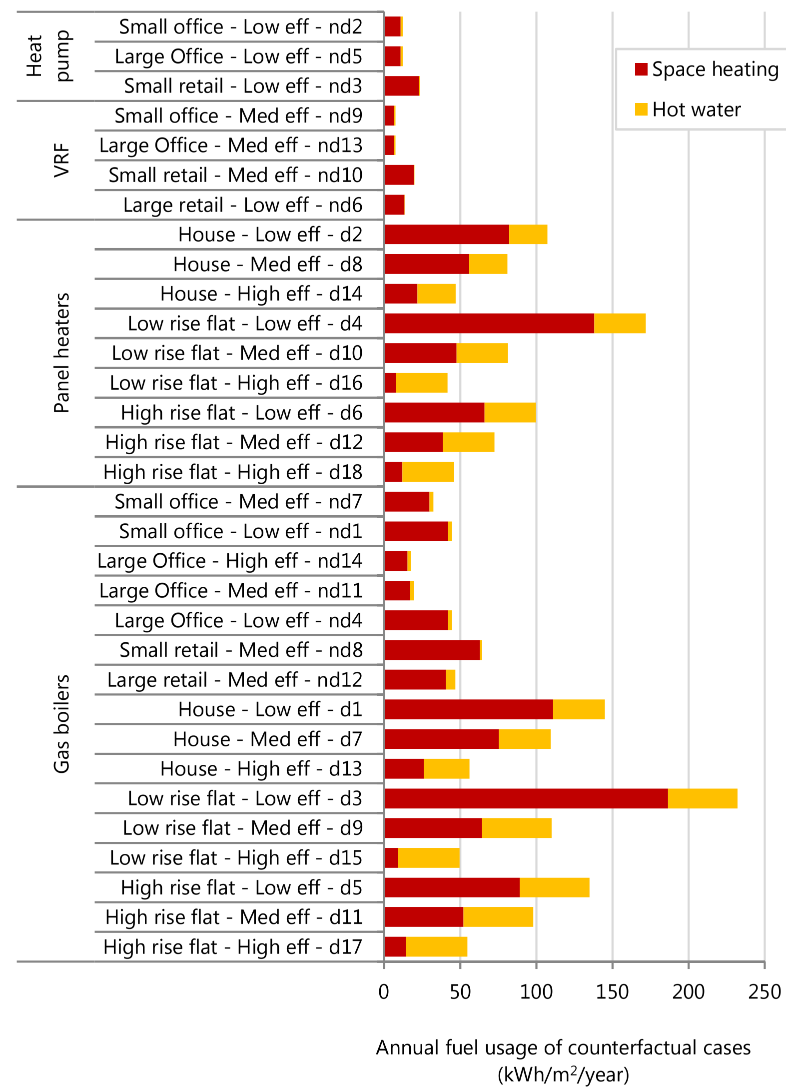
BUROHAPPOLD ENGINEERING

WORK PACKAGE 3A

COST EFFECTIVENESS & SPATIAL MAPPING

OVERVIEW

- Cost effectiveness of DH has been determined based upon a discounted payback calculation versus a counterfactual case, e.g. the annualised capital and running costs of a gas boiler / electric heating system.
- The calculation compared costs of retrofitting the various typologies against each other to determine a relative cost effectiveness of retrofit across the 32 typologies.
- Baseline energy use (shown to the right) was calculated using Strathclyde University ESP-r dynamic modelling software.
- The assessment of cost effectiveness is determined based upon whether a 30 year payback can be achieved across the range of indicative heat retail prices. High cost effectiveness is taken as less than 15 years.
- Outputs illustrate relative attractiveness of each typology and not a detailed network operator investment calculation. No market interventions, subsidies or additional policy interventions are assumed in the calculation.



BUROHAPPOLD ENGINEERING

COST EFFECTIVENESS

Payback period of district heating retrofit vs. a counterfactual scenario of a gas boiler or electric heating system. Results assessed against range of indicative DHN retail price scenarios.

		DH 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)
Archetype			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	Lowrise 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	Lowrise 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	Lowrise 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	11	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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£25
	nd-1	Small office - Low eff. - Gas boilers	64	81	n/a	n/a	n/a	n/a	n/a	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£100
	nd-14	Large Office - High eff. - Gas boilers	45	87	n/a	n/a	n/a	n/a	n/a	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£55
	nd-11	Large Office - Med eff. - Gas boilers	35	50	n/a	n/a	n/a	n/a	n/a	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£52
	nd-4	Large Office - Low eff. - Gas boilers	19	29	73	n/a	n/a	n/a	n/a	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£37
	d-1	House - Low eff. - Gas boilers	18	20	23	28	35	47	83	n/a	n/a	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£66
	d-7	House - Med eff. - Gas boilers	22	24	28	33	41	54	91	n/a	n/a	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£74
	d-13	House - High eff. - Gas boilers	35	40	46	56	72	n/a	n/a	n/a	n/a	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£106
	d-3	Lowrise flat - Low eff. - Gas boilers	16	17	19	21	22	24	32	54	n/a	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£63
	d-9	Lowrise flat - Med eff. - Gas boilers	17	18	20	23	26	30	36	46	65	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£85
	d-15	Lowrise flat - High eff. - Gas boilers	25	26	28	31	34	37	42	48	57	72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£140
	d-5	High rise flat - Low eff. - Gas boilers	13	14	16	18	21	24	29	38	54	n/a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£77
	d-11	High rise flat - Med eff. - Gas boilers	15	17	18	20	23	26	30	36	45	63	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	£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

Large electric heated offices and low efficiency flats show highest cost effectiveness.

Gas heated properties only found to be cost effective at retail heat prices less than market rate (circa 6-7p/kWh including fixed costs). High rise flats seen to be most cost effective.

Total counterfactual cost divided by total energy use. Costs based on:
- Annual running cost
- Annual O&M cost
- Annualised capital cost assessed with 15 year replacement cycle.

SUBSIDIES

Counterfactual cost payback calculations, re-run with reduced capital costs

			DH heat retail price fixed at £60/MWh							
			0% Capital funding		20% Capital funding		40% Capital funding		60% Capital funding	
			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

Table illustrates how cost effectiveness, assessed against a fixed district heating heat retail price, in this case £60/MWh, can be improved with increasing levels of capital grant funding obtained

With capital funding set at a level of 20% to 40% all low and medium efficiency electrically heated domestic properties can achieve high cost effectiveness at £60/MWh.

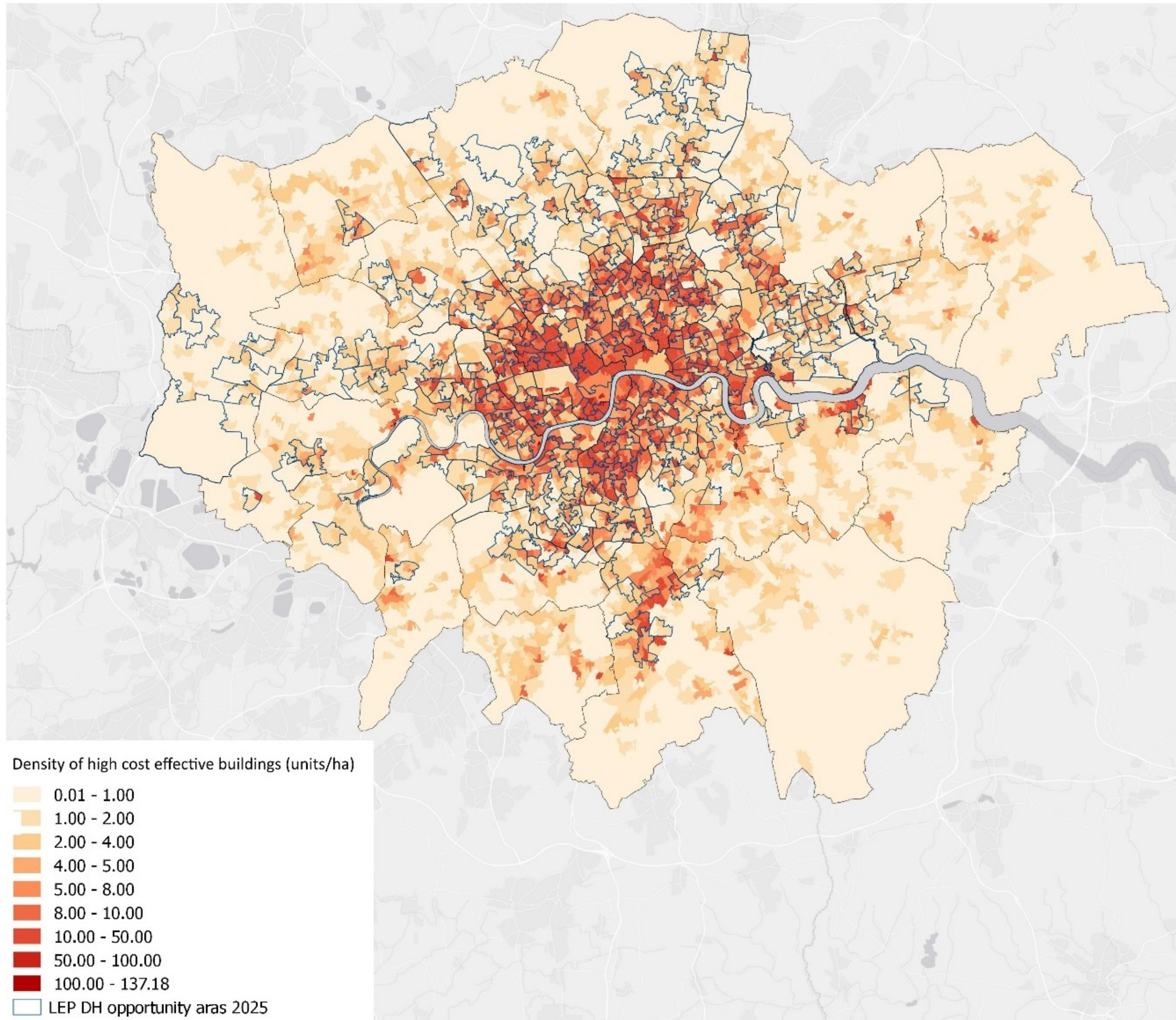
With capital funding reaching 60% low and high rise gas heated flats can achieve high cost effectiveness. At this level of funding, low and medium efficiency houses can also achieve medium levels of cost effectiveness too.

HIGH COST EFFECTIVE BUILDINGS

	Domestic	#/ha
1	Tower Hamlets 032D	136
2	Westminster 021B	116
3	Hammersmith & Fulham 023E	109
4	Southwark 003K	102
5	Tower Hamlets 028H	99

	Non-domestic	#/ha
1	Brent 015A	18
2	Hackney 027G	12
3	Westminster 016B	11
4	Westminster 013E	11
5	Brent 022D	11

	Combined	#/ha
1	Tower Hamlets 032D	137
2	Westminster 021B	117
3	Hammersmith & Fulham 023E	109
4	Southwark 003K	102
5	Tower Hamlets 028H	99



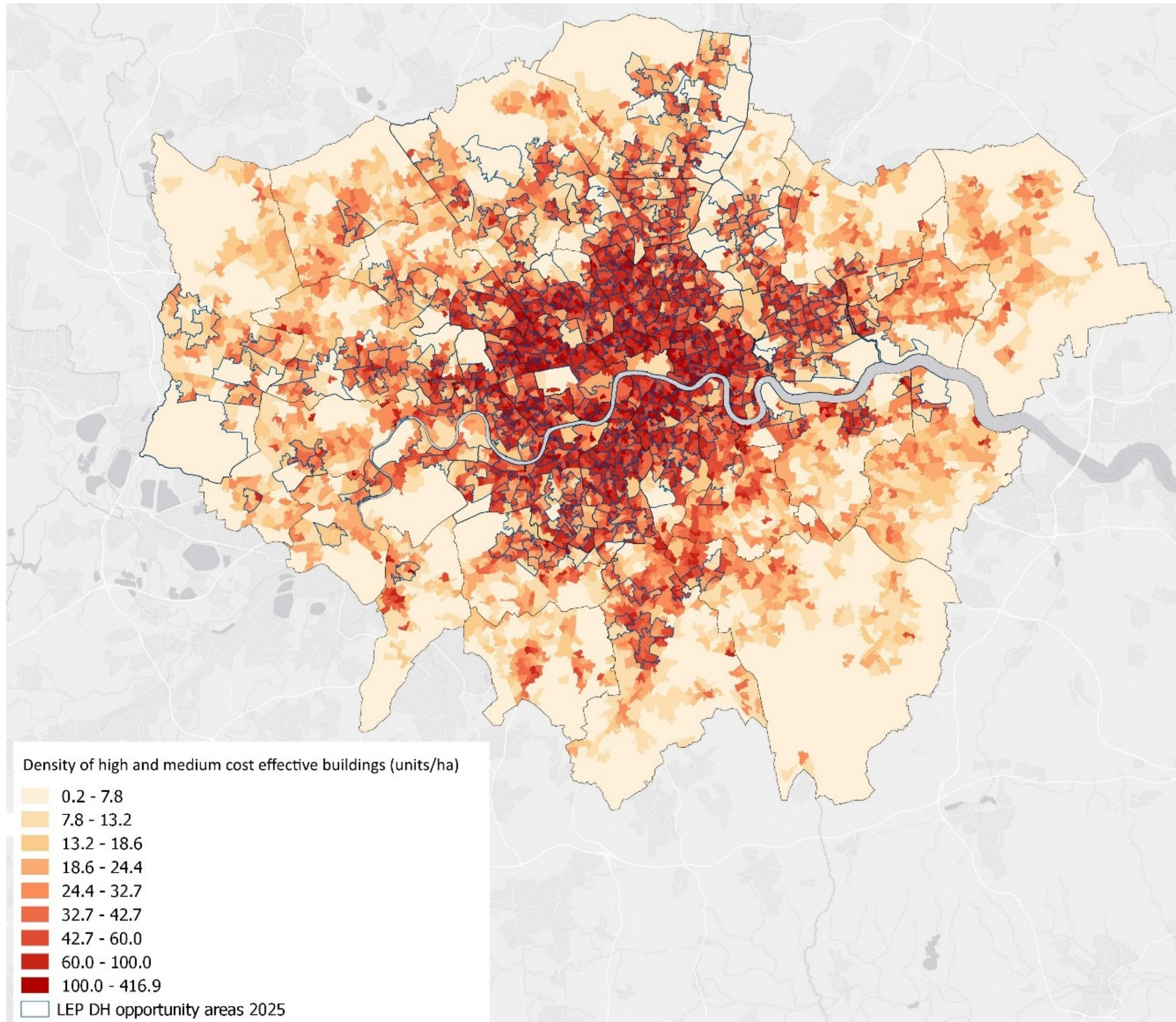
BUROHAPPOLD ENGINEERING

HIGH & MEDIUM COST EFFECTIVE BUILDINGS

	Domestic	#/ha
1	Tower Hamlets 032D	415
2	Westminster 024E	357
3	Tower Hamlets 028H	342
4	Hounslow 010B	342
5	Hounslow 014B	316

	Non-domestic	#/ha
1	Westminster 013E	40
2	Brent 022D	35
3	Brent 024D	34
4	Westminster 018D	27
5	Westminster 013B	26

	Combined	#/ha
1	Tower Hamlets 032D	417
2	Westminster 024E	359
3	Tower Hamlets 028H	343
4	Hounslow 010B	342
5	Hounslow 014B	317



WORK PACKAGE 3A

PILOT STUDY

OVERVIEW

- Each pilot area contains two MSOAs (Middle Super Output Area) with 2,000-6,000 households. Cost effectiveness is illustrated at Census output area, equivalent to circa 40-250 households.
- Census output area data was used for number of buildings, property type, heating system and building height. Information such as wall construction was not readily available for the analysis. Furthermore, EPC coverage was not significant enough to map to all areas. As such, data was extrapolated for these parameters based on previous information gathered for the LSOA studies.
- The proof of concept model for pre-feasibility showed good potential for identifying architectures of high cost effectiveness. It is recommended that 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 supporting pre-feasibility studies and energy masterplanning and capable of inputting into feasibility studies.

Non-domestic buildings

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 WP1	Building type and thermal typologies for all office and retail as percentages
Addressing	London Datastore Statistical GIS Boundary Files	OAs GIS shapefiles

Domestic buildings

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.

Additional GIS layers

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

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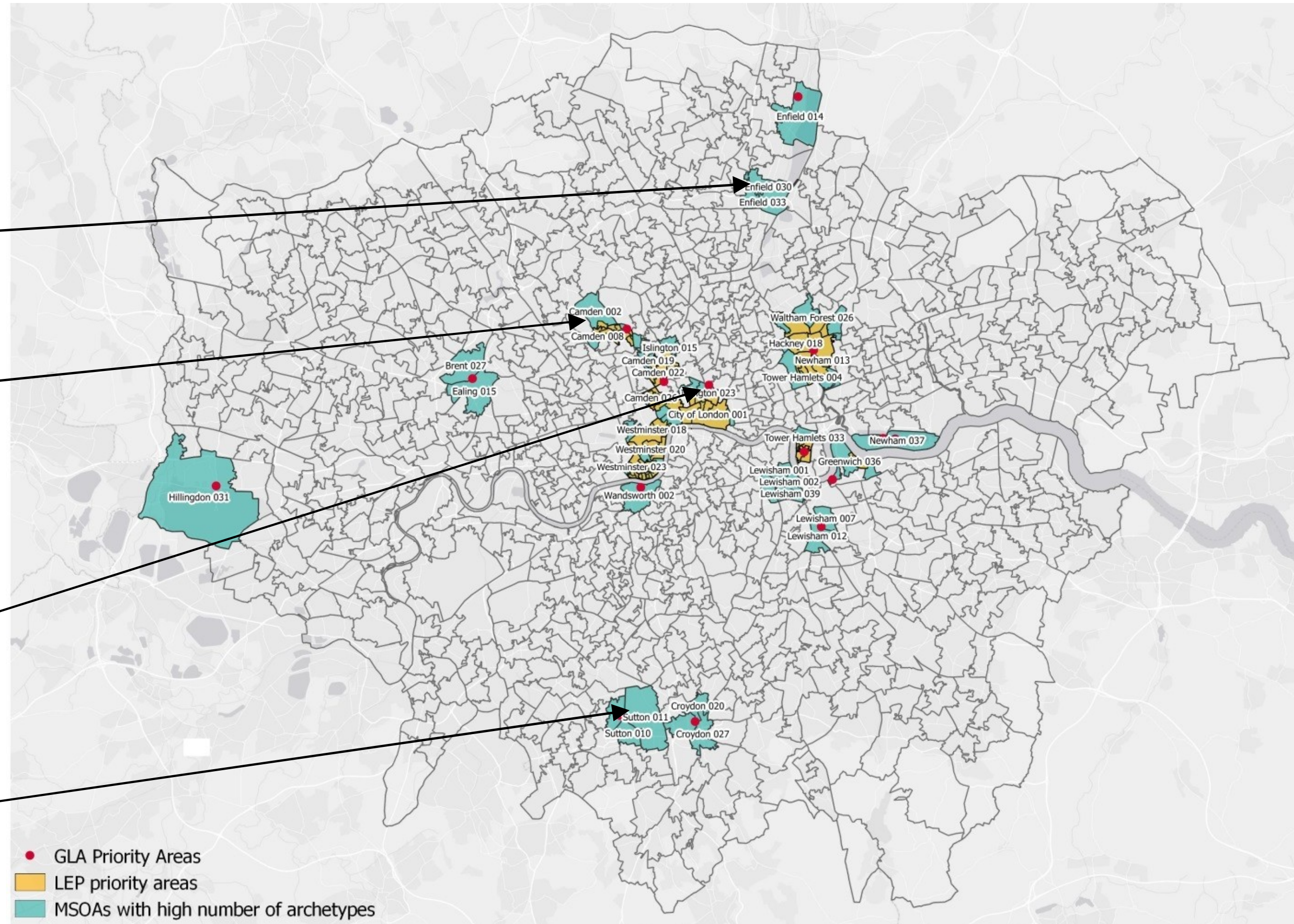
PILOT STUDY SITES SELECTED BY GLA

Two adjacent MSOAs for:

- **Lea Valley Enfield (030/033)**
  Including an 18 MW energy from waste CHP plant.
- **Gospel Oak Camden (002/008)**
  Including the Gospel Oak heat network which utilises surplus heat generated by the Royal Free Hospital.
- **Old Street Islington (022/023):**
  Including the Bunhill Energy Centre and the E.On Citigen CHP site.
- **Beddington Sutton (010/011):**
  Including a waste to energy plant being built with ~20 MW heat energy potential.



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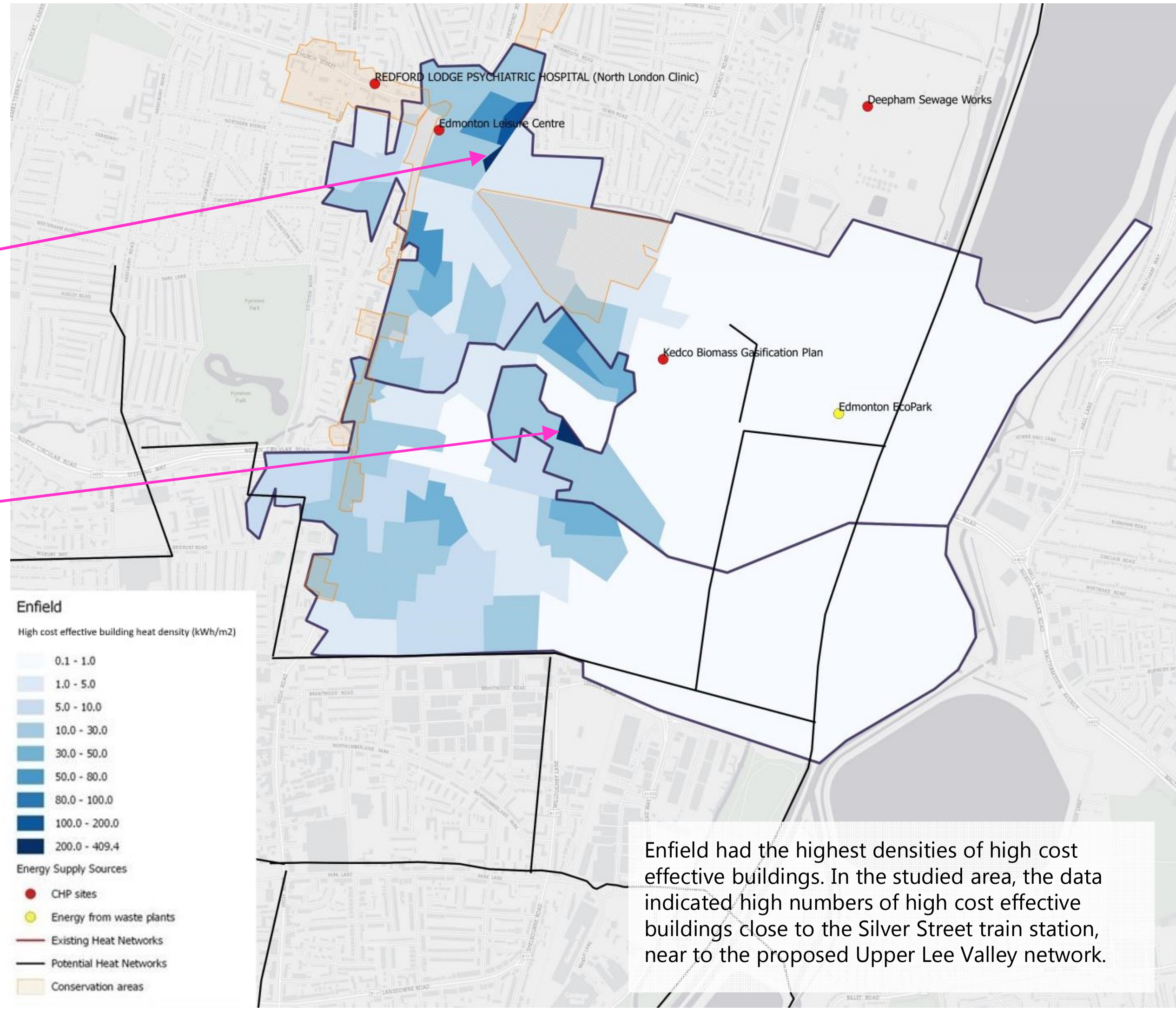
LEA VALLEY
ENFIELD (030/033)

Example high rise flats in area

Example high rise flats in area



Enfield had the highest densities of high cost effective buildings. In the studied area, 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.

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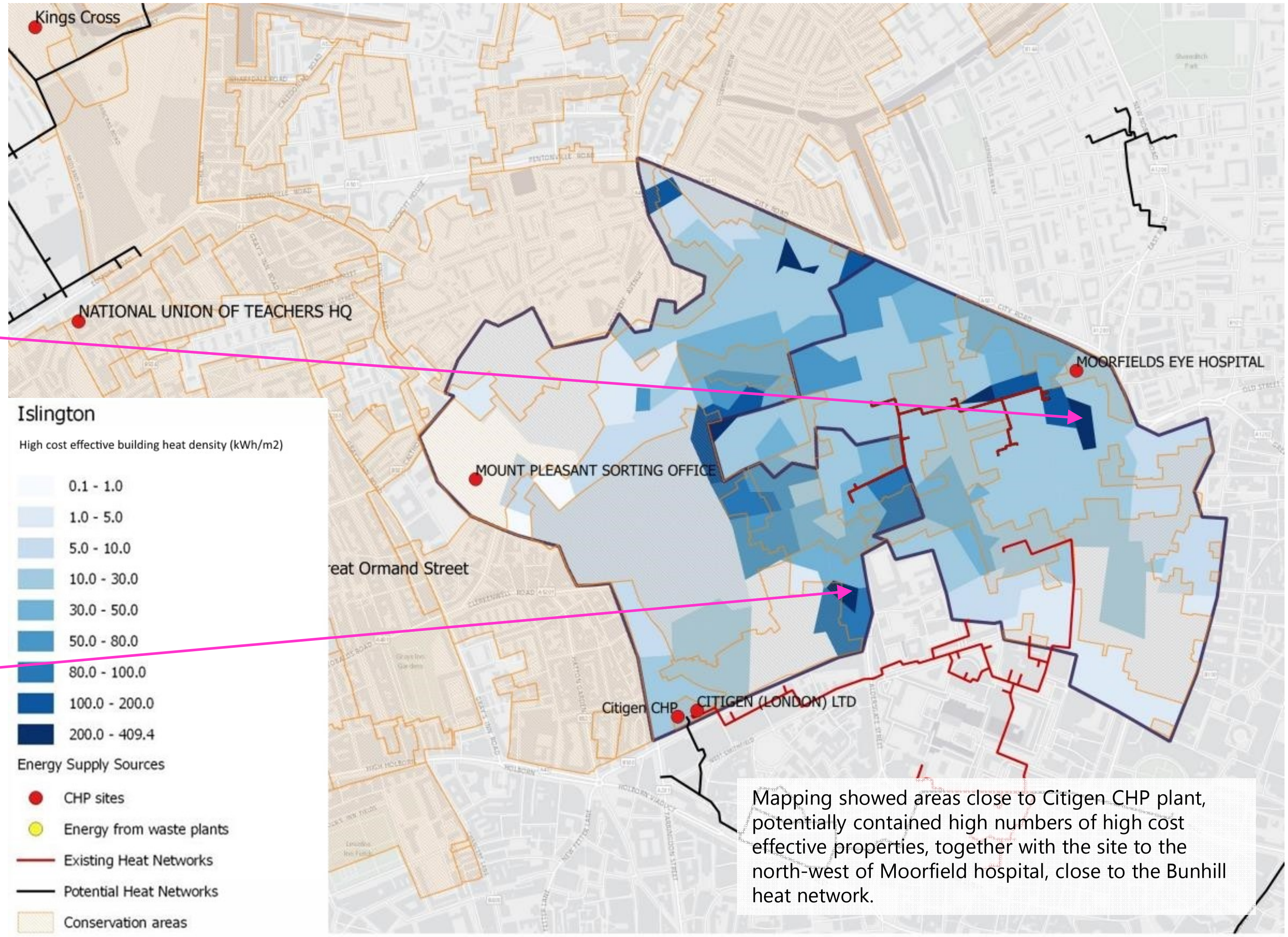
OLD STREET

ISLINGTON (022/023)

Example high rise flats in area

Example high rise flats in area



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.

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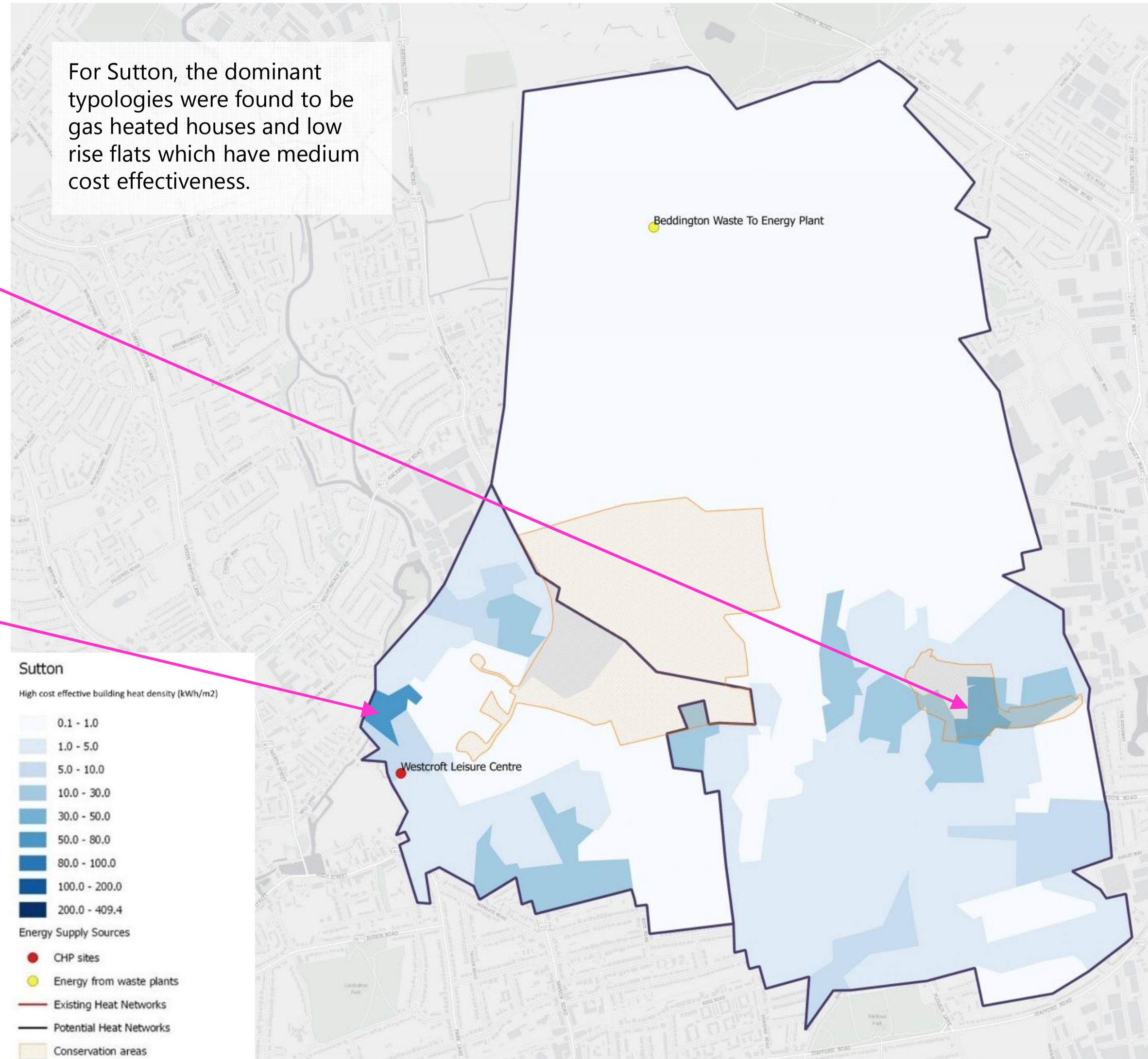
BEDDINGTON
SUTTON (010/011)

Example offices and low rise flats in area

Example higher density flats and lower density housing in area

For Sutton, the dominant typologies were found to be gas heated houses and low rise flats which have medium cost effectiveness.



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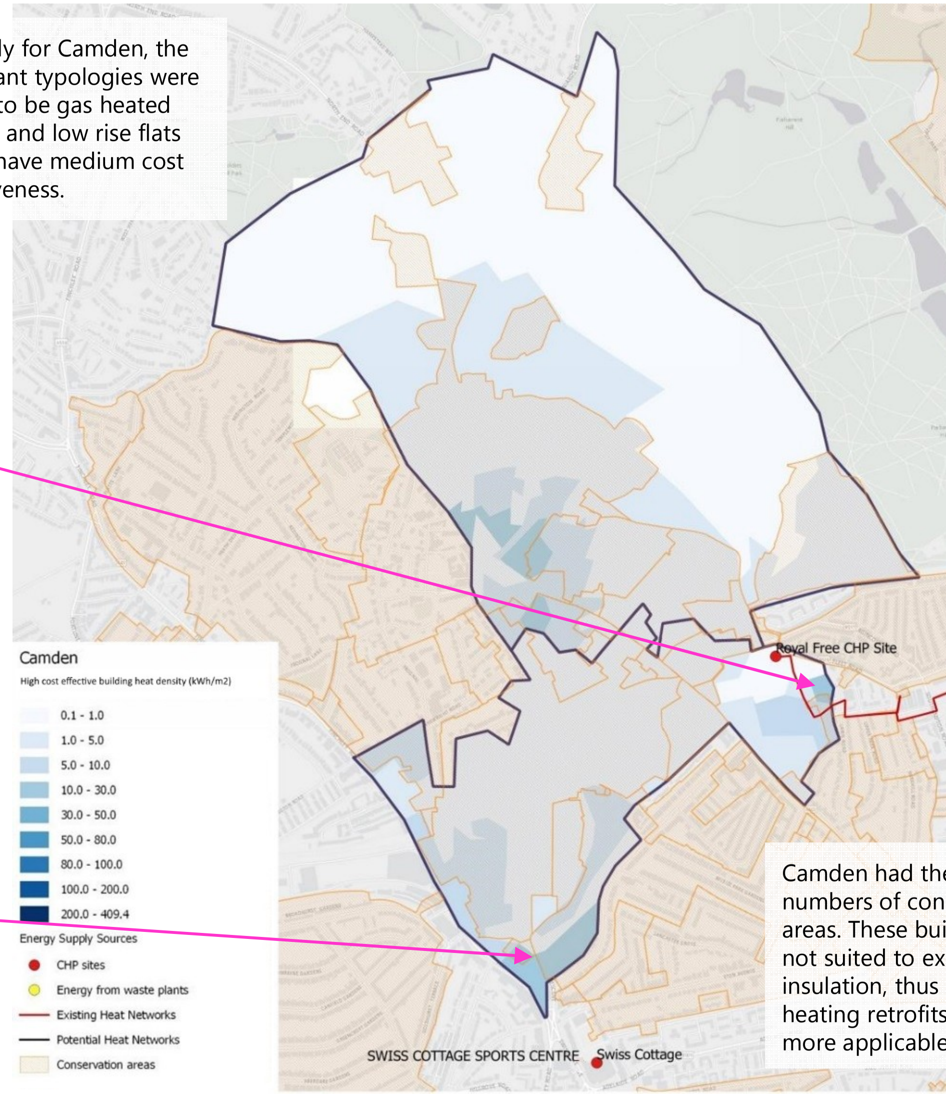
GOSPEL OAK
CAMDEN (002/008)

Example high rise flats in area

Example low-high rise flats & offices in area

Similarly for Camden, the dominant typologies were found to be gas heated houses and low rise flats which have medium cost effectiveness.



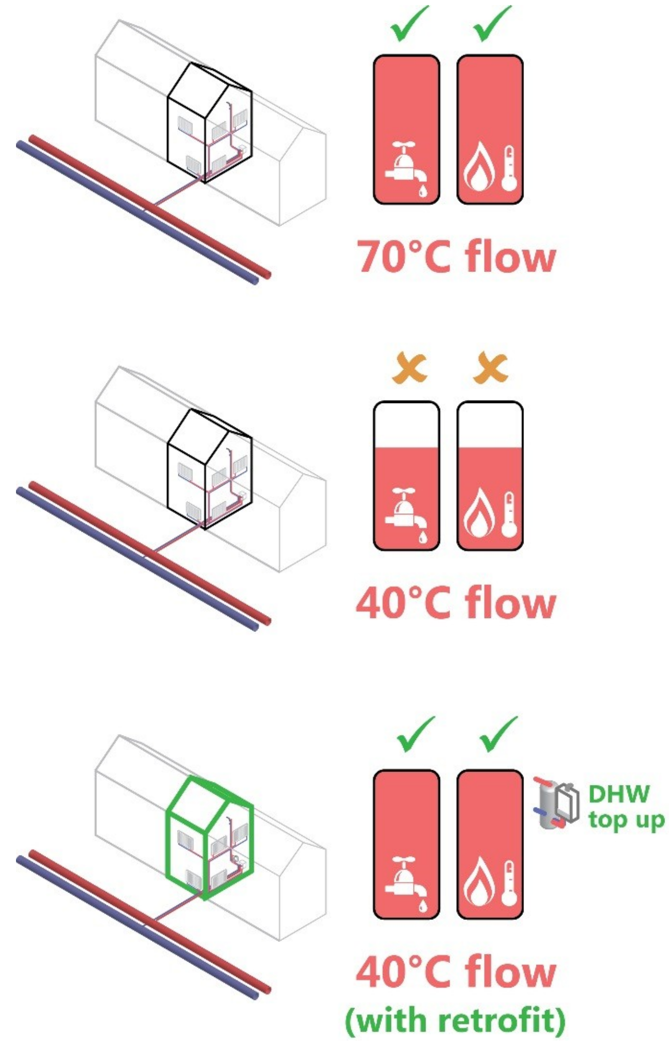
Camden had the highest numbers of conservation areas. These buildings are not suited to external wall insulation, thus district heating retrofits may be more applicable.

WORK PACKAGE 4A

4G DISTRICT HEATING OPTIMUM LEVEL OF ENERGY EFFICIENCY

OVERVIEW

- The final study is a review of the cost optimum level of energy efficiency retrofit to support the implementation of 4th generation district heat networks with supply temperatures from 70 °C to 40 °C
- Using the Strathclyde University ESP-r dynamic energy modelling software, load modelling was undertaken at different flow temperature scenarios e.g. 70, 60, 50, 40 °C. Load profiles were then prepared for each typology and temperature reduction strategy to determine the % of annual unmet energy demand.
- Two different strategies to address the unmet heat demand were tested. Firstly, the use of larger heat emitters was investigated using radiator conversion factors. Secondly, the impact of fabric efficiency measure was investigated through re-running the ESP-r models.
- Capital costing was then undertaken and cost effectiveness was re-assessed taking into account the impact of increased capital costs and domestic hot water provisions. This was applied to the 40 °C flow temperature scenario (which was found to require energy efficiency measures).



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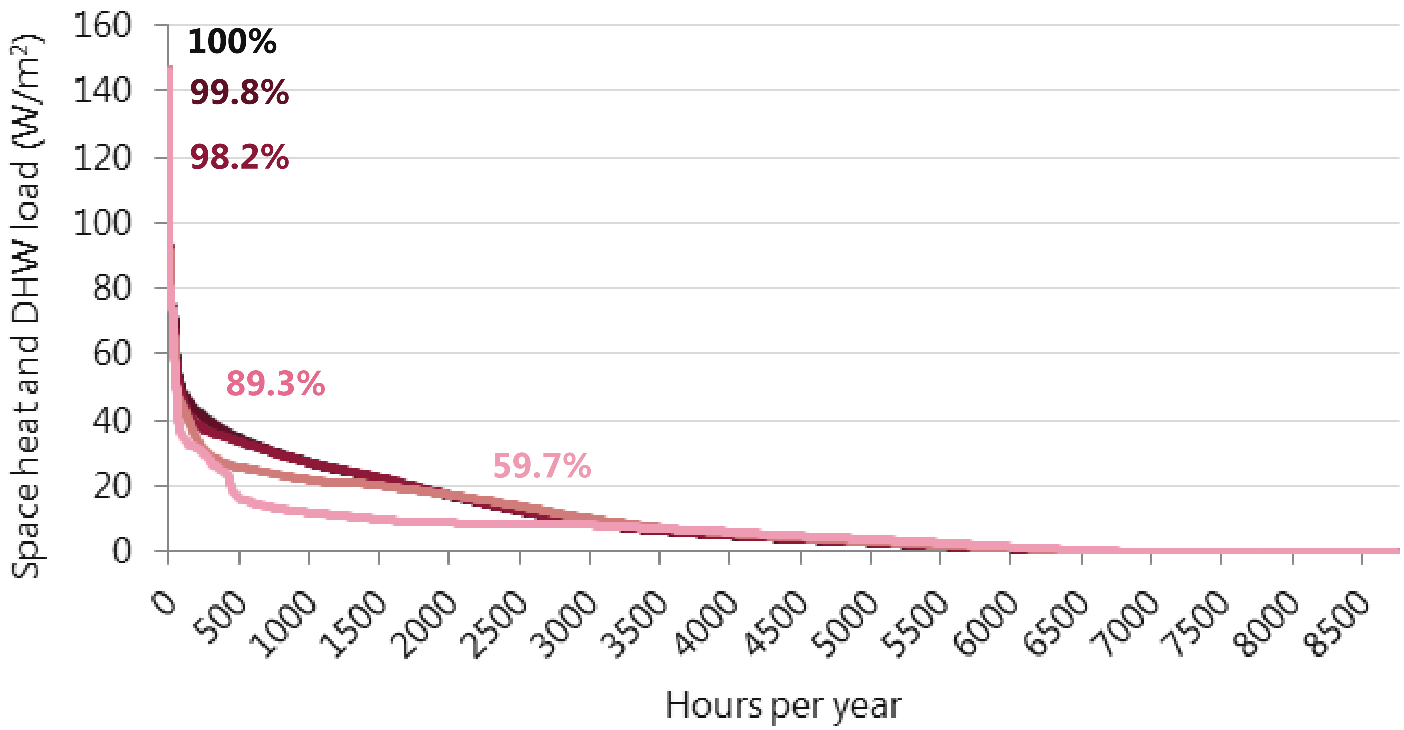
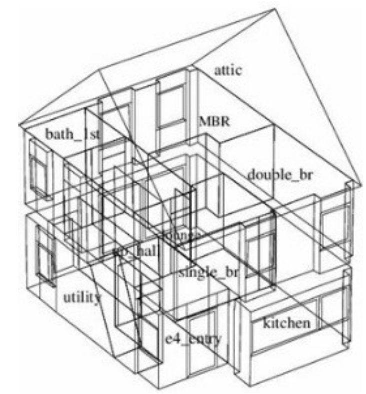
LOAD MODELLING

Percentage of annual heat demand met at reduced district heating supply temperatures





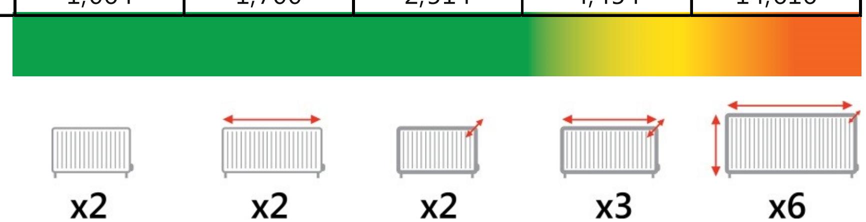
Low efficiency house

RESULTS FOR ALL TYPOLOGIES

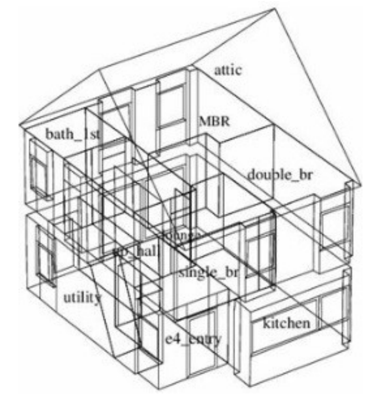
Typology		Load model	Percentage of annual heat demand met				
			Baseline	70 flow	60 flow	50 flow	40 flow
Domestic	d-1, d-2	House - Low efficiency	100%	99.80%	98.20%	89.30%	59.70%
	d-7, d-8	House - Med efficiency	100%	99.90%	99.00%	92.00%	66.60%
	d-13, d-14	House - High efficiency	100%	99.80%	99.60%	96.70%	81.40%
	d-3, d-4	Low rise flat - Low efficiency	100%	99.80%	98.70%	90.40%	59.60%
	d-9, d-10	Low rise flat - Med efficiency	100%	99.80%	99.80%	92.30%	70.10%
	d-15, d-16	Low rise flat - High efficiency	100%	99.90%	99.80%	98.80%	92.60%
	d-5, d-6	High rise flat - Low efficiency	100%	99.80%	98.30%	89.40%	64.20%
	d-11, d-12	High rise flat - Med efficiency	100%	99.80%	99.20%	93.70%	74.00%
	d-17, d-18	High rise flat - High efficiency	100%	99.90%	99.70%	98.20%	89.70%
Non-domestic	nd-2, nd-5	Modern office, Fully glazed	100%	98.80%	97.20%	89.90%	61.00%
	nd-9, nd-13	Modern office, Partially glazed	100%	98.80%	97.10%	89.70%	62.60%
	nd-1, nd-4	Pre 1960 office, Solid wall	100%	99.20%	97.80%	89.80%	60.00%
	nd-11, nd-14	Pre 1960 office, Insulated cavity	100%	99.00%	97.30%	89.90%	62.80%
	nd-3, nd-8, nd-10	Retail, small, High street	100%	98.80%	96.90%	86.70%	50.70%
	nd-12	Retail, large, Catering	100%	99.60%	97.40%	88.70%	59.10%
	nd-6	Retail, large, No catering	100%	98.80%	96.30%	86.40%	53.40%

FEASIBILITY OF LARGER HEAT EMITTERS

Flow temperature	°C	82	70	60	50	40
Radiator conversion factor calculation						
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	0.08
Increase in radiator size required to meet 100% of load (Room example)						
Room load (inc. 10% allowance)	W	1,166	1,166	1,166	1,166	1,166
Radiator heat output needed*	W	1,064	1,700	2,514	4,454	14,616



*Note: Equivalent output once radiator conversion factor is applied. (e.g. at the 60 degree heating flow temperature, a larger surface area of radiators are needed equivalent to 1,700 W).



Low efficiency house

Fabric upgrade needed to accommodate heating supply temperatures of 40 °C.

At 50 °C one additional radiator needed, which is likely to be acceptable in many cases.

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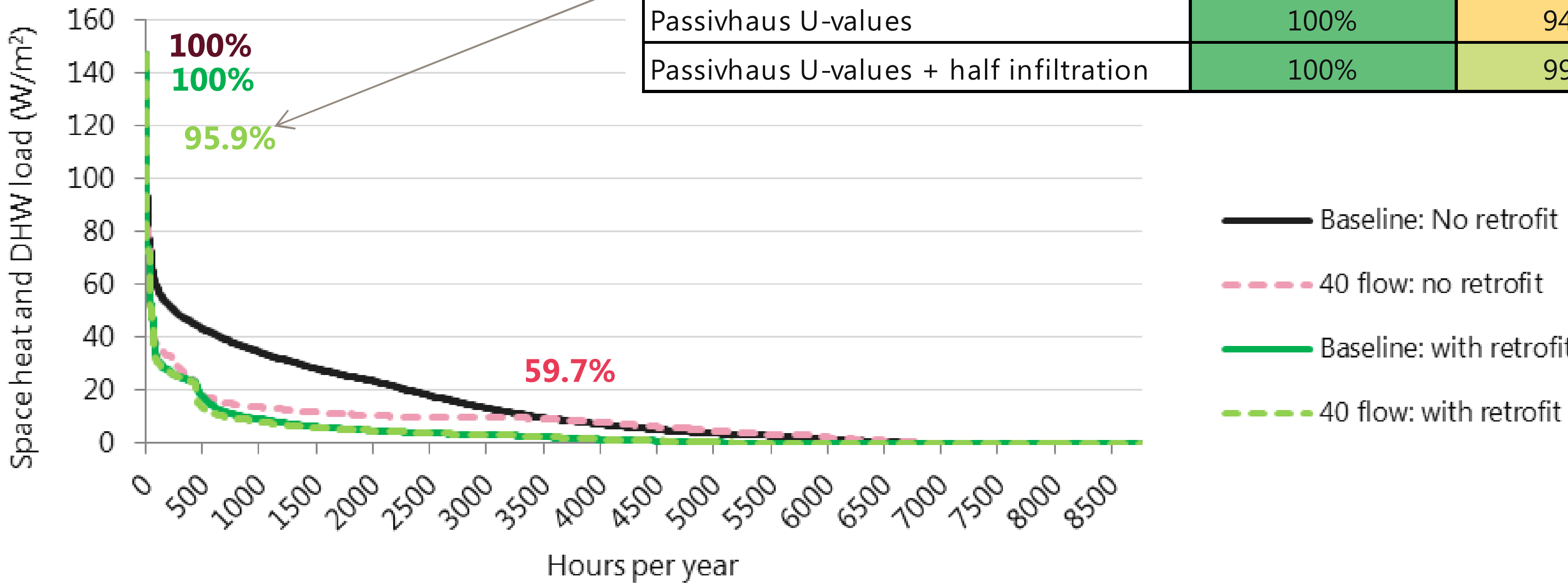
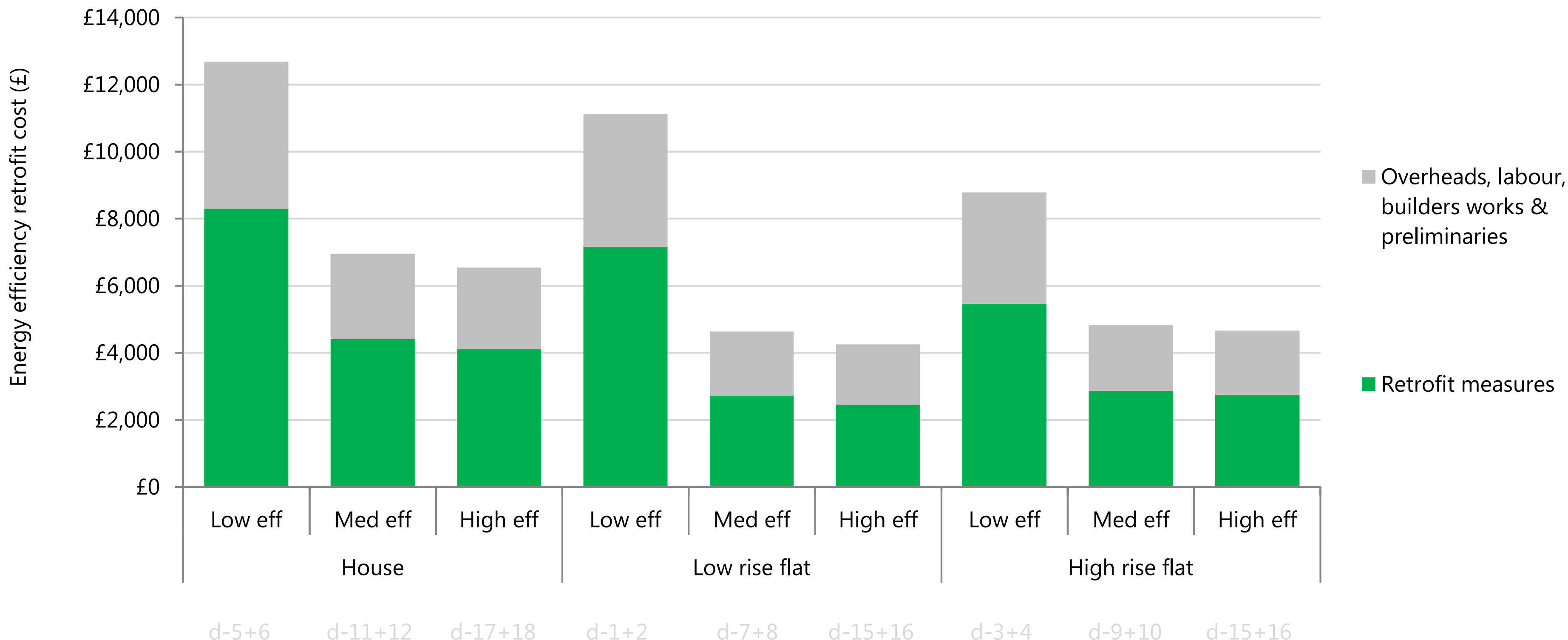
IMPACT OF ENERGY EFFICIENCY RETROFIT

Low efficiency house retrofit	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%



CAPITAL COSTING (ALLOWING COST EFFECTIVENESS TO BE RECALCULATED)

Example costs for fabric upgrade to Building Regulations Part L1B U-values + half air infiltration.
Additional costs added for larger heat emitters (now more practical size) and supplementary DHW systems to provide top-up above 40°C, e.g. DHW cylinder with district heating pre-heat and electric immersion.



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COST EFFECTIVENESS

ENERGY EFFICIENCY WORKS & DISTRICT HEATING RETROFIT ELECTRIC CONVERSION. 40°C HEATING SUPPLY TEMPERATURE

		DH 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)
Archetype			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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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
Electric conversion	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

Air tightness upgrade provides high cost effective results, however does not sufficiently meet the energy demand from previous analysis (i.e. ~70% annual heat demand met)

Building Regulation upgrades are capable of meeting up to 95% of annual heat demand. Medium cost effectiveness can be achieved with paybacks of circa 25-30 years.

BUROHAPPOLD ENGINEERING

COST EFFECTIVENESS

ENERGY EFFICIENCY WORKS & DISTRICT HEATING RETROFIT GAS CONVERSION. 40°C HEATING SUPPLY TEMPERATURE

		DH 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)
		Archetype	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

District heating retrofits with energy efficiency improvements found to be much less cost effective for gas heated dwellings.

NON-DOMESTIC 4G COST EFFECTIVENESS

ENERGY EFFICIENCY WORKS & DISTRICT HEATING RETROFIT. 40°C HEATING SUPPLY TEMPERATURE

Impact of new double glazing with halved air infiltration.

Non-domestic models (medium and high viability)	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%

Capital costing undertaken to re-calculate cost effectiveness. Supplementary heating and hot water met though back-up gas boiler or secondary electric system.

		DH 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)
		Archetype	Payback period (years) at different district heating unit prices																			
			New double glazing + half air infiltration																			
Electric 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 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

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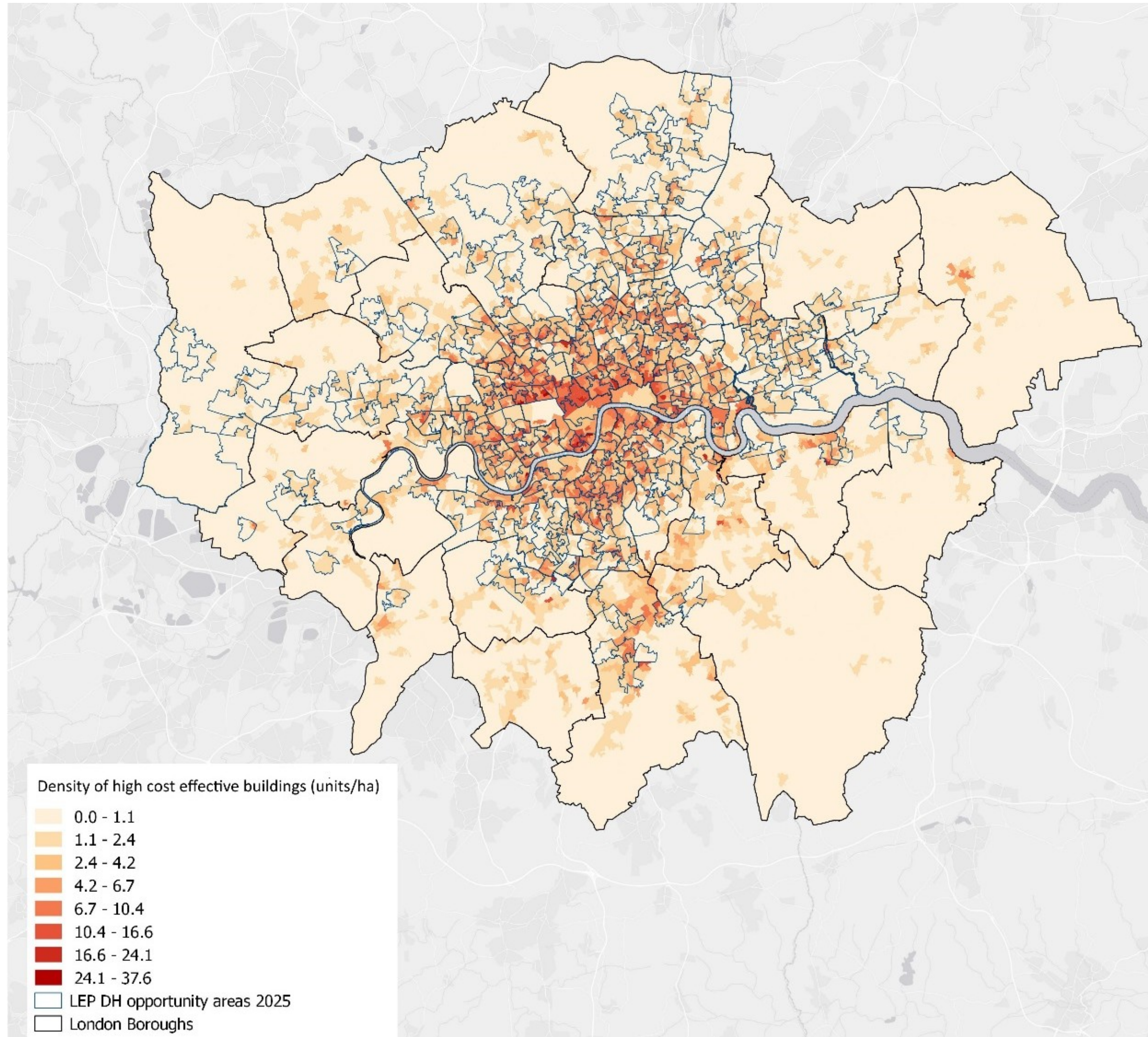
HIGH COST EFFECTIVE BUILDINGS AT 40°C HEATING SUPPLY TEMPERATURE

	Domestic	#/ha
1	Tower Hamlets 028H	38
2	Westminster 024E	34
3	Westminster 021B	30
4	Westminster 014F	30
5	Westminster 022D	30

	Non-domestic	#/ha
1	Brent 015A	18
2	Hackney 027G	12
3	Westminster 016B	11
4	Westminster 013E	11
5	Brent 022D	11

	Combined	#/ha
1	Tower Hamlets 028H	34
2	Westminster 017C	35
3	Westminster 024E	34
4	Westminster 021B	32
5	Westminster 014F	30

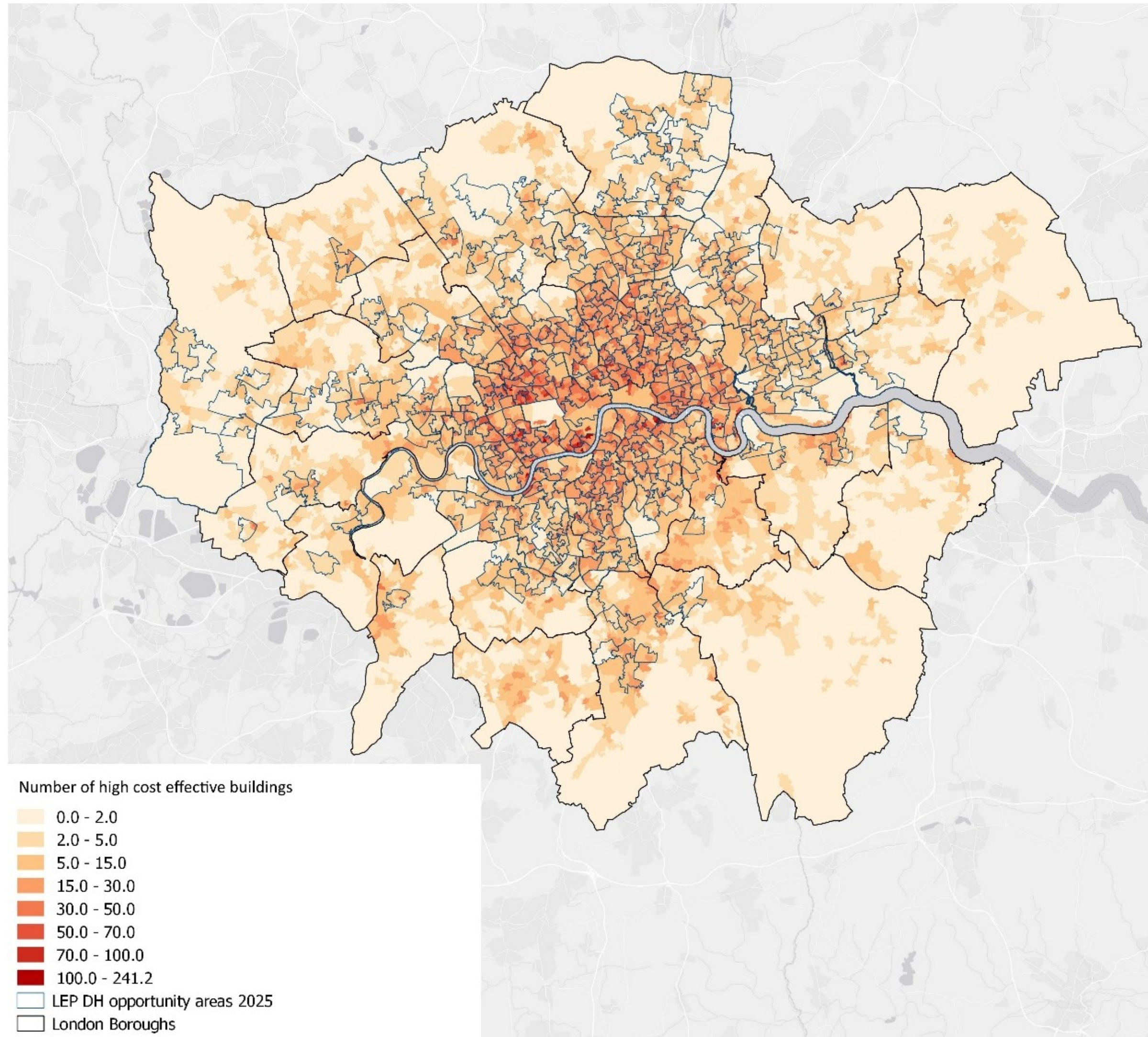


HIGH & MEDIUM COST EFFECTIVE BUILDINGS AT 40°C HEATING SUPPLY TEMPERATURE

	Domestic	#/ha
1	Tower Hamlets 032D	240
2	Westminster 024E	195
3	Southwark 003K	165
4	Hammersmith & Fulham 023E	163
5	Westminster 021B	141

	Non-domestic	#/ha
1	Westminster 013E	19
2	Brent 015A	18
3	Brent 028D	15
4	Brent 022D	14
5	Westminster 016B	13

	Combined	#/ha
1	Tower Hamlets 032D	241
2	Westminster 024E	196
3	Southwark 003K	165
4	Hammersmith & Fulham 023E	163
5	Westminster 021B	142



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WORK PACKAGE 4B

CNCA CITIES REPLICABILITY METHOD

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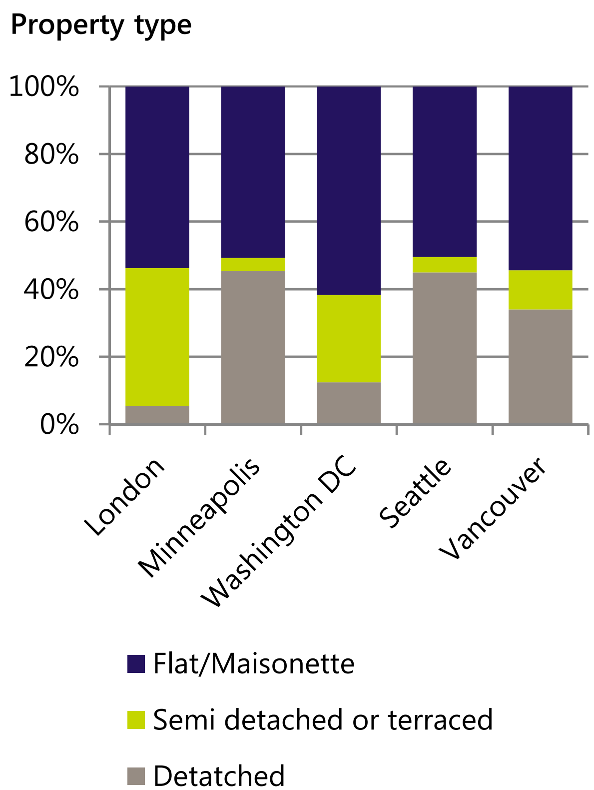
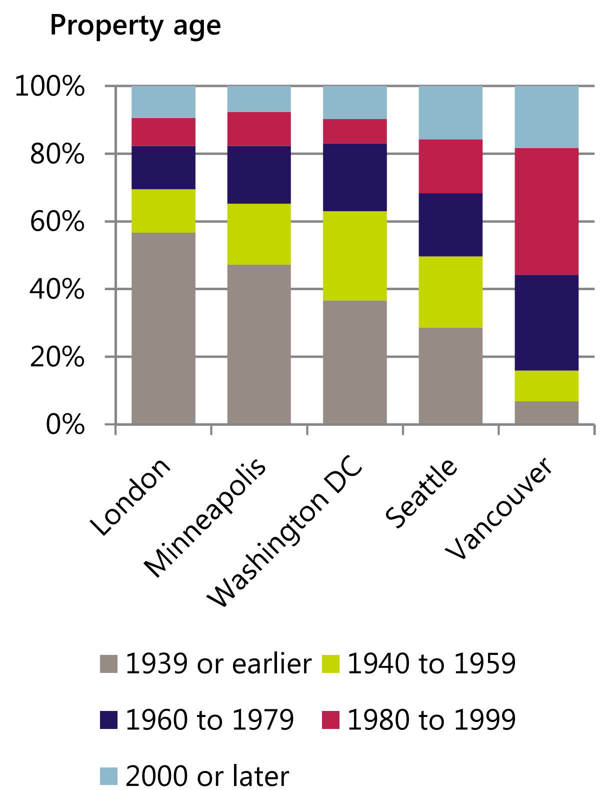
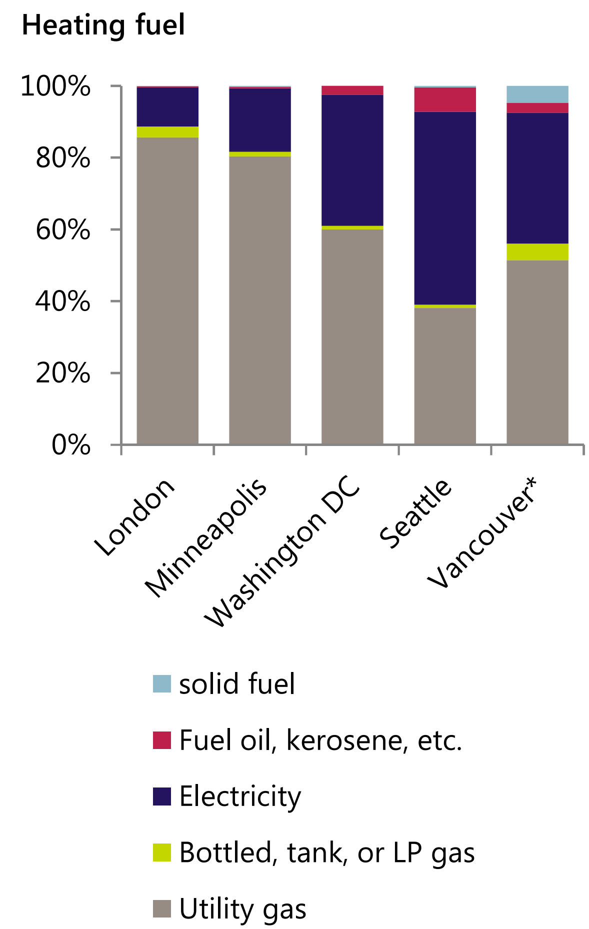
CNCA TYPOLOGY SUMMARY







REPLICABILITY METHOD

Building stock analysis > Develop set of thermal classes > Technical retrofit requirements > Costing of retrofit requirements > Cost effectiveness study > Pilot study > 4G energy efficiency study

Activity	Steps	Rationale
[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, age) [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 DH 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 typologies can be focussed on.

BUROHAPPOLD ENGINEERING

REPLICABILITY METHOD

Building stock analysis → **Develop set of thermal classes** → Technical retrofit requirements → Costing of retrofit requirements → Cost effectiveness study → Pilot study → 4G energy efficiency study

Activity	Steps	Rationale
[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, [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 [2.4]. Undertake location specific research to provide further detail to the above assumptions, e.g. heat transfer coefficient, heating system efficiencies	By developing a generic list of thermal classes it is possible to apply the results generated through this study to the whole domestic building stock.
[2b]. Development of thermal classes for most prevalent non-domestic buildings	[2.5]. Collate and review available data on 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 [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 [2.13]. Undertake location specific research to provide further detail to the above assumptions	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.

REPLICABILITY METHOD

Building stock analysis → Develop set of thermal classes → **Technical retrofit requirements** → Costing of retrofit requirements → Cost effectiveness study → Pilot study → 4G energy efficiency study

Activity	Steps	Rationale
[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 for heating and hot water demand of each typology [3.3]. Extract half hourly energy consumption profiles enabling load duration curves to be produced	Load modelling results help to inform capital costing of heat emitters. Annual energy figures feed into the payback calculations for cost effectiveness.
[3b]. Development of district heating retrofit connection strategies	[3.4]. For each typology, determine 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 DH 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, pipework 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.

REPLICABILITY METHOD

Building stock analysis › Develop set of thermal classes › Technical retrofit requirements › **Costing of retrofit requirements** › Cost effectiveness study › Pilot study › 4G energy efficiency study

Activity	Steps	Rationale
[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.

BUROHAPPOLD ENGINEERING

REPLICABILITY METHOD

Building stock analysis → Develop set of thermal classes → Technical retrofit requirements → Costing of retrofit requirements → **Cost effectiveness study** → Pilot study → 4G energy efficiency study

Activity	Steps	Rationale
[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 DH retail heat prices to determine, at which point the DH payback period becomes cost effective. [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.	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 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.

BUROHAPPOLD ENGINEERING

REPLICABILITY METHOD

Building stock analysis → Develop set of thermal classes → Technical retrofit requirements → Costing of retrofit requirements → Cost effectiveness study → **Pilot study** → 4G energy efficiency study

Activity	Steps	Rationale
[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" cost effectiveness properties, as well as "high + medium" cosy 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 & high heat demand, this will strengthen the case for investment in those areas.

REPLICABILITY METHOD

Building stock analysis → Develop set of thermal classes → Technical retrofit requirements → Costing of retrofit requirements → Cost effectiveness study → Pilot study → **4G energy efficiency study**

Activity	Steps	Rationale
[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 flow 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 4G 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.

SUMMARY & CONCLUSION

MAIN FINDINGS

District heating retrofit costs

- 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 typologies assessed.
- The cost to retrofit gas centrally heated commercial office and retail buildings 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 office and retail 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.

MAIN FINDINGS

District heating cost effectiveness

- The properties found to be the most cost effective for district heating retrofits are low and medium efficiency electrically heated high-rise flats, low-rise flats and houses, as well as large electric 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. 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 retrofit 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 domestic and non-domestic stock analysed (3,100,000 buildings). Areas with the highest density of medium cost effective buildings include Tower Hamlets, Westminster, Hounslow, Southwark, Islington and Wandsworth.

MAIN FINDINGS

Pilot study

- In the pilot study, a methodology to determine district heating retrofit cost effectiveness at a higher resolution of detail for LSOAs was carried out and tested for areas of Islington, Enfield, Sutton and Camden.
- The analysis of the pilot study areas found that Islington and Enfield had the highest densities of cost effective buildings, e.g. electrically heated properties, that fell into the high category, whereas Sutton and Camden consisted primarily of gas heated properties of medium cost effectiveness.
- The proof of concept model showed good potential for identifying typologies that fell into the high cost effective category, e.g. high rise flats and offices, provided that data at individual property level could be acquired.
- It is recommended that 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 supporting pre-feasibility studies and energy masterplanning and capable of inputting into feasibility studies aimed at identifying potential consumers for a new or expanding heat networks.

MAIN FINDINGS

4th generation district heating networks

- Lower temperature (70 °C to 40 °C) heat networks are necessary to enable transition away from fossil fuels (e.g. natural gas fired combined heat and power units) to renewable and secondary heat (environmental and waste heat) sources.
- 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 energy efficiency of the property being 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 °C 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. Supporting energy efficiency measures are required.

MAIN FINDINGS

Optimal level of energy efficiency for 4th generation district heating networks

- At the heating supply temperature of 40 °C, 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 still be needed to provide the level of thermal comfort required.
- 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 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 domestic hot water (DHW), point-of-use heaters or an electric coil in the calorifier / hot water tank can be installed, to provide additional heat as necessary. For high-rise flats DHW can also be provided through a centralised approach.
- It was estimated that large electrically heated offices, as well as low efficiency, electrically heated domestic properties can still be cost effective even after taking account of the additional costs of fabric, domestic hot water and radiators.

MAIN FINDINGS

Feasibility and roll-out of district heating

- 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.
- Where there are existing or planned district heating networks, retrofitting existing buildings to connect to them offers a cost effective solution to decarbonise their heat supply and create low and zero carbon neighbourhoods.
- In locations with no district heating networks, energy efficiency together with alternative low carbon heat supply solutions, such as heat pumps or green gas, will be required to decarbonise heat supply and the local building stock.
- It is likely that local authority and social housing estates would be the most straight-forward to retrofit for district heating due to simpler ownership and control; albeit subject to consumer preferences and maintenance considerations.
- Conservation areas may also be suitable for district heating retrofit as it would offer a cost effective solution in low efficiency dwellings where fabric upgrade measures are restricted and/or expensive (e.g. external/internal solid wall insulation).

MAIN FINDINGS

Feasibility and roll-out of 4th generation district heating

- Retrofitting existing buildings for connection to lower temperature district heating networks, supply temperatures from 70 °C to 50 °C, offers a cost effective solution for decarbonising their heat supply as they are able to meet 100% of their annual heat demand by a combination of increasing the size of radiators and/or variable supply temperatures during cold weather periods.
- This illustrates a realistic approach for decarbonising heat networks and consequently the building stock that is supplied by them and should be considered in the strategic planning for low and zero carbon neighbourhoods.
- 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.

COST EFFECTIVENESS OF DISTRICT HEATING RETROFIT

DH - High cost effectiveness

- Up to 9.0% (312,600) of domestic buildings
- Up to 5.0% (16,700) of non-domestic buildings
- Up to 8.7% (329,300) of all buildings

DH - High & medium cost effectiveness

- Up to 87.9% (3,037,000) of domestic buildings
- Up to 17.1% (57,000) of non-domestic buildings
- Up to 81.7% (3,095,000) of all buildings

District heating, 40 °C heating supply temperature and energy efficiency retrofit - High cost effectiveness

- Up to 4.7% (164,100) of domestic buildings
- Up to 5.0% (16,700) of non-domestic buildings
- Up to 4.8% (180,800) of all buildings

District heating, 40 °C heating supply temperature and energy efficiency retrofit - High & medium cost effectiveness

- Up to 22.8% (788,800) of domestic buildings
- Up to 6.6% (21,800) of non-domestic buildings
- Up to 21.4% (810,600) of all buildings

Note: The total number of domestic buildings in London was found to be 3,455,750 based upon LSOA datasets for 'Property type and bedroom count' from Office for National Statistics (ONS) neighbourhood statistics, 2014. The total number of non-domestic buildings in London was taken as 331,511 based upon Ordnance Survey Address-Base-Plus, Nov 2015 and 2011 Census Lower Super Output Areas; of these buildings, 206,193 are office and retail buildings.

KEY TAKE AWAY MESSAGES…

- In areas where there are existing or planned networks, connecting existing buildings to a heat network is an effective way of decarbonising them - particularly for hard-to-treat high rise electric properties, low rise flats and offices as the network can then actively plan for and invest in the connection of low and zero carbon heat sources.
- The capital cost of district heating retrofit is comparable to a whole house energy efficiency refurbishment, therefore it is a realistic alternative and/or supplementary decarbonisation approach in areas with existing or planned networks.
- Consumer benefits include lower cost heat, so more affordable warmth; plus instantaneous hot water and space savings.
- A diverse range of secondary heat and renewable energy sources can be exploited by cities with extensive district heating networks as they provide the distribution infrastructure to move heat from where it is produce to where it is consumed.
- Low temperature networks enable the cost effective use, in conjunction with heat pumps, of low grade secondary heat sources, such as heat from the tube, air-conditioning units, data centres and the environment.
- District heating networks can play a key role in London’s strategy for decarbonising heat, particularly in dense urban areas with a mix of building typologies. For example, they can accommodate very large peak heating demands on cold days and to do this using electric heating systems would require extensive reinforcement of London’s electricity grid.

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