CARBON TRUST

Heat pump retrofit in London

August 2020

Contents

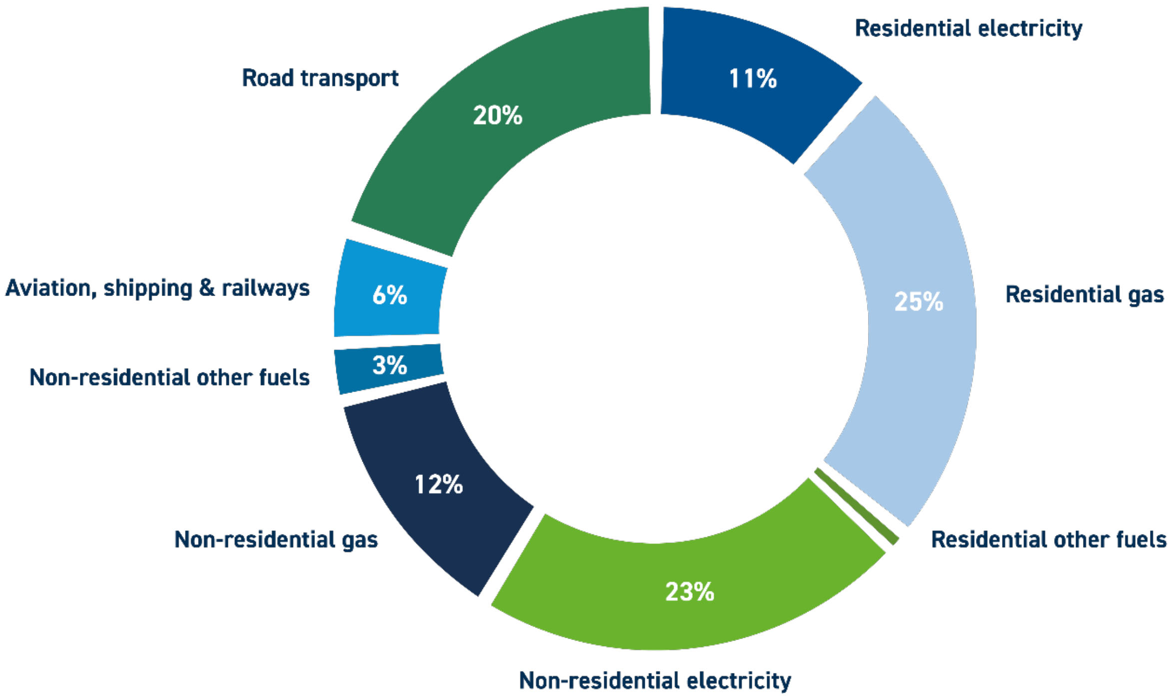
Executive summary

The Mayor of London has set ambitious aims for London to be a net zero carbon city by 2030 and to have the best air quality of any major city[1]. In addition, 28 London Boroughs have declared climate emergencies with over half of these committed to achieving net zero by 2030. The political will to deliver net zero carbon emissions in London has never been stronger.

Reducing emissions from heat is London's biggest decarbonisation challenge. Natural gas (primarily used for space and water heating) accounts for 37% of London's greenhouse gas emissions and 22% of NOx emissions[2].

Conventional electric heating also contributes significantly to CO_2 emissions and increases the peak demand on local energy networks.

Figure 1: London greenhouse gas emissions by sector: London Energy & Greenhouse Gas Inventory (LEGGI) 2017[3].



London's carbon targets cannot be met unless there is a rapid transition toward low carbon solutions, such as heat pumps and low carbon district heating.

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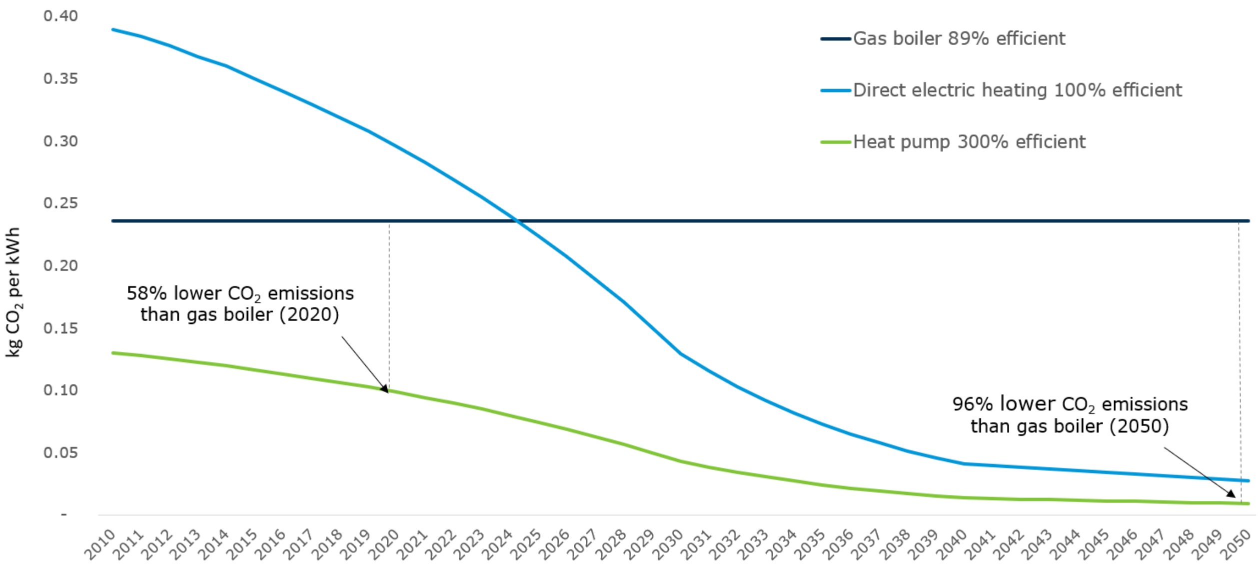
[1] Greater London Authority [2020] https://www.london.gov.uk/what - we - do/environment/climate - change/zero - carbon London

[2] Greater London Authority (2018). London Environment Strategy .

[3] Greater London Authority (2018). *London Environment Strategy.*

Heat pumps are a highly efficient form of electric heating. Due to their high efficiency and the ongoing rapid decarbonisation of grid electricity, heat pumps have the potential to deliver **CO_2 savings of 60-70% compared to conventional electric heating and 55-65% compared to an A-rated gas boiler**. These savings increase when combined with energy efficiency measures to reduce space heating demand. As the grid decarbonises further in coming decades, the carbon savings delivered by heat pumps are expected to increase further towards **90-100% CO_2 emissions reduction by 2050.**

Figure 2: Carbon intensity of gas boilers and heat pumps[4] at different efficiencies: 2010-2050[5]



Previous analysis for the GLA's 1.5°C Compatible Action Plan[6] outlines the need for a rapid acceleration in heat pump deployment in London, alongside energy efficiency improvements, reaching 120,000 heat pump

[4] In this report we have used percentages to represent predictions of both gas and heat pump efficiency over the course of a year under real world conditions. The percentages represent the kWh of heat output by the system divided by the kWh of gas or electricity input to the heating system. This enables a straightforward comparison between gas, direct electric, hybrid and pure heat pump based systems. Further information on defining heat pump efficiency can be found in Appendix 1.

[5] In this report we have used marginal emissions factors for gas and electricity from the Treasury Green Book. These are a long term projections of the carbon intensity of electricity generation needed to meet additional loads on the grid over time, ie not assuming that the additional load can be met at the current grid wide carbon factor. Thus they enable a robust analysis of the predicted long term impacts of heat pump retrofit on CO_2 emissions. In practice, the carbon intensity of grid electricity varies significantly by region, time of day and the relative production of different generation assets such as wind and solar. At the time of writing, the short term forecasts for the carbon intensity of grid electricity for both the UK and London are lower than the Green Book long run marginal emissions factor projection for 2020 (ie immediate CO_2 savings could be larger than those projected here). See https://carbonintensity.org.uk/ for further information.

[6] Greater London Authority (2018) *https://www.london.gov.uk/sites/default/files/1.5_action_plan_amended.pdf*

installations a year by the 2030s. The Committee on Climate Change (CCC) has estimated that, by 2050, 19 million heat pumps will be needed across the UK[7][8].

In addition to the environmental benefits, economists have identified the huge potential value that investment in energy efficiency and low carbon heating would bring to the post-COVID economy. Renovating homes and replacing heating systems is labour intensive and done mostly by small and medium sized enterprises (SMEs). The Energy Efficiency Infrastructure Group (EEIG) estimates that investing in energy efficiency as a national infrastructure priority would support 150,000 skilled and semi-skilled jobs to 2030[9] and an infrastructure investment to bring all UK homes up to EPC C would have a Net Present Value of £47 billion, through new jobs, reduced power system investment, increased household disposable income and improved health[10].

Unfortunately, current levels of heat pump installation fall far short of those required. In London, the Renewable Heat Incentive (RHI), the government's flagship mechanism for supporting heat pumps, has supported a mere 66 installations per year on average since 2014[11]. It is clear that a rapid acceleration of activity is needed.

This report, authored by the Carbon Trust and commissioned by the Greater London Authority (GLA), contains detailed analysis of the challenges and opportunities for heat pump and energy efficiency retrofit in London's building stock and recommendations for accelerating the transition to low carbon heat. It provides guidance on:

- Good practice system design for heat pump retrofit
- The importance of energy efficiency and flexibility of demand to facilitating heat pump retrofit at scale
- Types of heat pump technology and their potential applications in London
- Analysis of the capital costs, impacts on fuel bills, whole life costs of ownership and CO_2 savings of heat pump retrofit in 15 example London buildings.

The report is intended for the GLA, London Boroughs, Social Housing providers, building owners, facilities managers and anybody who is considering retrofitting heat pumps in to their buildings. It is also relevant to those with responsibility for energy or climate policy and strategy relating to buildings.

[7] Committee on Climate Change [2019] *https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-Technical-report-CCC.pdf*

[8] To deliver the CCC's 2050 forecast for 19 million heat pumps by 2050, around 633,000 heat pumps need to be installed each year. This is ambitious but, in context, this equates to only 38% of the 1.67 million gas boilers sold in the UK in 2019

[9] https://www.theeeig.co.uk/media/1091/eeig_report_rebuilding_for_resilience_pages_01.pdf

[10] Energy Efficiency Infrastructure Group (2019). *Making energy efficiency a public and private infrastructure investment priority.*

[11] Department for Business, Energy and Industrial Strategy (2020). *RHI monthly deployment data June 2020.*

The key over-arching messages of this report are that:

1. Heat pumps are the primary technology choice for decarbonising heat in existing London buildings.
2. Heat pump technology is varied, versatile and can work in all London building types.
3. Heat pumps are not a like-for-like replacement for gas boilers or conventional electric heating and good practice system design is essential.
4. Improved energy efficiency in buildings is a pre-requisite for heat pump retrofit at scale and will require significant investment.
5. Flexibility of heat demand is essential for a net zero carbon energy system and can bring significant financial rewards at the individual building level.
6. Based on current gas and electricity prices, heat pumps will reduce fuel bills compared to conventional electric heating but could increase fuel bills compared to gas unless paired with energy efficiency, best practice system design and flexible use of heat.[12]
7. The up-front cost of heat pumps is higher than traditional alternatives and many building types will require additional up-front financial support. However, the lifetime financial case for heat pump retrofit is already strong in some building types, such as electrically heated buildings, buildings with a high cooling demand and buildings that already require major renovations. These building types should be prioritised for heat pump retrofit.

The findings of this report highlight the urgent need for central government to provide a decisive regulatory and fiscal framework to support the installation of heat pumps and energy efficiency at the scale necessary. To this end, we have included an action plan for scaling up energy efficiency and heat pump retrofit. The recommendations in the action plan are primarily for central government, but also include recommendations for the GLA and London Boroughs.

Our action plan for scaling up energy efficiency and heat pump retrofit includes recommendations to:

1. Rapidly escalate investment in thermal energy efficiency in buildings
2. Reduce the upfront capital cost of heat pumps paid by the building owner
3. Re-balance gas and electricity energy taxation to incentivise low carbon heating
4. Maximise financial rewards for the flexibility of heat demand
5. Catalyse the deployment of heat pumps in building types where there is already a strong financial case for heat pump retrofit, such as electrically heated buildings, buildings with high cooling demand and aging communal and district heating systems.

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[12] In the heat pump retrofit action plan we also look at the need to re-balance taxation levels on gas versus electricity.

This report is accompanied by the document: **Options appraisals for heat pump retrofit in 15 London buildings**. This contains high level technical and financial appraisals of heat pump retrofit for 15 real buildings. The '15 example buildings' are referred to in the analysis throughout this report.

The Options appraisals document provides users with detailed reference cases to understand the interplay of costs, grants, heat pump efficiency, fuel bills, CO_2 savings and the practical challenges of heat pump retrofit in some common building types. Whilst each case is unique, they are intended to be useful for others considering heat pump retrofit in similar buildings.

This report is split in to four sections:

Section A: Key messages and a retrofit action plan

In this section, we outline:

- Key messages that emerged from the research regarding the role of heat pumps in decarbonising heat in London.
- An action plan for heat pump retrofit including recommendations for policies, programmes and priority actions that are needed to deliver heat pump retrofit at scale.

This section is recommended for those whose primary interest is in strategy and policy development for the decarbonisation of buildings. Whilst many of the proposed actions are for central government, there are also recommendations for the GLA, the London Boroughs, Ofgem and the Distribution Network Operators.

Section B: Three foundations for heat pump retrofit

In this section, we outline how the transition to heat pumps at scale in existing buildings will rest on the following three foundations:

1. Energy efficiency
2. Flexibility
3. Good practice system design

We discuss how each of these are critical to heat pump retrofit and outline the benefits they bring to building owners, as well as the energy system as a whole. Chapter 6 on good practice system design contains detailed information on the principles of optimising heat pump efficiency in existing buildings.

This section is recommended for those seeking a good technical grounding in the principles of heat pump retrofit. It will help you to identify the potential pitfalls of poor design and to appreciate that heat pump retrofit needs to be considered holistically, with energy efficiency and payments for flexibility bringing significant benefits.

Section C: Heat pump technology in London

In this section, we outline:

- The major heat pump technology types and their potential applications in London
- Potential heat sources in London that can be accessed for heat pump retrofit.
- The challenges of heat pump retrofit in common London buildings types and how the diversity and versatility of heat pump technologies can provide solutions.

This section is recommended for those seeking to understand the practical applications, limitations and opportunities of different heat pump technologies in different building types.

Section D: CO_2 savings, fuel bills and costs analysis

In the final section, we provide:

- Detailed analysis of the impact of heat pump and energy efficiency retrofit on CO_2 savings, costs and fuel bills in the 15 example London buildings.
- Analysis of factors influencing costs and the impact of different grant levels, CAPEX reductions and use of flexible time of use tariffs on lifetime costs.
- Analysis of the relative attractiveness of the financial cases for heat pump and energy efficiency retrofit relative to a 'business as usual' scenario (which is typically the replacement of a gas boiler).

This section is recommended for those seeking to understand the up-front, lifetime costs, fuel bills and CO_2 savings of heat pumps and energy efficiency retrofit in detail. It will be of particular interest to those seeking to identify buildings that could be considered near term priorities for heat pump retrofit within their stock.

Section A

Key messages and a retrofit action plan

In this section we present:

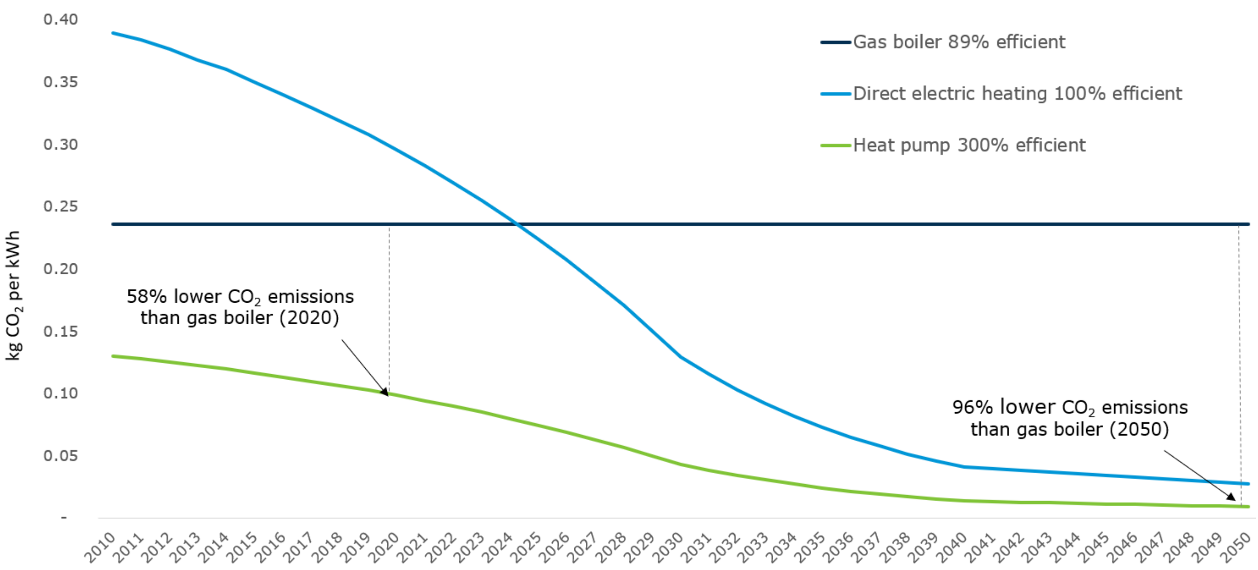
- The over-arching key findings of the analysis in this report
- An action plan for heat pump retrofit in London
- An overview of options for heat decarbonisation in buildings
- A summary of the 15 example buildings used for analysis in this report

1. Key messages

1.1 Heat pumps are the primary technology choice for decarbonising heat in existing London buildings

Whilst electricity has historically been a carbon intensive fuel for heating, the carbon intensity of UK grid electricity has declined rapidly in the last decade. An efficiently designed, installed and operated heat pump system, either at a building or heat network scale, can deliver immediate **CO_2 emissions savings of 60-70% compared to conventional electric heating and 55-65% compared to an efficient gas boiler**. As the grid decarbonises further in coming decades, the carbon savings delivered by heat pumps is expected to increase further towards **90-100% CO_2 emissions reductions by 2050.**

Figure 3: Carbon intensity of gas boilers and heat pumps at different efficiencies: 2010-2050[13]



Whilst hydrogen is likely to have a role to play in industrial and specialist applications that require high temperature heat demand, this is not predicted to happen at scale until the 2040s[14] and we cannot wait until then to start decarbonising our buildings. Green gas, injected in to the gas grid, has the potential to reduce

[13] In this report we have used marginal emissions factors for gas and electricity from the Treasury Green Book. These are a long term projections of the carbon intensity of electricity generation needed to meet additional loads on the grid over time, ie not assuming that the additional load can be met at the current grid wide carbon factor. Thus they enable a robust analysis of the predicted long term impacts of heat pump retrofit on CO_2 emissions. In practice, the carbon intensity of grid electricity varies significantly by region, time of day and the relative production of different generation assets such as wind and solar. At the time of writing, the short term forecasts for the carbon intensity of grid electricity for both the UK and London are lower than the Green Book long run marginal emissions factor projection for 2020 (ie immediate CO_2 savings could be larger than those projected here). See https://carbonintensity.org.uk/ for further information.

[14] Element Energy for Greater London Authority (2018). *London's Climate Action Plan WP3 Zero Carbon Energy Systems.*

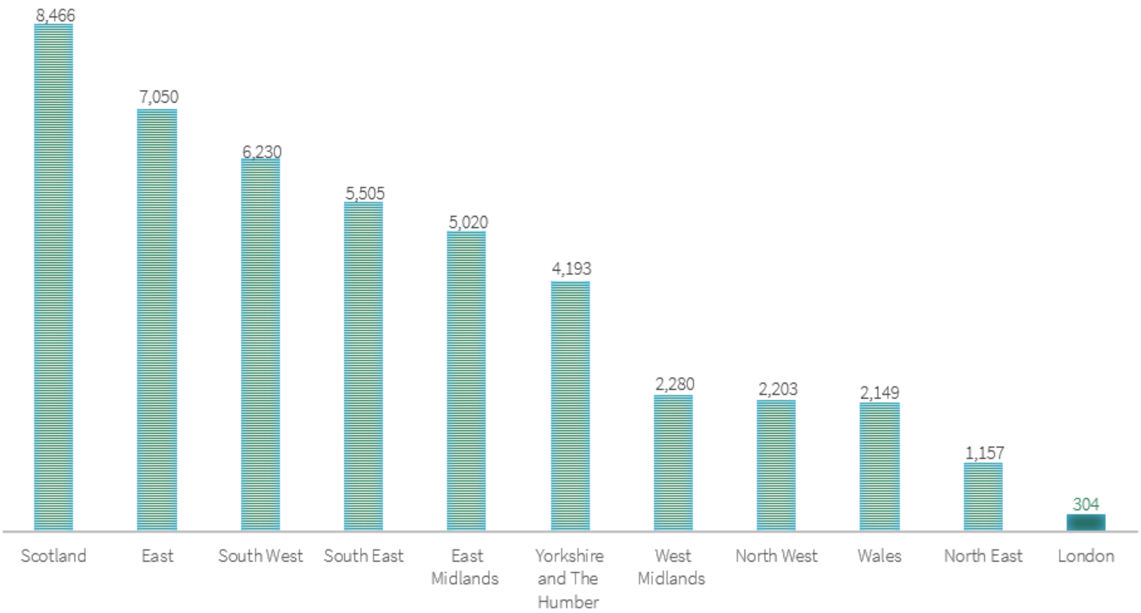
the carbon intensity of natural gas, but the potential contribution is thought to only be around 5% of current natural gas demand[15].

Heat pumps are a proven and scalable low carbon heat technology that can be readily and widely deployed to decarbonise heating in London's existing buildings at all scale, from individual dwellings through to large-scale heat pumps serving heat networks.

In three of the four possible 2050 pathways developed to inform the GLA's 1.5C Compatible Action Plan, heat pump uptake is required to increase rapidly with at least 300,000 heat pumps being installed by 2030, at least 50,000 of which would be needed in existing buildings. By the 2030s, around 120,000 heat pumps will need to be deployed in existing buildings each year[16].

However, current levels of heat pump installations in existing buildings in London are low. Across the UK, only around 20,000 units are being installed per year on average. In London, only 304 domestic Renewable Heat Incentive (RHI) applications had been made for air source heat pumps from April 2014 to January 2020, the lowest of any region of the UK.

Figure 4: Domestic RHI applications (Air Source Heat Pumps) to January 2020



1.2 Heat pump technology can work in all London building types

Urban areas can bring additional challenges for heat pump retrofit in terms of strict limits on noise and finding suitable external and internal space. However, heat pump technology is diverse and versatile and, with appropriate design, installation and operation, heat pumps are technically viable across all London building types. For example:

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[15] Committee on Climate Change (2016). *Biomethane Technical Note*.

[16] Greater London Authority (2018). *1.5C compatible climate action plan.*

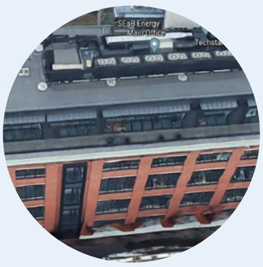
- Modern air source heat pumps are capable of noise levels well below those required for Permitted Development in dwellings.
- Fully internal air source heat pumps can remove the need for an outdoor fan unit where external space is not available.
- Shared ambient loops with individual heat pumps in each flat offer a solution for blocks of flats replacing individual gas boilers or direct electric heating.
- In dense urban areas, large heat pumps can be utilised in heat networks expanded to incorporate existing buildings, feeding off London's many sources of secondary and waste heat.

For situations in which higher temperatures cannot be avoided, high-temperature heat pumps are a developing, yet proven, area of technology that can be utilised. Alternatively, hybrid heat pumps and bi-valent systems (combining a heat pump with, for example, a back-up gas boiler) may offer an interim solution, although these are not compatible with net zero carbon objectives and with appropriate design and investment in energy efficiency, monovalent heat pump solutions are feasible in the majority of cases.

For individual buildings, the primary heat pump sources are likely to be air and ground source. In addition, for larger developments, London has a wealth of other renewable and secondary heat sources that can be utilised to improve the efficiency and financial case for heat pump retrofit. These include: shallow aquifers and ground water, surface water (e.g. rivers and lakes), waste heat from buildings, the London Underground, London sewers, data centres, waste treatment facilities and industrial sources.

Figure 5: Four examples of heat pump retrofit in different London building types

Central London office building



Refurbished under the Low Carbon Workplace partnership programme. Roof-mounted Mitsubishi VRF Reversible air source heat pumps provide total heating output of 427kW and total cooling output of 380kW. High performance glazing and new roof-level have improved thermal efficiency.

London Borough of Enfield, eight blocks of flats

Electric underfloor heating replaced with individual 3 – 6kW Kensa Shoebox heat pumps feeding off a shared ambient temperature ground loop. Fuel bills were reduced from £900-£1,100 to £260-£400 per year.

Image: Kensa Heat Pumps Ltd.

Bunhill 2 Energy Centre, Islington

The Bunhill 2 District Heating scheme utilises waste heat from the London Underground alongside heat pumps to provide heating and hot water to 1,350 homes, fully displacing the former communal gas boilers.

Air source heat pump - Victorian terraced house, Tower Hamlets

Oschner Compact 11kW Air to Water Heat Pump serving combined indoor unit and hot water cylinder. Low noise levels enabled siting of the heat pump despite close proximity of neighbouring properties.

Image: GroundSun Ltd.

1.3 Heat pumps are not a like-for-like replacement for gas boilers

Heat pumps can be applied to all building types, but they are not a like-for-like replacement for gas boilers and electric heating systems, and careful and detailed system design is required to ensure they will work efficiently and effectively.

A key difference between heat pumps and traditional forms of heating is that they operate most efficiently at lower flow temperatures. Some energy efficient buildings can already accommodate lower temperature heat and many heat pumps are capable of delivering higher temperature heat. However, optimising performance in London buildings will often require upgrading the heat emitters (i.e. radiators) and reducing heat loss through the thermal fabric of the building. In this sense, heat pumps require a greater focus on the holistic energy performance of the building and best practice design involves minimising heat losses as well as optimising supply.

But it is important to note that, given that the energy efficiency of buildings will need to be improved drastically to meet London's and the UK's net zero ambitions, these improvements will be required regardless of the low carbon heat technology path chosen.

Heat pumps: most efficient at lower temperatures

- In domestic and smaller non-domestic buildings, standard heat pumps operate most efficiently in the range of 35-55°C compared to gas boiler flow temperatures of 60-80°C. (Although many heat pumps are capable of delivering higher temperatures to periodically heat hot water above 60°C as legally required to kill the legionella bacteria).
- In communal and district heating schemes, flow temperatures of 55-65°C can be delivered efficiently through heat pumps serving upgraded heat distribution systems, compared to 70-90°C for traditional systems. The lower flow temperatures inherently reduce the system losses in heat networks that often account for a high proportion of overall energy use.
- In many non-domestic buildings, existing low flow temperature distribution systems (such as fan coil units) can often be utilised to deliver 35-55°C heat making these excellent candidates for heat pump retrofit. Where there is high cooling demand, reversible heat pumps are capable of providing free passive cooling, almost eliminating cooling bills.

A further difference between heat pumps and traditional forms of heating is that heat pumps need to be carefully and appropriately sized in relation to the heating and cooling requirements of the building. Also, particularly in larger (i.e. non-domestic or heat network scale projects) the heat source itself needs to be carefully assessed, for example through geological surveys or tests of ground water extraction. This will require qualified and experienced heat pump system designers to ensure that the heat pump solution is optimally designed and will deliver client expectations.

In this sense, heat pump retrofit involves extra requirements over traditional forms of heating in terms of system design. In larger applications, this may involve feasibility studies and options appraisals and detailed design stages to determine the most viable options and ensure the system will work effectively. However, this extra effort in design can reward building owners with high efficiency systems with the lowest lifetime costs.

For domestic and smaller scale projects, MCS certified installers should be used to ensure that best practice in heat pump design, installation and commissioning is followed. For larger projects, we recommend contacting a suitably qualified engineer or system designer through the Heat Pump Federation and Ground Source Heat Pump Association.

When designed, installed and operated to best practice standards, heat pumps can achieve very high annual efficiencies in the range of 250% to 385% for air source and 265% to 390% for ground or water source[17].

1.4 Improved energy efficiency will require significant investment

Energy efficiency measures to reduce heat loss are an essential prerequisite underpinning all scenarios for achieving net zero carbon, regardless of the technology path taken.

Energy efficiency improvements bring multiple benefits when undertaken alongside heat pump retrofit:

a. Overall demand is reduced, reducing the need for additional low carbon electricity generation and reducing fuel bills;

b. Peak demand is reduced, minimising expensive upgrades to local electricity networks and reducing the capital cost of the heat pump itself;

c. Flow temperatures can be reduced due to lower levels of building heat loss, increasing the efficiency of the heat pump;

d. Buildings can retain heat for longer, enabling them to benefit from time of use tariffs and other payments for flexibility;

e. Combining energy efficiency with heat pumps in an upgrade can ensure that fuel bills decrease relative to gas boilers, a priority for those in or near fuel poverty;

f. Combining works to install heat pumps and energy efficiency measures reduces time of disruption to building occupant.

[17] In this section we have used percentages to quantify the year-round efficiency of the heat pump. I.e. if 1000kWh of electricity is used to drive a heat pump that produces 3,000kWh of heat in a year, the annual efficiency would be 300%. This is also referred to as the Seasonal Co-efficient of Performance (SCOP) or Seasonal Performance Factor (SPF) each of which is expressed as a number, in this case 3.0. A full description of these metrics and how they can be used is provided in Appendix 1.

Some energy efficiency measures are cost effective and improve the overall business case for heat pumps. However, in many cases, energy efficiency will not pay for itself in fuel bill savings and will require significant up-front capital investment. This will likely require infrastructure level spending from government, combined with tighter building regulations for existing buildings undertaking changes involving the thermal fabric. The Government has recently announced £3bn will be spent on energy efficiency retrofit measures in public sector buildings and homes in the next year, but this will need to maintained and increased over the long term and be targeted at all building types.

Some building types in London can reduce space heating demand more cost effectively than others. Therefore, deep retrofits to net zero carbon standards will be necessary in some buildings to accommodate the shallower retrofits in harder to decarbonise buildings. For example, through the GLA's Retrofit Accelerator – Homes, a consortium, including Energiesprong UK, Turner & Townsend and the Carbon Trust, is currently working with social housing in London to identify how some archetypes can be retrofitted to net zero carbon standards at scale.

Case study:

Nottingham City Homes retrofit of terraced houses to Energiesprong UK net zero carbon standard

Under the Energiesprong approach, a 30-year performance guarantee ensures that carbon savings and low fuel bills are delivered and sustained. Bringing forward predicted capital spend on repairs and maintenance can improve the business case for whole house retrofit. Off-site manufacture of materials and procurement at scale can mean that costs can reduce as scale increases. Post 1930s terraces and low-rise blocks of flats could provide particular areas of opportunity for this approach, that typically involves applying a full air-tight, new external envelope over the top of the existing building.

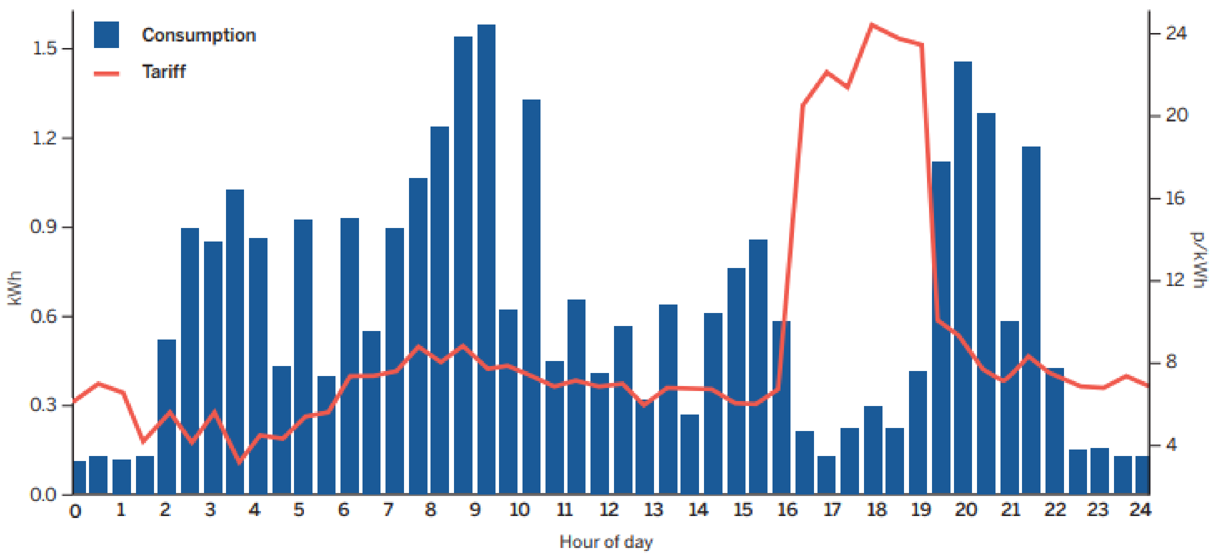
1.5 Flexibility of demand is essential for a net zero carbon energy system

Decarbonisation through the electrification of heat will increase the peak demand on local electricity networks and require increased overall levels of low carbon electricity generation. However, Demand Side Response (DSR) (flexing the timing of demand to when low carbon electricity supply is more readily available) has the potential to limit these additional costs.

Heat pumps owners can benefit from the value that new markets for flexibility are creating. For example, in our analysis of 15 example buildings in London, we found that flexible time of use tariffs could reduce fuel bills by up to 23% in some buildings, by shifting the demand for heat outside of the peak tariff times (typically between 16:30 and 19:30).

The figure below shows an example from a building using a popular domestic time of use tariff, where rates per kWh vary within each half hour period according to supply and demand for electricity. Adjusting heating patterns to avoid peak periods would enable a flattening of the peak demand for electricity, as well as aiding the financial case for heat pumps by lowering fuel bills.

Figure 6: Example dwelling shifting heating load outside of peak tariff periods[18]



Technology companies are increasingly seeking to automate demand side response through the use of smart technology that reacts to dynamic pricing in light of the demand for heat and hot water. Increased energy efficiency in properties will mean that heat can be stored for longer, enabling pre-heating of the buildings at cheaper tariffs.

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[18] Regulatory Assistance Project (2020). *Heating without the hot air: principles for smart heat electrification*

The market for building level flexibility services is nascent, but the flexibility of demand is key to enabling the widespread adoption of heat pumps, while simultaneously significantly contributing to the financial case for heat pumps at the individual building level.

1.6 Fuel bill impacts will vary

Compared to direct on-peak electric heating, heat pumps can deliver significant fuel bills savings of approximately 60-72%. Compared to off-peak electric heating (e.g. through storage heaters) heat pumps can achieve fuel bill savings of approximately 40-60%. However, when compared to typical gas fuel bills, the impact of a heat pump retrofit could increase or decrease fuel bills depending on a number of factors.

In the assumptions used in our 15 example buildings, standard electricity tariffs were 4.75 times the price of gas tariffs per kWh[19]. Under these assumptions, a heat pump would need to be 420% efficient to achieve the same fuel bills as a 90% efficient gas boiler. Compared to a 65% efficient gas boiler, heat pumps would need to be 300% efficient to achieve the same fuel bills[20]. In a retrofit context, heat pump efficiencies of 250%-350% are likely to be typical, therefore fuel bills could increase or decrease depending on the relative efficiency of the gas boiler being replaced.

However, this potential increase can be mitigated and even reversed by:

a. **Reducing space heating demand through energy efficiency:** Undertaking energy efficiency measures alongside heat pump retrofit reduces the demand for heat, lowering bills. In our sample, the deep retrofit of buildings showed the potential to reduce fuel bills by 60-90% through deep retrofit plus a heat pump.

b. **Maximising heat pump efficiency:** Through good practice system design and installation, heat pump efficiency can be maximised to achieve efficiencies in excess of 300%, minimising heat pump fuel bills.

c. **Using a more competitive electricity tariff:** Shopping around for the most competitive electricity tariff will minimise heat pump fuel bills.

d. **Using a dynamic time of use tariff:** In our sample of buildings, time of use tariffs with active load shifting had the potential to reduce fuel bills by up to 23%, often making heat pump fuel bills equivalent to or lower than gas, particularly for more energy efficient properties.

e. Removing **the gas standing charge:** In addition to the per kWh rates, we assumed standing charges of £87.60 for gas and £73 for electricity per year. Where a gas boiler is being removed from a property, this can remove the need to pay the gas standing charge[21]. This has the biggest impact on small properties, where the gas standing charge accounts for a higher proportion of the overall bill. In these cases, the removal of the gas standing charge can make the heat pump the lower cost option in terms of fuel bills, as the electricity standing charge is already being paid regardless of heating technology.

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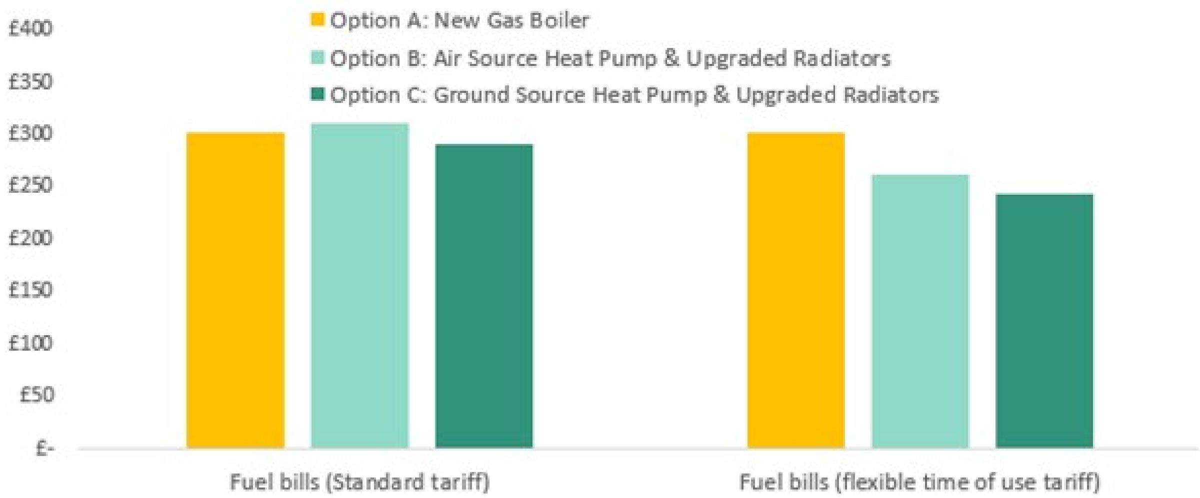
[19] For domestic customers we assumed a standard gas tariff of £0.032 per kWh and a standard electricity tariff of £0.152 per kWh, in line with the Treasury Green Book Central Domestic rates. I.e. our electricity standard tariff is assumed to be 4.75 times the cost of gas per kWh.

[20] A circa 65% efficient can be common in aging communal heating and district heat systems, often making these strong candidates for heat pump retrofit.

[21] It may be necessary to replace gas hobs with electric induction hobs in order to fully remove gas from the property.

Figure 7: Potential impact of time of use tariff with active load shifting of heat demand outside of peak hours. Example 1 bed flat. Source: Original analysis (See Chapter 5).



1.7 The financial case for heat pump retrofit is already strong for some buildings but additional incentives will be required for many

When considering the overall lifetime costs of heat pumps relative to other heating systems, some buildings already have a compelling financial case for heat pump investment and these should be prioritised for heat pump retrofit.

However, the primary barrier to heat pump retrofit is often the high up-front costs of the technology relative to gas boilers or standard electric systems. This is a fact that needs to be addressed in net zero carbon policy, strategies and actions plans and higher levels of subsidy would be required to make the financial case for heat pumps compelling.

We assessed the financial cases for heat pump retrofit relative to the replacement of a like-for-like heating system in 15 London buildings. This provided us with indications of the types of buildings that have the strongest cases for heat pump retrofit now and those that will require more financial or policy support to be cost effective.

	Building type	Summary
Strongest financial cases for heat pump retrofit now	Buildings heated by direct electric heating	Fuel bills could reduce by 60-75% leading to lower costs of operation for heat pumps in building types such as blocks of flats with electric heating or houses heated by electric boilers or storage heaters. Buildings with the potential for air source heat pumps will typically have the strongest financial cases.
	Buildings with a high demand for cooling	For example, office buildings that currently utilise electric chillers for cooling, can benefit from passive cooling via reversible heat pump systems to achieve large fuel bill savings. Financial cases are strongest where existing equipment is due for replacement and therefore the capital costs of replacing separate heating and cooling systems can be avoided. Where reversible air source heat pump systems are installed, installing solar PV at the same time can improve the financial case further due to the close correlation between PV generation and cooling demand.
Good financial case for heat pump retrofit now	Ageing communal and district heat networks in need of upgrade	A number of communal and district heating schemes across London are approaching end of life and require upgrades to the heat generation and distribution systems. In these cases, combining the heat pump installation with the wider building and heating system upgrades can make the financial case more attractive. In this sense, buildings can be made 'heat pump' ready at minimal additional cost to the retrofit works that are taking place anyway.
	Other buildings where major building refurbishments are being undertaken already	The poor efficiency and high system losses of some existing ageing gas boilers means that fuel bills can be reduced following heat pump retrofit, further reducing lifetime costs and improving the financial case. Undertaking energy efficiency of these blocks can reduce the capital cost of the heat pump and make more potential heat sources viable.
Marginal financial cases for heat pump retrofit at present. Additional support required	Gas-heated buildings with good levels of energy efficiency (EPC C or above) or where cost effective energy efficiency will bring the building to an EPC C standard	Approximately 25% of London's housing stock is already rated EPC C or above. These homes often represent relatively cost-effective opportunities for heat pump retrofit where capital investment in energy efficiency may not be required. In addition, some buildings have cost effective energy efficiency measures that can be carried out that could improve the financial case when undertaken as part of a package. These measures could include loft insulation, cavity wall insulation and upgrades to the air tightness of the building.

	Gas heated buildings with low temperature heat emitters	Low temperature heat emitters such as fan coil units and blown air systems (operating at flow temperature between 35-55°C) are common in London's non-domestic building stock. These can present good opportunities for heat pump retrofit as heat emitter upgrades are not required. In addition, many domestic buildings where energy efficiency improvements have already been made, have over-sized radiator systems that can accommodate lower flow temperatures without further upgrades.
	Buildings that require deep retrofit that are suitable for industrialised, scalable approaches	A number of house archetypes, particularly in London Borough and social landlord stocks, are well suited to scalable approaches to the deep retrofit of dwellings. In these approaches, the off-site manufacture of external wall insulation panels and renewable energy systems can be produced to achieve economies of scale in the deep retrofit of dwellings, with 30-year performance and maintenance guarantees. The avoided expenditure on planned maintenance and repairs can improve the financial case. Whilst these approaches require financial support in the near-term, at sufficient scale, these approaches have the potential to create compelling business cases for deep retrofit in their own right.
Weakest financial cases. Significant additional funding and policy support required	Buildings that require more expensive energy efficiency improvements (for example in heritage properties)	For buildings such as Victorian terraces with solid walls and single glazing, the cost of energy efficiency measures is high and unlikely to yield a positive return on investment. However, these measures are necessary in order to reduce overall heat demand and to enable efficient and effective heat pump operation. These buildings are likely to require financial support for energy efficiency improvements. Although the up-front costs are high, the cost per tonne of CO_2 reduced can be relatively low due to the high CO_2 savings achieved.
	Larger commercial buildings with high temperature heat demand and simple gas heating systems	In our small sample, office buildings with high temperature standard radiators, no cooling demand and relatively straightforward gas heating systems had the poorest financial cases for heat pump retrofit. In these cases, the very low cost of gas boiler replacement in the BAU scenario was the biggest factor driving this. This highlights the need for continued and additional subsidy and/or regulations for these types of building.

2. An action plan for heat pump retrofit at scale

Policy makers at all levels, including the UK government, Committee on Climate Change (CCC), GLA and London Boroughs, have identified the essential role that heat pumps and energy efficiency need to play if the UK is to deliver its net zero ambition.

The Department for Business, Energy & Industrial Strategy (BEIS) consultation – 'Future Support for Low Carbon Heat' – identifies that heat pumps could enable the UK to almost completely decarbonise heat alongside the decarbonisation of electricity generation[22]. This is supported by the CCC which forecasts that 19 million heat pumps will be needed by 2050[23].

Furthermore, economists have identified the huge potential value that investment in energy efficiency and low carbon retrofit could bring to the post-COVID economy. For example, a report from the Energy Efficiency Infrastructure Group has calculated that the economic impact of an infrastructure investment to bring all homes up to EPC C would have a Net Present Value of £47 billion, bringing new jobs, reduced power system investment and improved health[24].

Despite this, government hasn't yet provided the decisive regulatory or fiscal framework to support the installation of heat pumps or energy efficiency at the scale necessary.

To deliver the CCC's 2050 forecast for heat pumps, around 633,000 heat pumps need to be installed each year, (based on a straight-line trajectory from 2020). This is an ambitious goal but put in context this is equivalent to only 38% of the 1.67 million gas boilers sold in the UK in 2019[25][26]. In London, around 120,000 heat pumps will need to be deployed in existing buildings each year in the 2030s[27].

Current levels of heat pump installation fall far short of this. The current Renewable Heat Incentive (RHI) has supported approximately 9,900 heat pump installations a year across the UK. In London the RHI has supported a mere 66 installations per year since 2014[28]. BEIS' central scenario in its Future Support for Low Carbon Heat consultation is for only 12,500 heat pump installations a year with only £100 million proposed for heat pump grants over two years. This is several orders of magnitude below the level of ambition needed and contrasts starkly with the £2.2 billion identified for the Green Gas Levy (over four years)[29]. The £3 Billion announced for energy efficiency in homes and buildings in the summer economic statement (including the £2billion green homes grant) is a hugely welcome boost to the industry and a good starting point for future

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[22] Department for Business, Energy and Industrial Strategy (2020). *Consultation on future support for low carbon heat.*
[23] Committee on Climate Change (2019). *Net zero technical report.*
[24] Energy Efficiency Infrastructure Group (2019). *Making energy efficiency a public and private infrastructure investment priority.*
[25] Installer Online (2020). News article available at: www.installeronline.co.uk/2019-record-year-gas-boiler-sales/
[26] A number of gas boiler and heat pump manufacturers provide training to enable gas boiler installers to transition to the installation of heat pumps. See for example the Vaillant Evolve programme.
[27] Greater London Authority (2018). *1.5C compatible climate action plan.*
[28] Department for Business, Energy and Industrial Strategy (2020). *RHI monthly deployment data June 2020.*
[29] Her Majesty's Treasury (2020). *Budget Report: Delivering our promises to the British People.*

investment. However, according to CCC analysis, this will need to be increased to at least £15 billion a year to deliver the transition required.

The UK government, local authorities and the private sector will need to work together to catalyse the deployment of heat pumps. Public and private sector investment is needed to facilitate widespread and sustained growth in the development of a high-quality UK heat pump supply chain. In London, the GLA and London Boroughs can play a major role by identifying those heat pump projects that are ready to go and then work with the expertise of the private sector to identify solutions to make them happen. Projects such as these would help realise the government's and London's ambitions for a green recovery from the COVID-19 pandemic.

Based on some of the findings identified in this research, the following actions have been identified as necessary to enable and accelerate the widescale transition to heat pumps:

1. Rapidly escalate investment in thermal energy efficiency in buildings
2. Reduce the upfront capital costs paid by the building owner
3. Re-balance gas and electricity energy taxation to incentivise low carbon heating
4. Maximise financial rewards for the flexibility of heat demand
5. Encourage deployment of heat pumps in building types where there is already a strong financial case

This section sets out the actions we believe need to be taken, highlighting particularly the clear need for government to take further action.

2.1 Rapidly escalate investment in thermal energy efficiency in buildings

The examples in this report demonstrate that cost effective thermal energy efficiency measures can enhance the applicability of, and business case for, heat pump retrofits. However, the reality is that low hanging, cost effective, energy efficiency improvements – such as loft insulation and cavity wall insulation – have often already been undertaken.

To significantly reduce space heating demand in London's existing building stock to levels consistent with a net zero trajectory, will require investment in measures that do not pay for themselves through reduced fuel bills over their lifetime (e.g. replacing single glazing with double glazing in period properties, insulation for solid walls). Some buildings will need 'deep retrofit' to achieve best practice levels of heat demand (<50kWh per m^2 per annum)[30] bringing major benefits but also coming at significant capital costs of c.£40,000-£80,000 per dwelling. Substantial investment and new approaches to the financing of energy efficiency measures are required.

If a net zero ambition is to be achieved, the UK government needs to act quickly and:

- **Bring forward planned investment:** Ensure that the £50 million Social Housing Decarbonisation Fund announced in July 2020 is rapidly followed up by the £3.8 billion committed for social housing decarbonisation in the Conservative Party manifesto. The timing of the fund should be brought forward from the proposed 10 years to 3 – 5 years to help kick start the wider market.

- **Invest in energy efficiency as an infrastructure priority as part of the post COVD recovery plan for jobs and economic growth:** Commit to public investment to improve the energy efficiency of buildings as a national infrastructure priority, in line with the recommendations of the Business, Energy and Industrial Strategy Select Committee Report (2019)[31]. The £3bn announced in the July 2020 budget is a start but the remainder of the £9 billion identified for energy efficiency in the government's manifesto commitments needs to follow and will need to increase to at least £15 billion per year in line with the CCC's recommendations[32].

- **Invest in energy efficiency and low carbon heating together:** Ensure that future support for building decarbonisation encourages both energy efficiency and low carbon heating solutions, delivered at the same time or in planned succession, including through the use of building renovation passports. As an example, the current RHI disincentivises demand reduction. Heat pump installations should only be supported where cost-optimal levels of energy efficiency have already been reached or are planned as part of the installation.

[30] For example, approaches such as Energiesprong, Enerphit or the AECB building standard require space heating demand to be reduced to 25 – 50kWh per m^2 pa from typical levels of 100 – 250kWh per m^2 pa.
[31] UK Parliament Publications and Records (2019). *Energy efficiency, building towards net zero*
[32] Committee on Climate Change (2019). *Net Zero. The UK's contribution to stopping global warming.*

- **A strategy for EPC C:** Identify a strategy for how all buildings can be brought up to an EPC rating of C by 2035, in line with government targets, including in buildings where there is a long (or no) payback period for energy efficiency improvements.

- **Mandate Operational Performance Ratings for buildings:** Work with local authorities and others to mandate more meaningful and enforceable minimum operational performance ratings for different building types. These could be in the form of Energy Use Intensity (EUI) targets or Thermal Energy Demand Intensity (TEDI) targets and be set at levels compatible with a 2050 net zero carbon energy system, building on existing research such as the UKGBC Net Zero Carbon Buildings Framework[33].

- **Improve building energy efficiency to reduce peak load:** With Ofgem and the Distribution Network Operators (DNOs), explore options for DNOs to incentivise building energy efficiency as a mechanism for reducing peak load and network reinforcement under the RIIO-2 regulatory framework.

- **Devolve powers if necessary:** Where government is unable to take sufficient action at a national scale, they should enable local authorities to and regions, such as London, to take forward this agenda.

The GLA can:

- **Ensure heat pump are supported through existing programmes:** Ensure that funding programmes aimed at delivering retrofit in buildings, such as the Retrofit Accelerators for Homes and Workplaces and Warmer Homes are implementing heat pumps alongside energy efficiency measures to help build the supply chain and demonstrate the potential.

- **Pilot projects for heat pump retrofit at scale:** Work with London Boroughs, social housing providers and other partners to identify pilot projects for unlocking finance to deliver large scale deep retrofit of buildings, working with organisations such as the Green Finance Institute's Coalition for Energy Efficiency in Buildings (CEEB)[34] to develop pilot approaches and engage the finance industry.

London Boroughs and social landlords can:

- **Identify priority building, estates and heat networks for energy efficiency retrofits** through local authority climate action plans.

[33] UK Green Building Council (2019). *Energy performance targets for commercial offices.*
[34] Green Finance Institute (2020). *Financing energy efficient building the path to retrofit at scale.*

- **Engage with GLA programmes for the decarbonisation of buildings** such as Retrofit Accelerators for Homes and Workplaces programmes to unlock economies of scale and new ways of financing deep retrofit programmes such as Energiesprong.

- **Identify potential projects to be funded** through the Mayor of London's Energy Efficiency Fund (MEEF).

- Identify projects to be taken forward under the recently announced Social Housing Decarbonisation Fund and Green Homes Grant Local Authority Delivery scheme.

Public and private sector building owners can:

- Identify buildings where energy efficiency measures can be implemented, utilising available government funding including the Green Homes Grant, The Domestic RHI and Non-Domestic RHI.

2.2 Reduce the upfront capital costs paid by the building owner

Whilst there is scope for the capital costs of heat pump technologies to come down in the future[35], the current extra up-front capital cost of a heat pump when compared to a gas boiler is a fundamental barrier to their widespread uptake. This barrier is increased by the fact that, on first installation, most heat pump installations also require upgrades to a building's heating infrastructure such as radiators, hot water cylinders, thermal stores or district heating networks compatible with lower flow temperatures.

The gas boiler market in the UK is exceptionally mature. The economics of gas technology manufacture, installation and use (e.g. servicing) have been optimised. By contrast, the market for heat pumps in the UK is relatively new, with many economic efficiencies still to be captured.

Our analysis of 15 buildings in London suggests that the cost gap between a gas boiler and heat pump can vary significantly between properties. In our sample of nine individual domestic buildings, when upgraded radiators, hot water cylinder and installation were taken in to account the cost difference for an air source heat pump relative to a gas boiler was between £7,000 and £12,000 per property with an average gap of £9,498.

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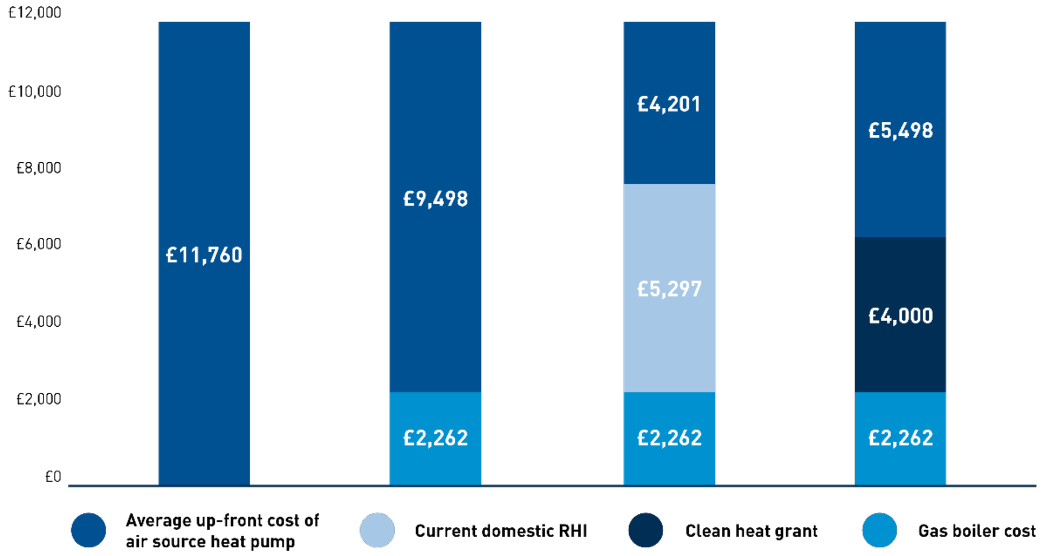
[35] Research undertaken in 2016 suggests that heat pump costs could reduce by ~20% when the market reaches full maturity. Delta EE for Department of Energy and Climate Change (2016). *Potential cost reductions for air source heat pumps.*

Figure 8: Additional up-front installed cost of domestic air source heat pumps (including heat emitters and hot water cylinders) in this study relative to gas boiler replacement, domestic RHI and the proposed Clean Heat Grant (Sample of 9 London dwellings)



Current levels of domestic RHI grant do not bridge this capital gap. The government's proposed Clean Heat Grant of £4,000 covers even less of this gap and would need to be increased by 200%-300% to incentivise heat pump uptake relative to gas boilers. Our research suggests that this capital gap is proportionally larger for many commercial buildings, and that current non-domestic RHI rates would need to be increased to incentivise a switch from fossil fuels.

Our research also highlights that capital installation costs may be higher in London and other dense urban areas than for the UK as a whole, contributing to the low uptake in these areas[36]. However, for some gas heated buildings that are already well suited for heat pumps (for example where further energy efficiency upgrades or upgrades to heating systems are not necessary) a 20% CAPEX reduction, on top of the proposed £4,000 Clean Heat Grant could be sufficient to make the total cost of heat ownership equivalent to gas over 10 years.

For example, the charts below are for a three-bedroom mid-terraced house (EPC C). Over 10 years, if an additional 20% CAPEX reduction is assumed on top of the proposed £4,000 Clean Heat Grant, the additional cost of ownership of the heat pump is only £1,200. The cost of the air source heat pump option then becomes lower than gas in years 12-15, before the air source heat pump is assumed to need replacing at year 15.

[36] A primary reason for this in our sample was that the dense urban more often gave rise to situations where specialist or premium heat pump models are required. In our sample of buildings this included heat pumps with very low noise levels; fully internal heat pumps with no external fan unit; and ambient shared ground loop heat pumps in buildings that were unsuitable for some lower cost air source heat pump solutions.

Figure 9: 3-bedroom terraced house (EPC C): cumulative lifetime costs. No RHI.

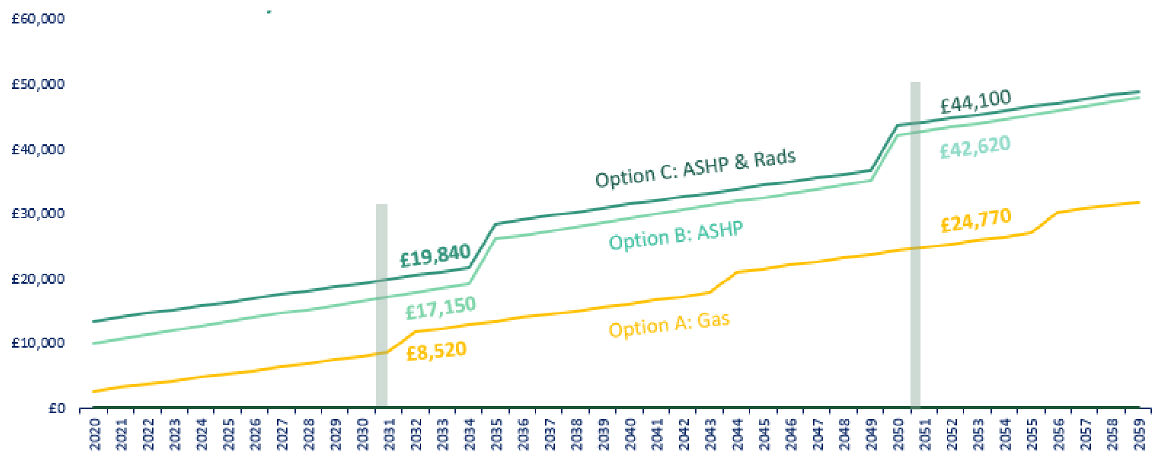
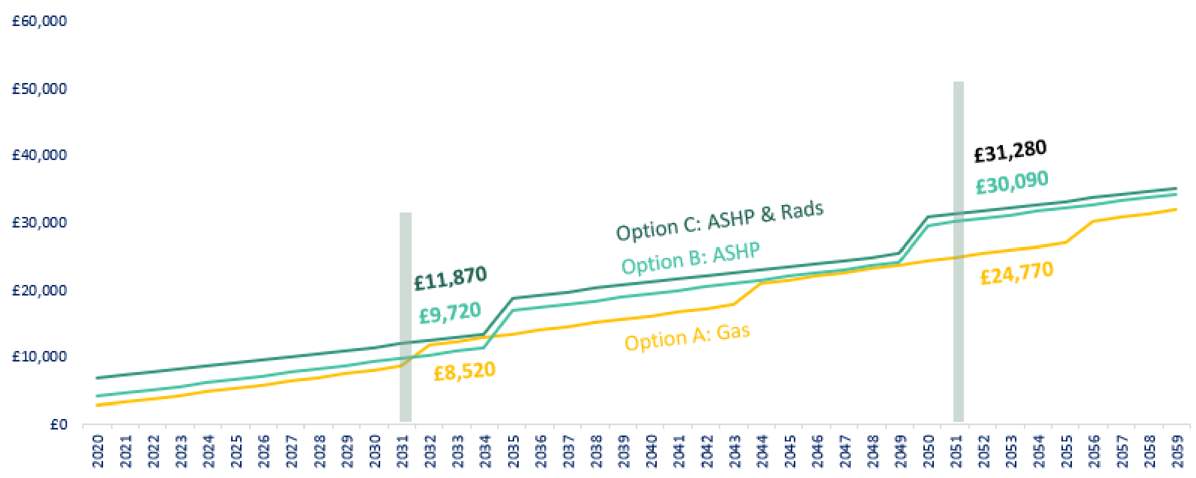


Figure 10: 3-bedroom terraced house (EPC C): cumulative lifetime costs including £4,000 Clean Heat Grant and 20% CAPEX reduction. Standard tariff.



A 20% reduction in CAPEX is realistic and could quickly be achieved through a combination of actions:

- Removing VAT (often charged at 20%) from heat pump equipment in existing buildings;
- Achieving economies of scale through the bulk purchase of equipment and installations by social landlords or reverse auction schemes;
- In the longer term, through reduced costs of sale, equipment and installation as the market reaches maturity[37][38].

The UK government needs to consider:

- **Increasing the proposed levels of the Clean Heat Grant:** Significantly increasing the proposed level for the Clean Heat Grant for heat pumps installations to a level that would remove or significantly reduce the capital gap with gas boilers. Levels of £7,000-£12,000 for domestic dwellings are necessary to remove the capital gap.
- **Removing the 20% VAT rate on heat pump equipment and the 5% VAT rate on heat pump labour costs[39].** Heat pump installations in new buildings are zero rated for VAT. Removing the current 20% VAT rate for equipment in retrofit installations would provide a significant boost to the financial case for heat pump retrofit, making heat pumps more cost competitive with gas.
- **Establishing a UK Heat Pump Accelerator** along similar lines to the Offshore Wind Accelerator, to bring together industry to identify common challenges which, if solved, would deliver reductions on capital or operational cost.
- **Setting a date for the banning of replacement fossil fuel systems in existing buildings,** sending a clear signal to the heat pump market to ramp up skills and capacity, enabling the supply chain to scale-up and deliver overall cost savings.

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[37] VAT is currently applied at 20% on heat pump equipment in retrofit compared to 0% in new build. A number of installers who contributed to this research, indicated that cost savings of 5-15% could be achievable through economies of scale. Research by Delta EE for BEIS in 2016 suggested that cost reductions of 15-20% could be achievable when the heat pump market reaches full scale.

[38] In our cost analysis, we assumed that each installation was an individual installation (i.e. not benefiting from economies of scale through bulk procurement) and included VAT at currently applicable rates (generally 20% for equipment and 5% for labour except in cases where equipment costs account for less than 60% of total costs where a 5% rate is applicable to equipment also). We included the capital costs of replacing equipment within the 30-year time frame. For air source heat pumps this typically involved a full replacement of the heat pump equipment at 15 years and for ground source heat pumps this typically involved a replacement of equipment (not including the ground loop) at 20 years. We took account of the fact that installation costs for heat pumps would typically be lower the second time around as much of the ancillary work and changes to pipework would not need to be repeated. However, we did not take in to account general reductions in the cost of heat pump equipment due to market maturity. In this sense, our estimates of cost could be seen as conservative relative to the potential for cost reduction in the market.

[39] GOV.UK (2020). *Tax on shopping and services.* Available at: https://www.gov.uk/tax-on-shopping/energy-saving-products

- **Providing options for introducing 0% interest loans for heat pump installation,** to spread the additional up-front cost over a longer period and remove the immediate financial barrier, similar to approaches taken by the Scottish Government[40].

The GLA should look to:

- **Explore the possibility of bulk procurement options** for groups of private households, such as group buying schemes and reverse auctions (similar to the Solar Together programme).
- **0% interest loans: Consider whether 0% interest loans for heat pump installation could be introduced through a green finance response to the COVID-19 recovery.**
- **Continue to support the heat pump market** wherever possible by installing heat pumps through its own programmes, including the Retrofit Accelerators and Warmer Homes.

London Boroughs, social landlords, commercial landlords and developers should look to:

- **Identify opportunities for larger scale procurements of heat pumps** across the building stock to achieve economies of scale

[40] Energy Saving Trust (2020). *Home Energy Scotland Loan.* Available at https://energysavingtrust.org.uk/scotland/grants-loans/home-energy-scotland-loan

The future of RHI funding

At the time of writing (August 2020):

- The Domestic RHI was confirmed to remain open to new applicants until midnight 31st March 2022.
- The Non-Domestic RHI closes for applications on 31st March 2021 with projects needing to be completed by 31st March 2022.
- For projects completing after 31st March 2022, there is the option to apply for a Tariff Guarantee. A tariff guarantee allows applicants to the Non-Domestic Renewable Heat Incentive (RHI) to secure a tariff rate before their installation is commissioned and fully accredited on the RHI. Tariff Guarantees are available to ground source heat pumps and water source heat pumps over 100kWth.
- New applications for Tariff Guarantees will need to be submitted by 31st March 2021 although earlier applications will benefit from higher tariffs. Projects approved for Tariff Guarantees will need to be commissioned by 31st March 2022.
- The RHI and Non-Domestic RHI analysis contained in this report was based on tariff rates applicable after April 2020. However, tariffs are subject to change over time. For the latest information on tariffs applicable to RHI projects, please consult the Ofgem website:
  - Domestic RHI
  - Non-Domestic RHI
  - Tariff Guarantees

2.3 Re-balance gas and electricity energy taxation to incentivise low carbon heating

Electricity and gas pricing, including taxation, is heavily skewed and encourages inefficient use of gas as the main fuel for heating. This pricing imbalance is a fundamental barrier to the mass adoption of heat pumps.

In 2018, 13% of electricity costs in the UK were for renewable energy levies. This figure was 0% for gas. It is clear that electricity currently shoulders the heaviest burden in terms of renewable energy costs despite it now having a lower carbon intensity than gas per kWh.

The 2020 Budget included the announcement of a Green Gas Levy which could add £1 to a domestic gas bill next year and £5 by 2025[41]. However, this does not address the significant skew in favour of the fossil fuel gas as the preferred source of heating in the UK. The Government needs to do more.

In our analysis, using standard gas and electricity tariffs, fuel bills were typically marginally higher for heat pumps than for gas boilers. However, if renewable energy levies were re-balanced, heat pump fuel bills could typically be lower than gas.

If a net zero ambition is to be achieved, the UK government needs to:

- **Do much more to level gas and electricity pricing**. It is essential that the imbalance between electricity and gas levies is redressed, and that the highest carbon forms of heating fuel bear the heaviest taxation burden. Redressing this imbalance will help ensure that consumer fuel bills do not increase in the transition from gas to heat pump heating.

2.4 Maximise financial rewards for the flexibility of heat demand

Flexibility and demand side response are recognised as essential components of the low carbon heating equation. Electricity tariffs which incentivise demand side participation are well suited to heat pump use. These tariffs, and other payments for electricity flexibility services, improve the financial case for heat pumps at the individual building and enable a more rapid and cost-effective transition for the energy system as a whole.

However, despite the high value of flexibility to the energy system, ways of monetising that value, particularly for smaller individual buildings owners, are currently limited. For example, there is currently only one dynamic time of use tariff available for homeowners. Bringing these services in to the mainstream is an important enabler for the transition to heat pumps. Time of use tariffs will help electricity customers to benefit from preferential electricity pricing that will reduce their energy bills and/or improve the case for investing in low carbon heat pumps.

The UK government should:

- **Ensure the smart meter roll out reaches all buildings,** as these are essential to enabling the transition to smarter tariffs that reward flexibility.
- **Work with Ofgem and DNOs** to identify ways of rewarding customers for the value of heat demand flexibility in RIIO-2.

[41] KPMG (2020). *Budget 2020. Implications for the Energy Sector*. Available at: https://home.kpmg/uk/en/home/insights/2020/03/budget-2020-implications-for-the-energy-sector.html

The GLA should:

- **Explore, through London Power,** whether there are opportunities to develop and promote tariffs suitable for heat pump owners that reward demand flexibility.
- **With London Boroughs, work with DNOs (UKPN and SSEN) and other partners** to identify pilot programmes for monetising the value of flexibility and peak demand reduction to the electricity network. Continue to support programmes such as Home Response which integrate flexibility and time of use tariffs.

2.5 Encourage deployment of heat pumps in building types where there is already a strong financial case

There is already a compelling financial case for deploying heat pumps in some London building types and these should be prioritised for heat pump and energy efficiency retrofit in the immediate term:

- **Homes, blocks of flats and non-domestic buildings heated by electricity.** Where a building is currently heated by on-peak electricity, installing a heat pump is likely to deliver annual fuel bills savings in the region of 60-80% and CO_2 emissions savings in the region of 60-70% compared to direct electric heating. In the most compelling cases, this can potentially be achieved at negative costs of carbon reduction, for example in example building 05 (a three-bedroom terrace, heated by on-peak electricity) an air source heat pump option could achieve CO_2 savings at -£537 per tCO_2 by 2050[42].
- **Buildings with a high demand for cooling such as large office buildings**. Where buildings currently have separate systems for heating and cooling, these can often be replaced by reversible heat pump technologies that are able to provide heating and cooling. Where ambient temperature ground loops or ground or surface water are used as the heat source, passive cooling is possible, at minimal operating cost to the building occupants. In terms of lifetime costs, the benefits of installing and maintaining a single technology can make the heat pump retrofit financial case attractive and lead to large CO_2 savings. For buildings with a high demand for cooling using reversible air source heat pumps, business cases can be improved even further through the installation of solar PV. The generation profile of the solar PV closely matches the demand profile for cooling, enabling building owners to benefit from significant electricity bill savings.
- **Blocks of flats where upgrades are required to the heating systems and heat distribution systems in any case.** Conversations with London Boroughs as part of this research suggest that are a large number of communal and district heating schemes with ageing boilers and inefficient heat distribution systems in need of renewal in London. The renewal of these systems provides excellent opportunities for either heat pump retrofit or connection to an existing or planned district heat network. As the costs

[42] This refers to the cost in £ for reducing CO_2 emissions by one tonne. In this case, both the costs and the emissions reductions are added up over 30 years to understand the overall, un-discounted, lifetime costs and CO_2 emissions reductions. Where the cost of carbon is negative, as in this case, this means that building owners are financially better off than had the measures not been undertaken (assuming the building owner is responsible for the investment and for reaping the rewards of lower energy bills).

of upgrades to heat emitters and distribution are required in any case, the financial case for heat pump retrofits is relatively stronger than in other building types. London Boroughs are actively seeking ways to reduce major sources of CO_2 emissions in their own estate, especially in response to their declarations of climate emergencies and their net zero carbon targets. The retrofit of communally heated blocks offers the opportunity for significant reductions in CO_2 emissions from local authority-owned estates

In order to ensure these buildings are prioritised in the immediate term, the UK government should consider:

- **Regulations that disincentivise the like-for-like replacement of on-peak electric heating systems.** Regulations could require buildings to install heating systems and retrofit measures that together deliver to minimum energy performance standards. Only in specific situations could these could be met by retaining conventional electric heating, e.g. by combining with a deep retrofit of the building to very low levels of space heating demand (<30kWh per m2 pa).
- **Work with the local authorities** to ensure that the Heat Network Delivery Unit (HNDU) and Heat Network Investment Project (HNIP) provide support for the replacement of existing heat sources on district and communal heat networks with low carbon heat sources.
- **Deliver a successor to the Non-Domestic Renewable Heat Incentive** that continues to support the financial case for heating systems serving multiple dwellings and also supports the exploitation of waste heat sources – a new Renewable and Waste Heat Incentive.

The GLA and London Boroughs should:

- **Continue to provide support (through the Decentralised Energy Enabling Project) for options appraisals and feasibility studies** for the refurbishment of existing heating systems and the replacement of gas-fired boilers with a connection to a local heat network, where one exists or is planned, or otherwise through heat pump ready infrastructure and the installation of heat pump-led energy centres.

Local authorities, social landlords and commercial landlords should:

- Identify electric heating replacement programmes in suitable properties and green finance packages to fund the transition to heat pumps.
- Work with commercial landlords and local authority estates to identify and implement opportunities for installing reversible heat pumps in buildings with high cooling demand.

- **Highlight the financial and environmental benefits to those building owners who use on-peak electric heating.**

- **Where gas heating systems in communal and district heat networks are due for renewal or upgrade, undertake** feasibility studies and options appraisals for their replacement with heat pumps and energy efficiency improvement works.

Case Study

Heat pump retrofit in three communally heated estates in Southwark

In 2019, the London Borough of Southwark undertook a feasibility study, with input from ICAX Limited, to determine the potential for installing heat pumps in a number of communally heated housing estates. Due to the geology below Southwark it was found that water source heat pumps, which use aquifer water as a heat source, could be a particularly efficient and financially viable renewable heating option for the Borough.

- Eight estates were initially considered for the technology with relevant factors including available plant room space, the heat loads of the building and geology particular to each site.
- Five estate were considered favourable to take forward to detailed feasibility study stage. This study considered detailed installation costs, running costs and carbon savings, as well as associated logistical and technical issues associated with retrofitting heat pumps in to the existing communal heating systems.
- Three of these five estates (Consort, Newington and Wyndham) were found to be technically and economically viable for the replacement of existing gas boilers with water source heat pumps.

A tender was run to find an installer and a contract was awarded in June 2020 to Vital Energi to design, build and operate the heat pump solutions, with ICAX Limited providing the design, supply and installation of high temperature heat pumps (for retrofit), ancillary equipment, and aquifer well pairs across the three sites.

When completed, the technology will become the primary heat source for the heat networks on the three housing estates supplying low carbon heat to 2,175 homes. The project is projected to save 1,774 tonnes of CO_2e per annum. The projected capacity of the heat pumps per installation is anticipated to be in excess of 1,000 kW (thermal). The heat pumps will also make a positive contribution to local air quality by replacing emissions from the existing gas boilers, which emit harmful NOx and particulate matter.

The technical and financial viability of the project is aided by the fact that pipework upgrades were already scheduled for the buildings, enabling them to be upgraded in a manner that will improve the overall efficiency of the heat pump technology.

The heat pumps will extract heat from water that occurs naturally below ground using 'open loop' supplied water source heat pumps to increase the temperature and this heat is then fed into a heat network which supplies the heat direct to homes. The project is anticipated to involve relatively little disruption for tenants and requires the drilling of only two boreholes (one for extraction and one for discharge of the aquifer water). The estates will retain their existing gas boilers as a back-up measures and to provide additional resilience for very cold days in winter.

The project is being undertaken with no additional costs passed on to the residents. As the heat pumps are serving multiple buildings, the project is eligible for the non-domestic RHI enabling it to benefit from 20-year guaranteed subsidy levels. In addition, the Mayor of London's Energy Efficiency Fund ('MEEF'), has provided £7 million to the London Borough of Southwark to finance the up-front costs of the installation of the water source heat pumps.

The project will support up to 45 new jobs with Vital Energi committing to ensuring a number of these roles will be filled by apprentices from within the Borough.

As tenants are not being charged for the upgraded heating system, this means that there is no legal obligation to consult with residents on the changes. However, the Council fully intends to liaise with residents to ensure that disruption is kept to a minimum and they have all necessary information. Heating costs are predicted to remain unchanged.

3. Other options for decarbonising heat

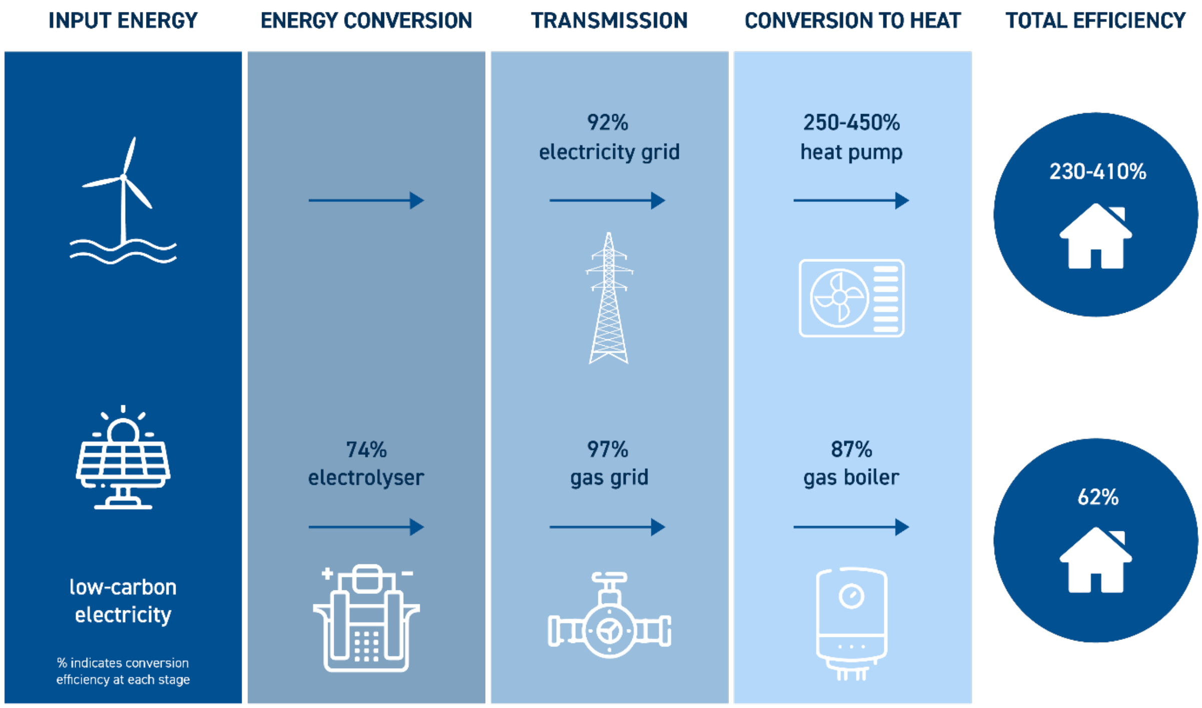
Decarbonising heat from buildings will require a range of technologies to be deployed, with heat pumps being installed alongside other technologies that are currently at different readiness levels and scales. The following table summarises some of the main options for decarbonising heat in buildings.

Hydrogen

The UK government, the Committee on Climate Change (CCC) and Gas Distribution Networks are exploring whether the natural gas grid in the UK could be fully converted to carry hydrogen or whether a mixture of natural gas with 20% hydrogen could be carried.[43] When burned, hydrogen produces no CO_2 emissions, just water vapour and heat. Hydrogen boilers have already been developed by companies including BAXI and Worcester Bosch that operate in a similar way to existing gas boilers

To achieve full and widescale decarbonisation of heating, this would require the London gas distribution network to be fully converted to hydrogen, which would require upgrades to the gas grid that are not anticipated to be complete until the 2030s.

Figure 11: relative primary fuel use efficiency of heat pumps and hydrogen boilers (CCC)[1].



[43] Hydeploy (2020). *Hydrogen is vital to tackling climate change.* Available at https://hydeploy.co.uk/

Even then, the main challenge for hydrogen is that its production requires large amounts of energy. To be low carbon this would require additional low carbon electricity or Carbon Capture and Storage (CCS) capacity. CCS capacity does not yet exist in the UK at scale and as the graphic below suggests, hydrogen production is an inefficient way of using low carbon electricity in buildings compared to using heat pumps. Fuel bills would be likely to increase substantially with a hydrogen boiler. In short, hydrogen does not look set to become a prominent low carbon heating fuel for London's buildings in the short to medium term. Previous studies for the GLA suggest that hydrogen is most likely to play a role from the 2040s onwards[44], primarily for industrial uses where very high temperature heat is required.

Green Gas

Biomethane produced from the anaerobic digestion of biomass feedstocks (e.g. food waste) can be injected directly into the gas grid following a suitable upgrading process. As biomethane is produced from biomass, it is considered renewable and can offer significant carbon savings when compared with natural gas. The UK government has recently set out plans to continue to support producers of biomethane through the Green Gas Support Scheme.

However, the CCC's central estimate of the available biomethane resource is around 20 TWh, which would equate to displacing about 5% of fossil natural gas in 2050. Therefore, green gas alone is unlikely to provide a true low carbon heating solution.

Secondary (waste) heat

The 2013 London Secondary Heat Study identified that London has huge heat potential from secondary sources including rejected heat from building cooling systems, waste heat from water and sewage treatment works and sewer heat mining. Heat can also be extracted from existing energy from waste plants. This waste heat resource is also well located in terms of nearby sources of heat demand.

In the majority of cases, waste heat requires upgrading by heat pumps in order to achieve temperatures useful for heat networks and buildings. Chapter 9 of this report discusses potential waste heat sources and how heat pumps can utilise these to deliver efficient low carbon heating.

[44] Element Energy for Greater London Authority (2018). *London's Climate Action Plan WP3 Zero Carbon Energy Systems*. See p28.

Heat networks

Heat networks are likely to play a vital role in the decarbonisation of London's heat supply, particularly in areas of high heat density. Heat networks can provide heat more efficiently than individual building technologies by benefiting from economies of scale and the diversity of demand across users.

Heat networks can operate at a range of temperatures depending on their heat sources and the buildings they are supplying. Flow temperatures in heat networks are reducing to increase their performance and reduce heat losses, especially allowing them to take advantage of low-grade waste heat sources. When using low grade waste heat, the efficiency of heat networks increases when combined with lower flow temperatures in the system, as this reduces losses in the distribution network, minimises the uplift in temperature required between the heat source and the heating system and enables the heat pump technology to operate at a high efficiency.

All scenarios considered in the GLA's 1.5C Compatible Climate Action Plan include at least 100,000 homes connected to district heating by 2025, an increase of 70,000 over current levels.

Biomass

Whilst biomass boilers are likely to have a role to play in decarbonising heat in rural areas, due to air quality concerns, this technology is not predicted to play any significant role in decarbonising heat in London. None of the GLA's 1.5C Compatible Climate Action Plan scenarios include biomass heating.

Energy efficiency

Energy efficiency facilitates low carbon heating by reducing overall demand, enabling low temperature heat sources (such as heat pumps) to work efficiently and minimising the need for reinforcement of the electricity grid. Furthermore, buildings with greater energy efficiency can be more flexible in when heating is supplied, enabling buildings to respond flexibly to supply conditions.

Summary of 15 buildings used for analysis

As part of this research, we identified 15 buildings in London that are typical of common building types. For each building we undertook an options appraisal, assessing the potential for the retrofit of heat pumps and energy efficiency measures and modelling the CO_2 savings, fuel bills, up-front costs and lifetime costs.

We developed costings for each project by consulting with heat pump manufacturers and installers regarding the costs of measures, taking in to account the upgrades to heat emitters, hot water cylinders and energy efficiency measures that would be necessary for each property.

Full details of every property and the Options appraisal undertaken are available in the document: Options appraisals for heat pump retrofit in 15 London buildings.

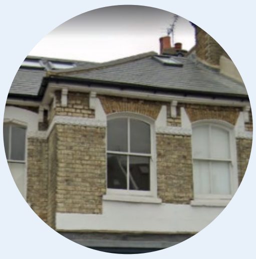
Whilst the 15 examples were not intended as an exhaustive or statistically representative sample of buildings in London; they provide valuable insights into the challenges and opportunities of heat pump retrofit in London using worked, real world examples. GLA analysis of the London building stock indicates that the 11 domestic examples are broadly representative of approximately a quarter of London's homes[45].

[45] Based on properties of the same type (flat, terraced house etc), property age and EPC band.

01. 1 bed flat, Lymington Road, Camden

02. 2 bed flat; Cavendish House, Barnet

03. 2 bed Flat, Sherwin House, Lambeth



04. 3 bed flat, Northcote Road, Wandsworth

05. 2 bed house, Aldenham Drive, Hillingdon

06. 3 bed house, Surrey Road, Southwark

07. 3 bed house, Mowbray Road, Croydon

08. 3 bed house, Albany Road, Newham

09. 5 bed house, Tradescant Road, Lambeth

10. Ernest Dence Estate (95 flats), Greenwich

11. Enfield tower block (50 flats), electric heating

12. Small office building, Gifford House, Merton

13. Medium office building, Billet Road, Waltham Forest

14. Large office building. Docklands Road, Newham

15. Wimbledon Library, Merton

Table: Summary of 15 example London buildings used in analysis

	Street	Borough	Size	Floor area	Type	Age	Heating fuel	EPC Rating	Space heating demand (kWh per m² pa)
01	Lymington Road	Camden	1 Bed	49m²	Ground floor flat	1970s	Gas	C	69
02	Cavendish House	Barnet	2 Bed	75m²	Mid floor flat	1980s	Gas	B	26
03	Sherwin House	Lambeth	2 Bed	53m²	Ground floor flat	1930s	Gas	C	74
04	Northcote Road	Wandsworth	3 Bed	114m²	Top floor maisonette	1880s	Gas	D	105
05	Aldenham Drive	Hillingdon	2 Bed	60m²	Terraced house	1980s	Electric boiler	C	66
06	Surrey Road	Southwark	3 Bed	93m²	Terraced house	1960s	Gas	C	72
07	Mowbray Road	Croydon	3 Bed	133m²	Detached house	1930s	Gas	D	123
08	Albany Road	Newham	3 Bed	94m²	Terraced house	1900s	Gas	D	94
09	Tradescant Road	Lambeth	5 Bed	142m²	Terraced house	1870s	Gas	E	156
10	Ernest Dence Estate,	Greenwich	95 Flats	~5,700m²	Block of flats	1930s	Gas (communal)	C - E	116
11	Tower Block	Enfield	50 Flats	~2,900m²	Block of flats	1960s	Electric heating	C - E	52
12	Gifford House	Merton		~800m²	Small office	1983	Gas	D	110
13	Billet Road	Waltham Forest		2,413m²	Medium office	1970s	Gas	C	90
14	Docklands Road	Newham		37,544m²	Very large office	2000s	Gas (electric cooling)	D	90
15	Wimbledon Library	Merton		500m²	Library	Pre 1900	Gas	D-E	130

Section B

Three foundations for heat pump retrofit

Heat pumps are not a like-for-like replacement for gas boilers. The transition to heat pumps will involve heating and cooling becoming a major component of the wider low carbon electricity system. To facilitate this, overall demand for heat must be reduced, heat will need to be used more flexibly in response to dynamic changes in supply, and the efficiency of installed heat pumps will need to be optimised. At the building level, these same factors are essential to ensuring high performance and low fuel bills with heat pump retrofit.

In this section we introduce these three key foundations:

- Energy efficiency and the need to reduce heat demand
- Heat pumps and the benefits of flexible time of use tariffs
- Optimising heat pump system design

4. Energy efficiency and the need to reduce heat demand

Energy efficiency is a pre-requisite for the decarbonisation of heat under all potential technology scenarios in London. Not every individual building will require energy efficiency improvements before heat pumps can be installed but many will, and at the energy system level reduced energy demand is essential to achieving net zero carbon emissions.

As part of the GLA's 1.5°C Compatible Climate Action Plan, the potential impact on local electricity networks was modelled. All four zero carbon scenarios[46] show the necessity for a sharp increase in the levels of building energy efficiency retrofit in London with approximately 1.5 million buildings retrofitted to EPC C by 2035[47]. Without this, the electrification of heat in buildings would lead to major increases in peak electricity demand with associated high costs for upgrading the network.

Energy efficiency enables the widespread introduction of heat pumps in a number of ways:

- Peak heat load is reduced, minimising reinforcement of the electricity network;
- The additional requirement for zero carbon electricity generation is reduced;
- Buildings are able to be heated by lower temperatures, increasing heat pump efficiency;
- Buildings can retain heat for longer, enabling greater flexibility in their demand for heating;
- The capital cost of the heat pump system is reduced, improving the financial case for heat pumps at the building level.

4.1 The need to reduce overall demand for electricity

Despite forecast increases in renewable electricity generation, these are not predicted to provide sufficient supply for the electrification of heat at current levels of heating demand.

According to analysis undertaken by the UK Green Building Council (UKGBC), projections for low carbon electricity supply in 2050 range from 68% of today's electricity demand (Committee on Climate Change projections) to 40% (BEIS projections). The case for demand reduction is even more acute considering that heat pumps will generally represent additional load on the grid relative to current use[48].

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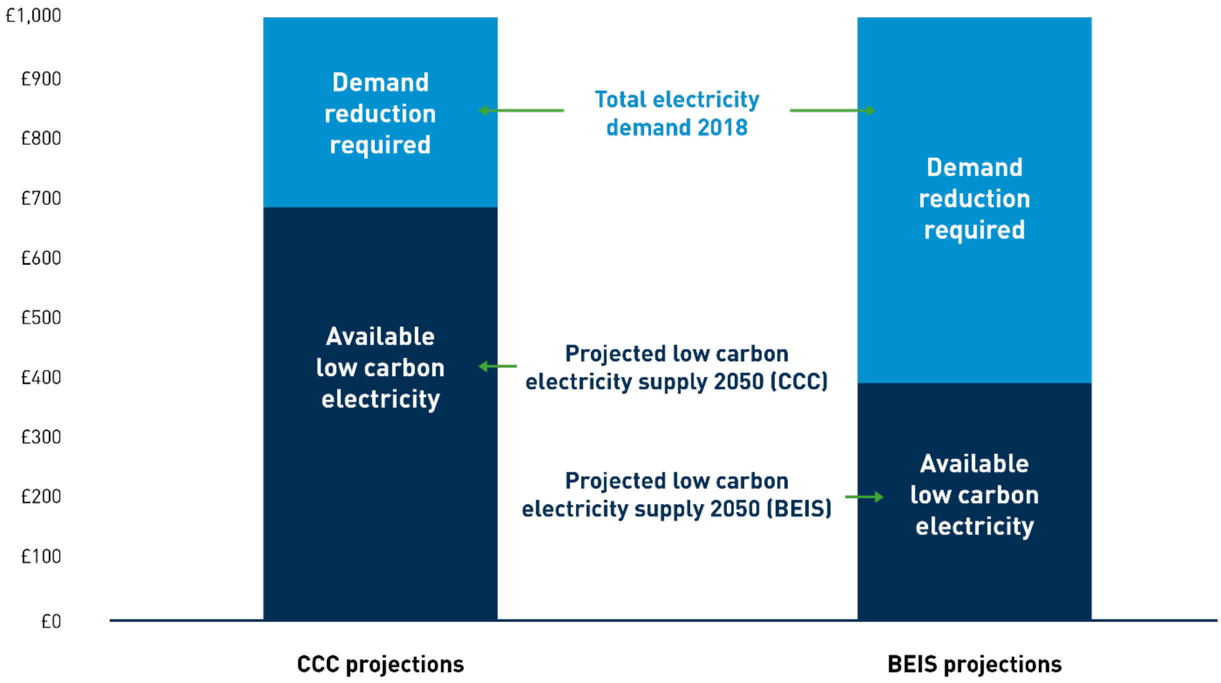
[46] Element Energy for Greater London Authority (2018). *London's Climate Action Plan WP3 Zero Carbon Energy Systems*.

[47] After 2035, it was assumed that increased levels of Demand Side Response (made possible partly by the increased energy efficiency) would then be capable of off-setting a large proportion of investment that would otherwise be necessary in the electricity grid.

[48] UK Green Building Council (2019). *Energy performance targets for commercial offices.*

Figure 12: Projections of 2050 renewable electricity supply vs demand for electricity (UK, All Sectors) TWh



4.2 Energy efficiency improves the performance of heat pumps

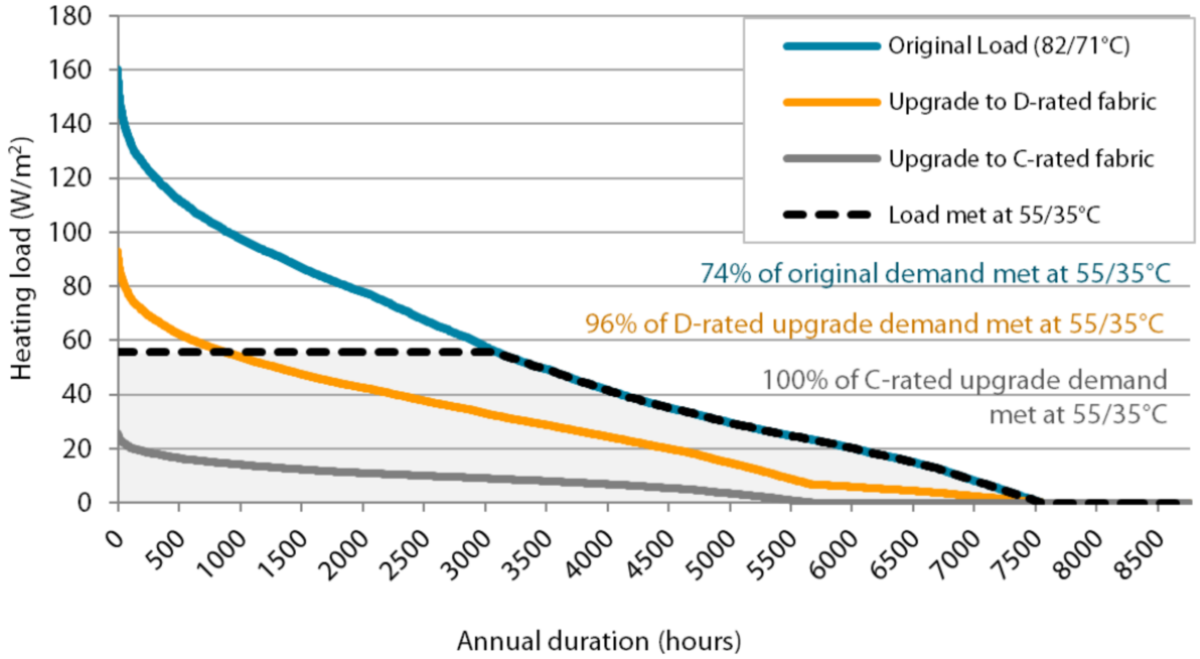
Heat pumps are most efficient at lower flow temperatures, typically below 55°C. Energy efficiency reduces heat loss in buildings, enabling lower temperature heat to be used.

Analysis carried out as part of the London Secondary Heat Study found that around 70% of the heat load in a range of example building types could be met with flow temperatures of 55°C where appropriate heat emitters are utilised. Only 30% of the heating load could be met by flow temperatures of 40°C.

The addition of energy efficiency retrofit measures significantly improved the ability of buildings to utilise low grade heat. The figure below demonstrates this effect for upgrading an example E-rated building. Without retrofit measures, a flow temperature of 55°C is estimated to meet only 74% of the annual demand. Upgrading the energy performance of the building to a D rating would allow this low temperature supply to meet 96% of the annual heating demand. Further upgrade to a C rating could allow 100% of demand to be met by a 55°C flow temperature[49].

[49] Please note that this figure refers only to the provision of space heating demand. Most heat pump systems are capable of heating water to the legally required minimum of 60°C for the purpose of killing the legionella bacteria, either through occasional use of the heat pump at lower efficiency or through in-built immersion heaters.

Figure 13: Flow temperatures for example building at different EPC bands: re-produced from London Secondary Heat Study



4.3 Should we set minimum energy performance standards for buildings?

It is clear that overall heat demand needs to reduce and that buildings with better thermal performance can accommodate heat pumps more efficiently. Should we therefore set minimum energy performance standards for buildings prior to heat pump retrofit and what should these be?

Minimum standards for efficient use of the heat pump

As noted above, for a standard heat pump, a minimum level of thermal performance is required to enable the heat pump to operate at efficient flow temperatures, typically 55°C or lower[50]. Flow temperatures are function of both fabric heat loss and the output of the heat emitters (such as radiators), but in practice there are limits to the extent that heat emitter sizes can be increased in buildings. In our sample of 15 Buildings, all buildings below EPC D required upgrades to the building fabric in order for flow temperatures below 55°C to be feasible, mirroring the findings in the London Secondary Heat Study (above).

[50] Please see Chapter 8 for information on low temperature, standard temperature and high temperature heat pumps.

In that sense, an EPC rating of C could be used as a very rough rule of thumb to indicate a building has achieved the minimum level of thermal performance for the heat pump to work efficiently.

However, EPCs are an imprecise tool for assessing thermal efficiency and therefore have limitations as a guide to heat pump suitability[51]. Also, whilst that approach may be suitable at the building level, at the system level, greater levels of reduction are necessary.

The UKGBC amongst others has started to consider how Energy Use Intensity (EUI) targets could be used to set minimum energy efficiency standard for buildings, based on the performance levels that all buildings will be required to achieve by 2050 in a net zero carbon scenario. Focussing solely on offices, UKGBC identified that the office sector will need to achieve an overall 60% reduction in energy use. Work is ongoing to identify how these targets could be equitably disaggregated to individual buildings.

A further metric that could be used is **Thermal Energy Demand Intensity (TEDI),** for example, kWh per m2 per year (as used in the Options appraisal for heat pump retrofit in 15 London buildings report). Unlike the EUI, this metric focussed solely on thermal energy demand, irrespective of how the energy is supplied. In this sense, it is the most useful metric on which to a base minimum standard of thermal performance for buildings, prior to installation of a heat pump.

Different types of buildings have different levels of ability to reduce space heating demand. Therefore, different TEDI targets could be set for different types and age of building. Further research is needed to understand good practice TEDI levels for different building types and in the context of overall levels of low carbon electricity supply and, at the local level, constraints on capacity.

Whilst our report does not explore the necessary balance between demand reduction and electricity supply in detail, we have included energy efficiency as critical criteria in each of our 15 case studies.

[51] There is a well evidenced 'performance gap' between modelled energy use and actual energy use. Also, as EPCs cover both demand and supply, a building with poor energy efficiency but a large array of solar panels could show up as a B or C rated building.

5. Heat pumps and the benefits of flexible time of use tariffs

5.1 The increasing role of flexibility in the power system

To achieve net zero emissions by 2050, both the supply and demand sides of the UK's power system are undergoing drastic change. Supply is increasingly met by intermittent renewables and inflexible nuclear generation, whilst the electrification of heat and transport sectors is significantly increasing power demand. To accommodate the larger demand from a more unpredictable and inflexible supply, increased flexibility in demand will become essential to delivering low carbon electricity supplies in a cost effective and sustainable manner.

Analysis by the Carbon Trust and Imperial College has suggested that the deployment of flexibility technologies will save the UK £17-40bn across the electricity system between now and 2050[52].

The flexible use of heat can also bring significant financial rewards for individual building owners. For example, flexible time of use tariffs enable building owners to benefit from lower fuel bills by modifying heating patterns to match periods of lower electricity prices.

Developing and engaging with the markets for flexibility will be crucial to delivering low carbon heat in a way that is affordable for individual buildings and for society as a whole.

5.2 Heat pumps and the markets for flexibility

Unlike buildings with gas boilers, buildings with heat pumps have the ability to engage with emerging markets for electricity demand flexibility, by being flexible in when the heat pump is using electricity to provide space and water heating.

Two main ways in which customers can take advantage of national flexibility markets are:

1. Time of use tariffs. Utility tariff that encourages consumers to shift their electricity demand outside of peak hours (16.00-19.00) by charging a premium for any use within peak hours and a discounted rate for off-peak consumption. First introduced in the UK by Green Energy UK in 2017.
2. Demand-side response (DSR) aggregation. Platform that aggregates smaller loads to provide the scale necessary to offer flexibility services to the National Grid in exchange for financial incentives[53].

Many larger commercial and industrial energy users such as supermarkets, manufacturers, universities, and public sector buildings are well accustomed to engaging in the markets for flexibility, receiving

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[52] Carbon Trust and Imperial College for Department of Business, Energy and Industrial Strategy (2016): *Capturing the benefits of smart flexible energy system.*

[53] National Grid has set an aspiration to meet 30 – 50% of balancing capacity from demand side response by 2020.

payments through the capacity markets and through taking advantage of price fluctuations in the energy market.

At the smaller commercial and domestic scale, rewards for flexibility are less well established, however, a number of technology companies and energy suppliers have provided platforms to enable homeowners to engage in demand side response. These include automated smart controls for homes and businesses to enable an automatic response to changing price signals with less need for active management from householders and businesses[54]. As the grid decarbonises further through the use of renewable energy, this will become increasingly important to the balancing of supply and demand.

Examples of Time of use tariffs and demand side response aggregation

Supplier	I.D.	Description
Flexible Time of use-tariffs		
	Octopus Agile Tariff	Time of use tariff linked to wholesale prices, with a premium for consumption inside peak hours 16.00 - 19.00 and lower tariffs at other times. Calculates pricing half hourly according to the Agile algorithm with consumers alerted to negative tariffs where they will be paid to consume electricity.
	Bulb Smart Tariff	Time of use tariff with three distinct rates: overnight rate (23:00-7:00), off-peak rate, and peak rate (16:00-19:00). Rates vary depending on region, for London at the time of writing (Inc. VAT): Overnight rate = 7.46 p/kWh Off-peak rate = 12.19 p/kWh Peak rate = 29.75 p/kWh
Domestic Demand-side response aggregation services		
	Social energy	Utility provider that aggregates residential flexibility assets to offer balancing services to the National Grid and customers access to low wholesale electricity prices. 70% of all earnings and savings distributed amongst customers. Customers require a solar PV installation and smart energy storage installation; potential to further complement with additional flexible loads (e.g. heat pump, electric vehicles).

54 For example, customers on the Agile tariff can download the free IFTTT platform to connect compatible heat pumps to an Octopus Energy API, automatically triggering heating, for example of the hot water tank at cheaper and lower-carbon times in the day.

Energise Barnsley	Energise Barnsley	Project focusing on 600 homes that have been fitted with air source heat pumps (ASHP). Combining the use of smart batteries and the thermal store of the building system to shift peak demand of the ASHP-fitted homes away from peak national power demand. Upside Energy participating as the aggregator.
Non-domestic demand side response aggregation services		
upside	Upside energy	Aggregator that utilises a cloud-based smart energy management system to connect devices across commercial, industrial and domestic sites, including heating and cooling systems. Delivered demand response services to heat pumps connected to the 'Balanced Energy Network' project at London South Bank University and the Energise Barnsley DSR project.
moixa	Moixa Gridshare	Cloud-based software platform that aggregates and connects storage and high energy using devices to the grid to enable them to benefit from lower tariffs and payments for flexibility services. Gridshare analyses a buildings energy generation and consumption patterns and matches them against available flexible tariffs, generating a personalised charging and energy plan for each customer.
q·Energy	QBots	Smart Energy Management System that can be used by building owners/managers to optimise their electricity consumption, balancing the buildings requirements with low tariffs, solar PV and battery storage.

5.3 Reducing fuel bills through flexible time of use

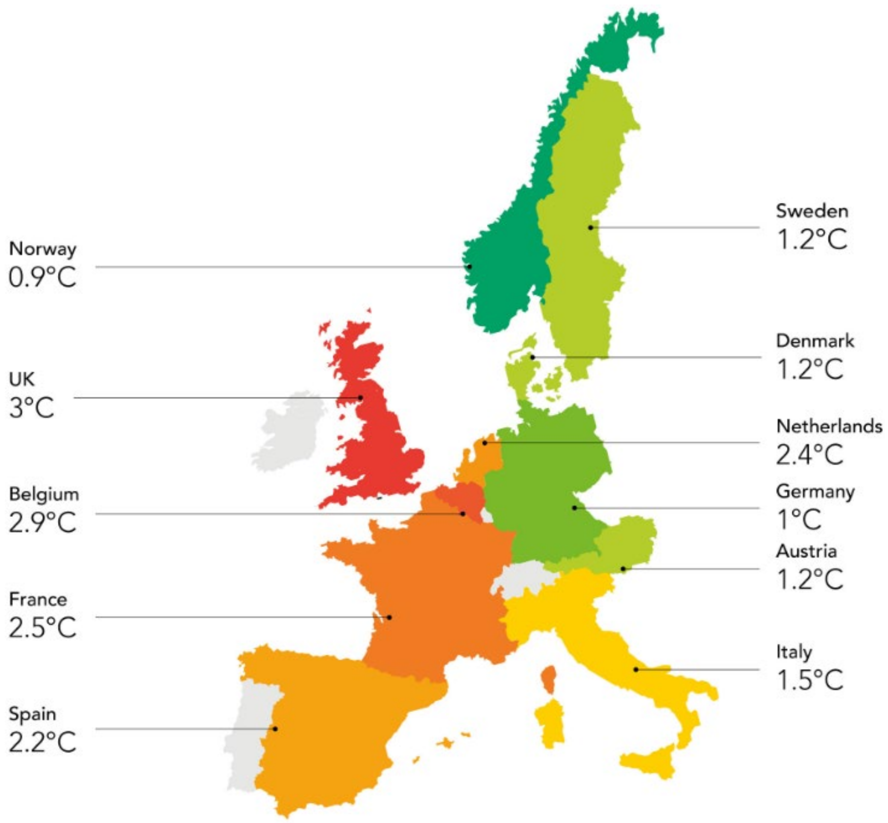
Being flexible in the timing of heat pump use requires the building to act as a 'heat battery' either in the form of the hot water cylinder, a dedicated thermal store or in the fabric of the building itself. In terms of adjusting space heating load (typically the largest source of energy use), a building's ability to store heat will depend on the building's level of thermal fabric efficiency. Energy efficient buildings retain heat for longer.

A recent study by smart heating control company Tado[55] based on a sample of over 80,000 European homes, shows how UK homes in general have the highest levels of heat loss in Europe. The average UK home in this study loses 3°C after five hours with an outdoor temperature of 0°C – up to three times faster than other European countries. Many inefficient buildings in London will lose heat faster than this. Therefore, improved energy efficiency can be an essential component of the ability to provide and benefit from flexibility services.

Figure 14: Tado analysis of heat loss in 80,000 European homes.

Home temperature loss after 5 hours

With a temperature of 20⁰C inside and 0⁰C outside



Based on a sample of over 80,000 European homes

[55] Tado (2020). Available at: https://www.tado.com/t/en/uk-homes-losing-heat-up-to-three-times-faster-than-european-neighbours/

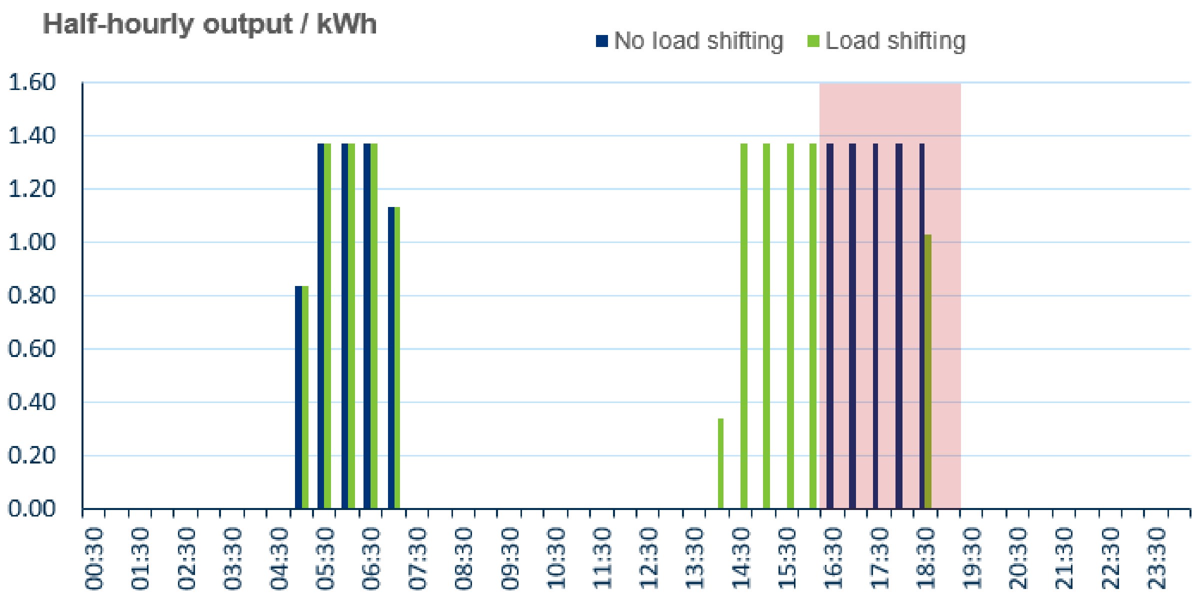
5.4 Results from analysis of the 15 example buildings

For this project, we modelled the potential for our example buildings to shift heating load outside of peak hours and assessed what impact this could have on fuel bills and the overall financial case for heat pump retrofit.

We developed a basic heat loss model for each of the nine example residential buildings used in our study. For each building, we assessed its ability to retain heat for a range of different heating periods. For example, the chart below shows the heating required to maintain an internal temperature of 20°C between 06:30 - 08:30 and 17:30-20:30 for an example dwelling on a typical February day (average 9°C).

In this example, heating would ordinarily have been required between 16:30 and 18:30 to achieve the required internal temperature, however, due to the low level of heat loss of the building, it is possible to shift the heating period forward to 14:30-16:30 with a top-up requirement at 18:30, i.e. in this case, the building could benefit from lower tariffs prior to 16:30 without impacting comfort.

Figure 15: Model of ability to shift heat load outside of peak tariff times (highlighted in pink) and still retain required temperatures between 06:30-08:30 and 17:30-20:30.



We modelled the potential energy bills using published 2019 half hourly rates for the Octopus Agile time of use tariff. This analysis suggests that heating bill savings could vary between 0% and 23% depending on the energy efficiency of the building. Homes that were rated EPC C or higher had the potential to save between 13 and 23% where homes with EPC ratings of D-F could only achieve savings of 0-12%.

In some cases, e.g. 09. Tradescant Road and 04. Northcote Road, EPC Rating E and D respectively, our model suggests that these buildings would currently not be able to shift any heat load while retaining thermal comfort.

In a number of cases, the ability to shift heating load outside of peak tariff rates meant the heat pump option had lower fuel bills than gas.

Figure 16: Potential fuel bill savings for nine domestic buildings using Octopus Energy Agile tariff under different retrofit scenarios[56].

	No energy efficiency improvements: % heating bill saving from time of use tariff (EPC rating)	Improved energy efficiency: % heating bill saving from time of use tariff (EPC rating)	Deep retrofit: % heating bill saving from time of use tariff (EPC rating)
01. Lymington Road	16% (EPC C)	No energy efficiency improvements modelled	
02. Cavendish House	22% (EPC B)	No energy efficiency improvements modelled	
03. Sherwin House	17% (EPC C)	No energy efficiency improvements modelled	
04. Northcote Road	0% (EPC D)	17% (EPC C)	22% (EPC B)
05. Aldenham Drive	13% (EPC C)	No energy efficiency improvements modelled	
06. Surrey Road	19% (EPC C)	No energy efficiency improvements modelled	
07. Mowbray Road	8% (EPC D)	16% (EPC C)	23% (EPC B)
08. Albany Road	4% (EPC D)	12% (EPC C)	
09. Tradescant Road	0% (EPC E)	10% (EPC D)	18% (EPC B)

For non-domestic buildings, modelling the impact of time of use tariffs and other payments for flexibility is more complex and bespoke modelling was outside the scope of this project. However, at a high level, the Association for Decentralised Energy (ADE) has calculated that 16% of the UK's peak electricity requirement (9.8GW) could be provided by businesses being flexible in their energy demand. These figures have the potential to increase as heating increasingly becomes electrified through heat pumps[57].

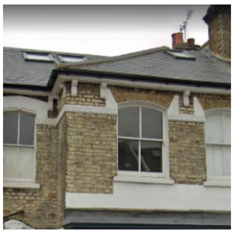
[56] For full details of each retrofit scenario please refer to the document: Options appraisal for heat pump retrofit in 15 London buildings.
[57] Association for Decentralised Energy (2020). Available at: https://www.theade.co.uk/resources/what-is-demand-side-response

5.5 Summary of results from example buildings

We assessed the impact of energy efficiency alongside heat pump retrofit in several of our example London buildings. The figures in the table below highlight some of the interactions between energy efficiency, overall heat demand, heat pump performance, time of use tariffs and fuel bills.

These examples demonstrate the importance of energy efficiency in reducing fuel bills in heat pump retrofits and the interactions between heat demand, heat loss, heat pump efficiency and the ability to benefit from time of use tariffs. For heat pump retrofit in homes suffering from fuel poverty, it is essential that detailed consideration is given to energy efficiency improvements to avoid the resident's bills increasing.

Table 1,2,3,4: Energy use and predicted fuel bills for replacement gas boilers compared to heat pump & energy efficiency packages

Building example	BAU scenario			Retrofit scenario			
	Heating and hot water demand (kWh pa)	Boiler efficiency	Fuel bills (standard tariff)	Heating and hot water demand (kWh pa)	Heat pump annual efficiency	Fuel bills (standard tariff)	Fuel bills (time of use tariff and active load shifting)
04. Northcote Road. 3 Bed Maisonette. Victorian 		**Gas Boiler EPC D**		**Air Source Heat Pump** Triple panel convector radiators Double glazing **EPC C**			
	19,606	89%	£800	16,528	265%	£947	£786
				Air Source Heat Pump Four column radiators Deep retrofit **EPC B**			
				9,004	331%	£413	£322

In building 04, a Victorian three bed maisonette; double glazed sash windows and top-up loft insulation decrease the overall space and water heating demand by 16%. However, in this instance a relatively low heat pump efficiency of 2.65 was predicted for the chosen technology. This means that, using a standard electricity tariff, fuel bills increase to £947 for the heat pump option, despite the overall heating demand reduction. However, because of the better energy efficiency, the building is now able to benefit from load shifting outside of peak times and a flexible time of use tariff could result in fuel bills reducing to £786, marginally lower than gas. Under the deep retrofit scenario, fuel bills reduce significantly under all tariffs. Furthermore, the reduced heat loss enables more load shifting and the time of use tariff further reduces fuel bills to £322.

Building example	BAU scenario			Retrofit scenario			
	Heating and hot water demand (kWh pa)	Boiler efficiency	Fuel bills (standard tariff)	Heating and hot water demand (kWh pa)	Heat pump annual efficiency	Fuel bills (standard tariff)	Fuel bills (time of use tariff and active load shifting)
07. Mowbray Road. 3 bed detached house	**Gas Boiler** **EPC D**			**Air Source Heat Pump** Triple panel convector radiators Upgraded loft insulation **EPC C**			
	20,237	89%	£823	16,855	281%	£911	£765
				Air Source Heat Pump Triple panel convector radiators Deep retrofit **EPC A**			
				7,146	314%	£345	£266

In building 07, a detached three bed house; a similar picture emerges, with fuel bills marginally increasing under a shallow retrofit scenario, where standard tariffs are used, but fuel bills decreasing where a time of use tariff is used alongside the energy efficiency improvements. The deep retrofit scenario reduced fuel bills by 58% relative to the gas boiler, increasing to 68% with the time of use tariff.

Building example	BAU scenario			Retrofit scenario			
	Heating and hot water demand (kWh pa)	Boiler efficiency	Fuel bills (standard tariff)	Heating and hot water demand (kWh pa)	Heat pump annual efficiency	Fuel bills (standard tariff)	Fuel bills (time of use tariff and active load shifting)
08. Albany Road	**Gas Boiler** **EPC D**			**Air Source Heat Pump** Triple panel convector radiators No energy efficiency **EPC C**			
	14,742	89%	£623	14,742	302%	£741	£711
				Air Source Heat Pump Triple panel convector radiators Loft insulation and detailed air tightness measures **EPC C**			
				10,038	310%	£492	£433

In building 08, a three bed Victorian Terrace; where no energy efficiency measures are carried out alongside the heat pump installation, then fuel bills increase under both a standard tariff and a time of use tariff, despite a reasonable heat pump efficiency of 3.02 being predicted. This is because the high heat loss of the building would only enable a small amount of load shifting, achieving only a 4% reduction in fuel bills. When energy efficiency and air tightness measures are included, this property is able to achieve a significant heating demand reduction of 32%. This is primarily due to the very poor levels of air tightness assumed in the original building being addressed with a dedicated package of air tightness measures. This results in heating bills reducing under both standard and flexible time of use tariffs.

	BAU scenario			Retrofit scenario			
Building example	Heating and hot water demand (kWh pa)	Boiler efficiency	Fuel bills (standard tariff)	Heating and hot water demand (kWh pa)	Heat pump annual efficiency	Fuel bills (standard tariff)	Fuel bills (time of use tariff and active load shifting)
10. Ernest Dence Estate. 95 flats inter war tenement block	**Gas Boiler** **EPC D**			**400kW Ground water source heat pump** Triple panel convector radiators No energy efficiency **EPC C/D**			
	864,500	91%	£27,618	864,500	390%	£30,735	£25,818
				**400kW Ground water source heat pump** Triple panel convector radiators External wall insulation and double glazing **EPC B**			
				370,500	360%	£14,270	£13,200

In Building 10, a block of 95 inter-war tenement flats under the scenario involving no energy efficiency measures, fuel bills increase only marginally due to the high predicted heat pump efficiency of 3.9. In this scenario, the potential savings for shifting heat load were limited to 7.5% due to uncertainty around the ability of the block to adjust heating patterns. However, under a deep retrofit scenario, fuel bills could be expected to reduce significantly by 49% under a standard tariff and further still with active load shifting a time of use tariff.

6. Optimising heat pump system design

Heat pump technology is diverse and versatile and, with appropriate design, can work in London buildings of all types, delivering large reductions in CO_2, comfortable temperatures, high user satisfaction and competitive fuel bills.

However, heat pumps are not a like-for-like replacement for existing heating systems. They require detailed design, closely matching heat pump design to the heating and cooling requirement in buildings, in order to work efficiently and effectively. This requires taking in to account the energy efficiency of the building and the capacity of the heat emitters as a 'whole building energy system'.

This is particularly important in a retrofit context where buildings and heating systems vary widely and improvements to the thermal fabric and heat emitters will often be required.

Depending on system design, technology choice and source temperatures, annual heat pump efficiencies can vary significantly between less than 200% and greater than 400%. At low efficiencies, heat pumps will cost more to run and place a greater strain on networks and low carbon electricity supplies. At the system and individual buildings levels, therefore, good practice system design is essential.

Why good practice system design is essential

Without good practice heat pump design, installation and operation heat pumps could fail to deliver on expectations in the following ways:

a. **The heat pump may not deliver the temperatures required:** A number of historic heat pump installations have failed because of a lack of proper consideration of flow temperatures and the fact that heat pumps operate efficiently at lower flow temperature than gas boilers. This potential pitfall can be designed out through attention to improving energy efficiency and upgrading heat emitters appropriately.

b. Fuel bills may be higher than anticipated: A poorly designed heat pump system is likely to result in a lower efficiency. A heat pump with a year-round Co-efficient of Performance (CoP) of two will use 50% more electricity and 50% higher fuel bills than a heat pump with year-round CoP of three.

c. The heat pump may not work: In extreme examples, where a heat pump installation has been poorly designed (or not designed), it may have a limited lifetime. For example, incorrectly sizing a ground loop for a ground source heat pump could result in the ground freezing and the heat pump failing to operate.

6.1 Key principles of good heat pump system design

1. **Maximise the energy efficiency of the building first.** Energy efficiency improvements deliver multiple wins when delivered alongside heat pumps by:

    - reducing the required flow temperatures;
    - reducing the overall demand for heating;
    - reducing upfront costs for heat pump equipment; and
    - better enabling the building to store heat and benefit from payments for flexible time of use.

2. **Understand the building's energy requirements in detail and size the system appropriately.** Compared to gas boilers, heat pumps require a more detailed and accurate understanding of the heating and cooling demand. Over-sized heat pumps can suffer from lower efficiencies and so correct sizing is essential for efficient operation that meets the building's needs.

3. **Minimise flow temperatures.** A primary driver of heat pump efficiency is the difference between source and flow temperatures. Flow temperatures can be reduced through a combination of reducing heat loss (through energy efficiency improvements) and upgrading heat emitters (such as radiators). In nearly all cases, upgrading heat emitters to ones that require lower flow temperatures can significantly improve heat pump efficiency and the overall lifetime costs of ownership. Every 1°C reduction in flow temperature can improve efficiency by 1.5%-3%.

4. **Maximise source temperatures.** While air and ground source are the primary heat sources likely to be used in buildings, in larger applications there can be major advantages to seeking alternative sources of heat, such as ground water or secondary heat from sewers, waste heat from buildings or other secondary sources. Regardless of the heat source used, thorough investigation of the energy yield and design of the system to maximise year-round temperatures is essential to good life-long performance of the heat pump.

6.2 Understanding the building's heating requirements and sizing systems appropriately

Whilst it is common practice in the UK for gas boilers to be over-sized for their application[58], for heat pumps it is vital that they are sized specifically for the level of space heating, water heating and cooling demand of the building.

For most buildings, space heating represents the biggest source of heating load. Therefore, to determine the size of the heat pump needed, installers or system designers will typically calculate how much heat the property loses through its fabric and ventilation and how much energy is required from the heat pump to replace this lost heat. Using these measurements, or by studying historic energy use data, system designers can calculate the predicted peak heat demand of the property[59]. This value is calculated in kilowatts (kW) and directly translates to the necessary size of the heat pump in kW.

As space heating is often the largest source of demand for heat in a building, systems are often designed to meet the peak space heating load, with water heating then being provided at times of no, or smaller, demand for space heat (for example how water tanks or thermal stores can be heated in the middle of the night)[60].

The table below provides indicative figures for dwelling design heat losses (in kW) for typical house types based on heat loss from the English Housing Survey and a London 'design day' with an external temperature of -1.8°C and internal temperature of 20°C.

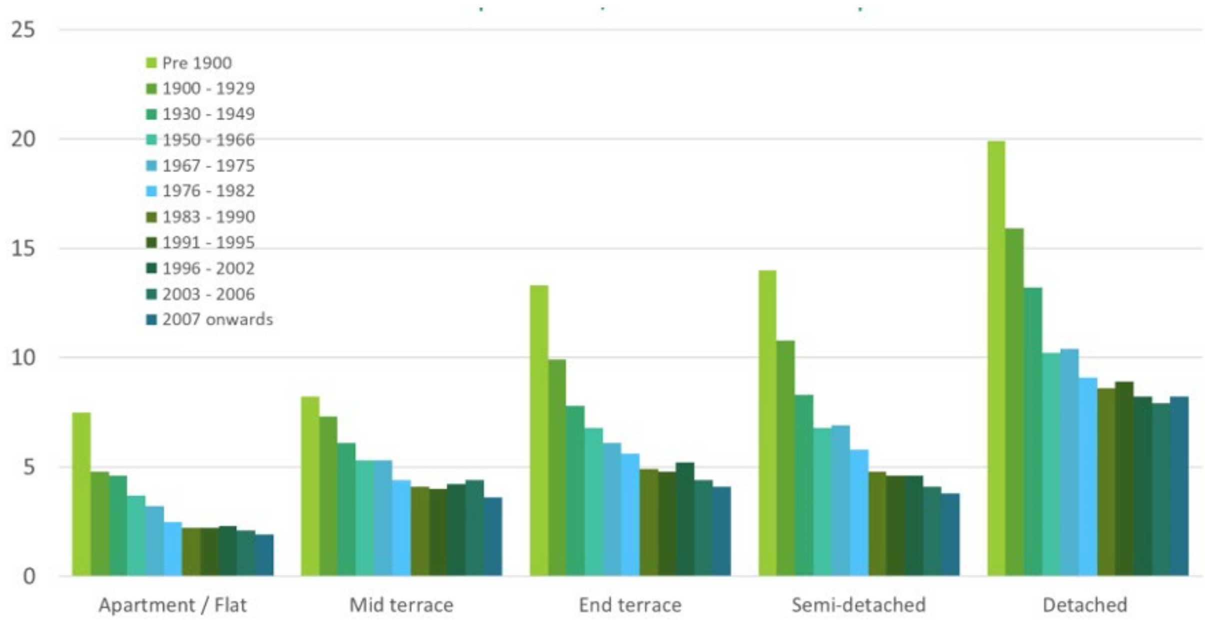
[58] It is not uncommon to see 30kW gas boilers in flats with a peak heat loss of only 5kW (i.e. the boiler is six times bigger than it needs to be).

[59] For installations up to 45kWth (kilowatts thermal), e.g. domestic and small commercial premises, Microgeneration Installation Standard (MIS) 3005 sets out the requirements for contractors undertaking the supply, design, installation, commissioning and handover of heat pump systems. Compliance with MIS 3005 is a requirement for MCS certified installers and for being able to claim RHI payments. MIS 3005 specifies that heat loss calculation should be undertaken according to standard BS EN 12831. For London this means that heat pumps will typically be sized to meet the heating load for 'design day' conditions of -1.8°C external air temperature and 20°C internal temperature. In London, 99% of hours are warmer than -1.8°C.

[60] In applications where water heating demand has a larger peak heating requirement than space heating, heat pumps should be sized to take both the peak space heating and water heating requirements into account. In some cases, immersion heaters in the hot water tanks can be used to provide top-up supply for water heating.

Figure 17: Average heat loss for common building types (kW) for London 'design day' conditions.

Typical heat loss values for English Housing Survey dwellings at -1.8^{0}C internal temperature / 20^{0}C internal temperature



For example, typical heat loss values range between 2kW and 7.5kW for flats and between 8kW and 20kW for detached houses.

For an average 1930s flat, the power output of the heat pump required to maintain an internal temperature of 20°C at -1.8°C external temperature would be 4.6kW. Therefore, a heat pump with a 4.5kW-5kW rated output would be appropriate[61] for an average dwelling of this type.

However, heat loss is unique to each dwelling and varies according to the dwelling form factor (i.e. the level of exposed external wall relative to floor area), the construction type, floor area, levels of energy efficiency, levels of air tightness and local environmental factors such as altitude and exposure to wind.

It is therefore vital that heat loss is calculated on an individual basis for each building. For example, in this report, room-by-room heat loss calculations were undertaken for nine individual domestic properties. The results show alignment with the 'average' heat losses in some cases but wide variations in others.

61 It is important to note that heat pump output varies with temperature. Heat pump output ratings are given for specific temperature differentials (e.g. a source temperature of 2°C and an output of 35°C). Heat pump output declines as the temperature differential between source and load gets larger. An MCS certified installer will ensure that the heat pump specified is capable of delivering the required heating load for the design conditions.

Methods for calculating heat loss in buildings

To establish levels of heat loss in a building, installers or system designers will typically use thermal modelling software, ideally supplemented by historic actual data or monitoring. Heat loss calculations for domestic and small non-domestic buildings of this size can be calculated via a range of tools compatible with BS EN 12831:2017, ranging from basic spreadsheets or online heat loss calculators to advanced tools such as SAP and Passive House Planning Package (PHPP). MCS certified installers will undertake these calculations as standard practice.

For larger installations, a detailed profile of building heating, cooling and hot water demand is typically required, often using advanced thermal demand simulations. This may be something that in-house staff or mechanical and electrical consultants can provide, or it may be necessary to engage specialist heating engineers with experience of thermal demand modelling as part of the heat pump design or consultancy service.

In all cases, it is desirable to supplement modelled data with historic real data on energy use to ensure heat loss has been calculated as accurately as possible. This could involve using historic energy bills or smart meter readings. Heat Transfer Co-efficient testing can also be a good way to accurately measure heat loss from buildings using meter readings and temperature sensors. These services can be provided by a range of building testing companies and mechanical and electrical services consultancies.

Fixed speed, inverter driven, multiple heat pumps and bi-valent systems

One of the key considerations for heat pump sizing is the type of heat pump or pumps being used.

Fixed speed heat pumps utilise fixed speed compressors meaning that a 5kW heat pump can only output at 5kW, and variations in heat demand are met by the heat pump being run for longer or shorter periods depending on demand.

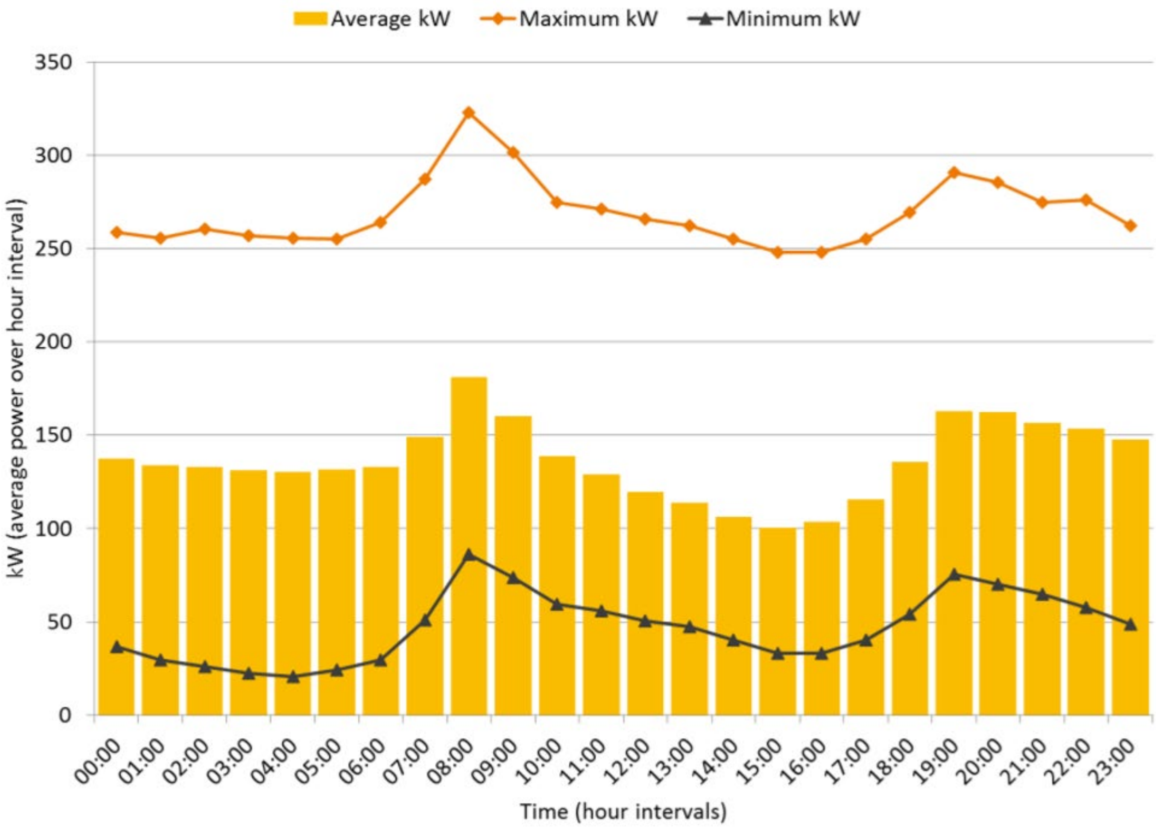
Alternatively, an inverter driven heat pump can modulate its output across a range, typically between around 30% and 100% of its maximum capacity. This means that when heat demand is below peak levels, the heat pump can output at lower levels of heat, using less electricity.

A third option, particularly in larger applications is to use multiple heat pumps arranged in parallel, with different numbers of heat pumps being able to flex on and off in response to changes in demand.

A further consideration is whether a thermal store is to be used and the extent to which this store will be able to cover temporary peaks in demand.

Finally, in a bi-valent/hybrid system, an alternative heating source, such as a gas boiler, could be used to supply a proportion of overall heat demand with the heat pump meeting the baseload for heat.

Figure 18: Calculating maximum, minimum and average heat demand over 24 hours in the Ernest Dence Estate, Greenwich (example building 10). Source: Analysis by Sustainable Energy for the London Borough of Greenwich.

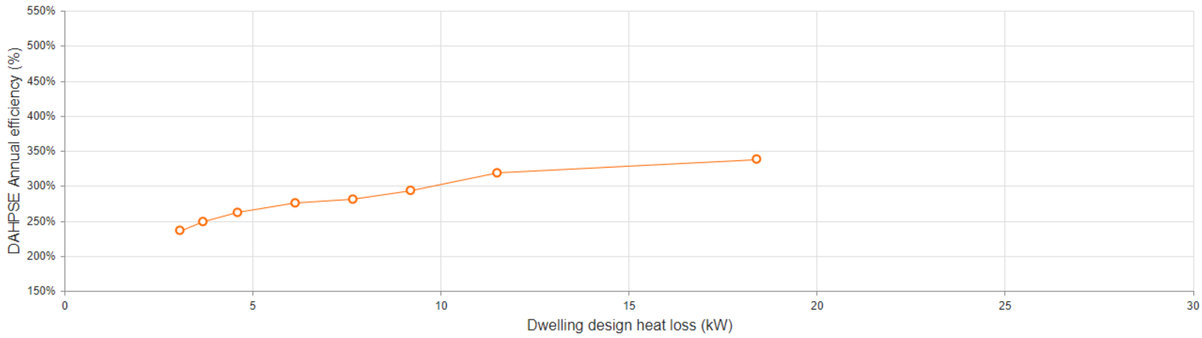


Why heat pumps shouldn't be over-sized

Heat pumps, particularly those with fixed speed compressors operate very efficiently when maintaining a constant temperature in continuous operation. Over-sizing fixed speed heat pumps can reduce efficiency as they are more frequently stopping, starting and accelerating rather than running smoothly (a bit like a car constantly accelerating and decelerating in the lower gears). This is often referred to as short-cycling of the heat pump and this can have a big impact on overall system efficiency. At the other extreme, an under-sized heat pump will struggle to heat the building to sufficient temperatures during the coldest conditions.

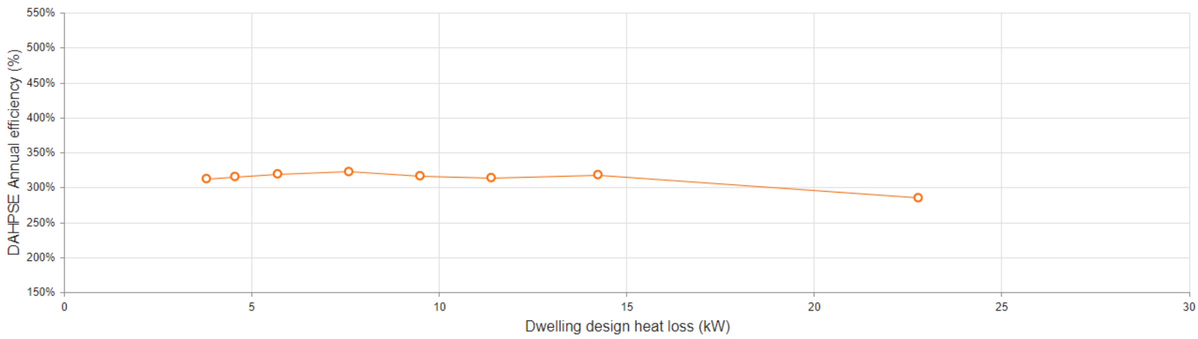
This effect is illustrated in the example efficiency profile for a 15W fixed speed heat pump below. The heat pump operates most efficiently when meeting the design heat loss of 15W. Where the heat demand is lower than this, the efficiency of the heat pump decreases.

Figure 19: Annual efficiency for a 15kW fixed speed compressor heat pump operating at different levels of building heat loss. Modelled using the BRE Domestic Annual Heat Pump Seasonal Efficiency Estimator (DAHPSE) model



In contrast, an inverter driven heat pump is better able to modulate output in response to lower levels of heat demand, showing a lower drop in efficiency at lower outputs. However, a decrease in efficiency is still present.

Figure 20: Annual efficiency for a 15kW variable speed compressor heat pump operating at different levels of building heat loss. Modelled using the BRE Domestic Annual Heat Pump Seasonal Efficiency Estimator (DAHPSE) model



Whilst modulating heat pumps have the advantage in terms of efficiency at lower outputs, fixed speed heat pumps can bring a number of benefits which means they are the preferred choice for some manufacturers and installers:

- In some circumstances, they may achieve better real-life whole system efficiencies than modulating heat pumps due to the shorter run times for the rest of the heating system, e.g. hot water system pumps.

- In some cases, fixed speed heat pumps could have longer service lives and can be easier to maintain.
- In some cases, fixed speed heat pumps may have lower noise levels than inverter driven heat pumps.

An experienced heat pump system designer will be able to design the system to provide the appropriate balance between the most efficient operation of the heat pump while meeting the expectations of the building occupants. For example, if a building regularly needs to be heated from cold, or where the demand for hot water is larger than the space heating demand, a larger heat pump may be desirable.

The need to educate the heat pump user

Based on the above principles, in a well-designed system, the heat pumps will typically be much smaller in terms of kW output than the gas boiler it is replacing. For example, it is not uncommon to see a 20-28kW boiler in a property with a heat loss of only 4-8kW. This results in people using gas boilers to inject relatively short, sharp bursts of heat in to a building.

In contrast, the load profiles for heat pumps are necessarily longer and flatter than for gas boilers. In other words, a heat pump can put the same amount of heat into a building, but will typically do so over a longer period of time throughout the day. For example, if the building is required to be 20°C by 08:00, and the current gas boiler is switched on at 07:00 to bring the building up to temperature, the heat pump may need to be switched on 06:00 or earlier, depending on the conditions.

Consumer education on the appropriate use of heat pump controls is therefore also essential to maximising efficiency and ensuring comfort.

To avoid over-sizing, heat pumps installed under the Microgeneration Certification Scheme (MCS) are often sized to deliver heat demand for design conditions of -1.8°C in London. 99% of days in London remain warmer than -1.8°C. This means that for the very coldest days of the year, or for severe cold weather events, supplementary heating may be required. In practice, heat pumps may be marginally over-sized, enabling them to deliver comfortable temperatures for 100% of external conditions.

Alternatively, supplementary electric heaters may be required or a boost direct electric heating element may be built in to the system.

If the heat pump is sized to operate at 100% output at the design heat loss, then at times when the external temperatures fall below design conditions, additional heating will be required. Using MCS-recommended design conditions, this could be in the order of 90 hours per year and this heating is likely to be provided by an associated electric heater.

An alternative is to 'oversize' the heat pump to satisfy the extreme conditions but this can lead to a disproportionate increase in heat pump size for the relative short period during the year that the additional load will be used. Oversizing is likely to increase on/off cycling at moderate loads, which may reduce efficiency.

The system owner should also be aware therefore that under this method of sizing, short term supplementary heating may be required if:

- The building is being heated from a cold state on a cold day
- The desired heating mode is not continuous (i.e. making use of a split rate tariff)
- Large quantities of domestic hot water are required frequently during cold weather

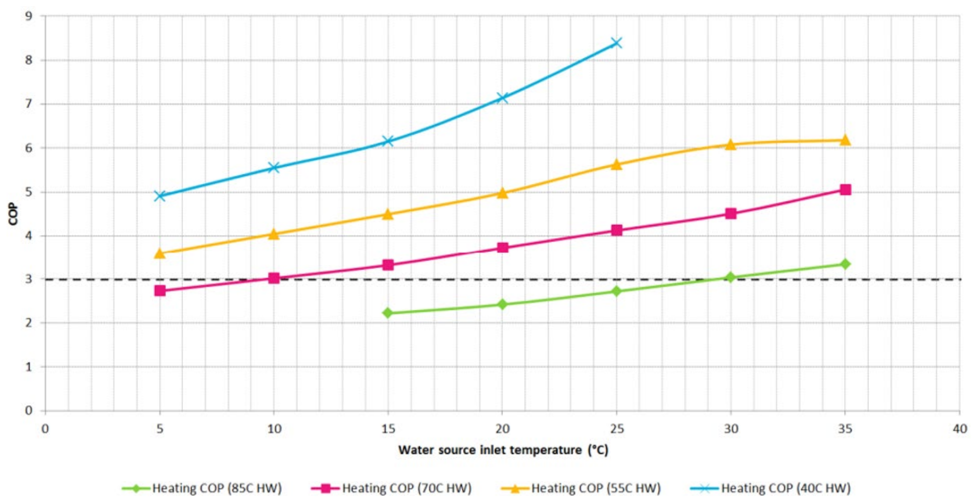
A qualified and experienced heat pump engineer will take account of the unique circumstances of the building in the correct sizing of the heat pump and overall specification of the heat pump and system.

6.3 Minimising flow temperatures for heat distribution

For a correctly sized heat pump, the primary factor determining efficiency is the difference between the temperature of the source and the flow temperature of the heat emitters. Minimising this temperature difference is a key consideration in designing an efficient heat pump retrofit.

The chart below shows heat pump Co-efficient of Performance (COPs) for four different flow temperatures against source temperatures ranging between 0°C and 40°C. The data is based on a review of heat pump manufacturer data for large heat pumps in the 500-1,000kW range as presented in the London Secondary Heat Study. This chart clearly shows the importance of source and flow temperatures, with heating at 55°C being approximately twice as efficient as heating at 85°C.

Figure 21: Importance of source and flow temperatures to heat pump efficiency. Source: Secondary Heat Study (2013)[62]



[62] Greater London Authority (2013); Secondary Heat Study: London's zero carbon energy resource

Typical flow temperatures for heat emitters in existing buildings

Heat emitters in many existing buildings are designed to work with flow temperatures of between 60-80°C as delivered by gas boilers. Whilst a number of heat pumps can operate effectively up to 60-65°C, they are most efficient at lower temperatures of 35-55°C.

Therefore, reducing the flow temperatures of the heating distribution system is sometimes an essential pre-requisite for heat pump installation. In all cases, reducing flow temperatures will increase heat pump efficiency. Every 1°C reduction in flow temperature typically results in approximately a 1.5%-3% increase in heat pump efficiency.

Flow temperatures can be reduced by a) increasing the size or improving the efficiency of heat emitters, b) reducing building heat loss or c) a combination of both.

Heat distribution systems and their flow temperatures can vary significantly between buildings. The table below provides an overview of common heat emitters and the associated flow temperatures.

Common heating and hot water systems	Notes	Indicative flow temperatures
Low output radiators (single panel, single convector or double panel radiators)[63]	Standard radiators are typically used in conjunction with gas boilers or district heating systems that operate at high flow temperatures of 60-80°C	60-80°C
High output radiators (over-sized, double and triple panel convector radiators, fan convector radiators, four column radiators)	By using higher output radiators with a larger surface area, flow temperatures can be reduced while still delivering the equivalent kW of heat. Fan convector radiators can also be used to provide cooling	35-55°C
Underfloor heating	Underfloor heating typically covers a large surface area enabling much lower flow temperatures. This makes underfloor heating an ideal partner for heat pumps although it can be expensive and disruptive to install in a retrofit context	30-35°
Blown air HVAC units	Common in office buildings and other non-domestic buildings such as shops, blown air HVAC units operate at temperatures that are well suited to efficient heat pump use. Can also be using in cooling mode	40-45°
Fan coil units (FCU)	A fan coil is a type of heat emitter that consists of a heat exchanger and a convector fan. Energy is transferred from water circulating the building in to the FCU. Common in office buildings, FCUs operate at lower temperatures that are ideal for efficient heat pump use. Can be operated in cooling mode	35-50°C

[63] It is possible for standard single and double panel radiators to be over-sized to an extent that would enable them to deliver sufficient heating at lower temperatures. However, in practice, this is likely to require an unfeasible level of wall surface to be covered. The values in the table are a broad illustration of the heat emitters most suitable for delivering different flow temperatures in standard contexts.

Hot water provision	Water temperatures for bathing and showering will typically be 39-43°C – well within the efficient operation of standard heat pumps. Hotter temperatures have the potential to scald. However, it is common for temperatures at the tap to be in the region of 55°C and then mixed with cooler water at the point of use	39-55°C
Hot water legionella cycle	Legionella is a form of bacteria that grows in water at temperatures between 20°C and 45°C. In order to kill off legionella it is a requirement to heat water to 60°C or hotter. Gas boilers will achieve this as part of their standard operation. For heat pumps, a periodic 'legionella' cycle is typically programmed in, sometimes involving an electric immersion element heating the hot water above 60°C once a week	60-65°C

Assessing the capacity of heat emitters in existing buildings

Increasing the size and or efficiency of heat emitters should be considered alongside all heat pump retrofits, as this can enable lower flow temperatures and higher efficiencies. This section provides guidance on how to assess current radiator capacity and the extent to which flow temperatures can be reduced by upgrading them.

Heat emitter outputs are often quoted in kW. This figure refers to the power output of the heat emitter for a given temperature differential between the desired room temperature and the heat emitter temperature. This differential is referred to as Delta T, often denoted by the symbol ΔT.

Radiator outputs in kW are often quoted for a ΔT of 50°C[64], as would be typical for use with a gas boiler:

Mean water temperature inside heating system (70°C)[65] – Desired room temperature (20°C) = Delta T 50°C

However, as heat pumps typically operate at lower temperature (to maximise efficiency), the Delta T will be lower, for example:

Mean water temperature (42.5°C) – Desired room temperature (20°C) = Delta T 22.5°C

The kW output of a radiator is higher at a Delta T of 50°C than at a Delta T of 22.5°C. Because radiator kW values are typically stated for Delta T50, it is necessary to apply an adjustment factor to determine their output at lower Delta Ts as illustrated in the following table:

[64] Delta T (often denoted by the symbol ΔT) refers to the difference between the required room temperature and temperature of the heat emitters.
[65] Assumes a flow temperature of 80°C and return temperature of 60°C = mean water temperature of 70°C. Boiler flow and return temperatures of 80°C / 60°C have traditionally been used for calculating radiator size and this remains the radiator industry standard approach. However, in practice these are not common or recommended temperatures for modern condensing boilers which are more likely to have flow and return temperatures in the region of 70°C / 50°C.

Table 5: Heat emitter outputs for different Delta T outputs relative to Delta T of 50°C (Source: adapted from information in CIBSE Domestic Heating Design Guide)

Mean water temperature required to achieve internal room temperature of 20°C	Delta T (ΔT) (Difference between required room temperature and Mean water temperature)	Heat emitter kW output relative to ΔT50°C	Required increase in heat emitter capacity (relative to ΔT50°C)
70°C	Δ50°	100%	1.0
60°C	Δ40°	75%	1.3
55°C	Δ35°	63%	1.6
52.5°C	Δ32.5°	57%	1.8
50°C	Δ30°	51	2.0
47.5°C	Δ27.5°	46%	2.2
45°C	Δ25°	41%	2.4
42.5°C	Δ22.5°	35%	2.9
40°C	Δ20°	30%	3.3
37.5°C	Δ17.5°	26%	3.8
35°C	Δ15°	21%	4.8

For example, a radiator rated 1kW at Delta T50°C would be rated only 0.41kW at Delta T25°C. In order to reduce water flow temperature from 70°C to 45°C (for example if replacing a gas boiler with a heat pump), it would be necessary to increase radiator capacity by a factor of 2.4.

The following table provides a range of values in kW per m^2 for common radiator types at different flow temperatures.

Table 6: Common radiator type outputs (kW per m^2 wall surface area) at different flow temperatures. (Source: manufacturer websites).

Radiator type	Mean water temperature						
	70°C	60°C	55°C	50°C	45°C	40°C	35°C
Single panel radiator	1.1	0.8	0.7	0.5	0.4	0.3	0.2
Single panel, single convector radiator	1.6	1.2	1.0	0.8	0.6	0.5	0.3
Double panel radiator	2.3	1.7	1.4	1.2	0.9	0.7	0.5
Double panel, single convector radiator	2.4	1.8	1.5	1.2	1.0	0.7	0.5
Double panel, double convector radiator	3.0	2.2	1.9	1.5	1.2	0.9	0.6
Triple panel, triple convector radiator	4.1	3.1	2.6	2.1	1.7	1.2	0.9
Four column radiator	3.3	2.5	2.1	1.7	1.4	1.0	0.7
Double panel fan convector radiator	3.5	2.6	2.2	1.8	1.4	1.1	0.7
	Typical radiator output in kW						

For example, it would be possible to reduce flow temperature from 70°C to 45°C by replacing a single panel radiator with a double panel, double convector radiator with the same m^2 surface area, although the double panel convector radiator would protrude further from the wall.

Increasing the size of heat emitters will need to be considered for any heat pump installation in order to allow reduced flow temperature, and therefore improve efficiency.

6.4 Maximising heat source temperatures

Another factor that impacts heat pump efficiency is the temperature of the heat source. The higher the temperature, the higher the seasonal efficiency. Whilst, for an air source heat pump, the air temperature is not in the heat pump designer's control, careful consideration should be given to the siting of air source units in order to ensure that a free flow of air is available and that the environment immediately surrounding the fan unit will not accumulate cold air.

For larger buildings and heat pumps serving heat networks, a far wider array of heat sources become viable. A list of potential heat sources that could be particularly relevant in London is detailed in Section C.

6.5 Results of the analysis of 15 example buildings

Combining heat emitter upgrades with energy efficiency to achieve the lowest flow temperatures

The tables below provide a summary of the calculated heat loss and heat emitter capacity for nine example dwellings in London and the flow temperatures that would be required to deliver an internal temperature of 20°C. The subsequent table presents the required flow temperatures after a range of energy efficiency and heat emitter upgrades have been undertaken. These temperatures show that while some buildings in the sample could accommodate heat pumps before upgrades are undertaken, all buildings could achieve a more efficient flow temperature by undertaking upgrades and in many cases, the upgrades are an essential pre-requisite for efficient heat pump operation.

Table 7: Example buildings required flow temperatures before improvements

	Street	Borough	Beds	Type		Age	Current radiators	EPC Rating	Peak heat load (kW)	Current heat emitter output (kW at ▲T 50°C)	Required flow temp for -1.8°C design day with current radiators	Improvements necessary to accommodate a heat pump
1	Lymington Road	Camden	1 Bed	Ground	Flat	1970s	Double panel	C	2.6	3.9	50°C	50°C achievable with standard heat pump but at relatively poor efficiency. Upgrades to energy efficiency and radiators recommended.
2	Cavendish House	Barnet	2 Bed	Mid	Flat	1980s	Single panel	B	2.1	2.9	59°C	A number of standard heat pumps could achieve a 59°C flow temperature. However, efficiency may be poor. Upgrading heat emitters and / or reducing heat loss essential.
3	Sherwin House	Lewisham	2 Bed	Ground	Flat	1930s	Single panel	C	3.7	5.4	58°C	A number of standard heat pumps could achieve a 58°C flow temperature. However, efficiency would be poor. Upgrading heat emitters and / or reducing heat loss essential.
4	Northcote Road	Wandsworth	3 Bed	Top	Maison ette	1890s	Single panel convector	D	8.7	7.6	79°C	Standard heat pump unable to deliver 79°C. Upgraded heat emitters and reducing heat loss essential. Alternatively, a hybrid heat pump may be appropriate.
5	Aldenham Drive	Hillingdon	2 Bed	Terraced	House	1980s	Double panel, double convector	C	3.6	11.2	41°C	41°C could be delivered at good efficiency with a standard heat pump. Upgrades to heat emitters and reduced heat loss would improve performance further.
6	Surrey Road	Southwark	3 Bed	Semi	House	1960s	Double panel, single convector	B	4.8	10.3	48°C	48°C achievable with standard heat pump but at relatively poor efficiency. Upgrades to energy efficiency and radiators recommended.
7	Mowbray Road	Croydon	3 Bed	Detached	House	1930s	Double panel	D	8.7	13.8	53°C	53°C achievable with standard heat pump but at relatively poor efficiency. Upgrades to energy efficiency and radiators recommended.
8	Albany Road	Newham	3 Bed	Terraced	House	Pre 1919	Single panel	D	5.7	5.1	77°C	Standard heat pump unable to deliver 77°C. Upgraded heat emitters and reducing heat loss essential. Alternatively, a hybrid heat pump may be appropriate.
9	Tradescant Road	Lambeth	5 Bed	Terraced	House	Victorian	Single panel	E	14.5	13.8	74°C	Standard heat pump unable to deliver 74°C. Upgraded heat emitters and reducing heat loss essential. Alternatively, a hybrid heat pump may be appropriate.

Table 8: Example buildings required flow temperatures after improvement

	Street	Borough	Beds	Type		Age	Current radiators	EPC Rating	Post retrofit Peak heat load (kW)	Upgraded heat emitter output (kW at ▲T 50°C)	Required flow temp for -1.8°C design day with upgrades radiators and energy efficiency	Impact of building and heat emitter upgrades
1	Lymington Road	Camden	1 Bed	Ground	Flat	1970s	Triple panel convector	C	2.6	7.0	40°C	Upgrade to triple panel convector radiators reduces required flow temp to 40°C, potentially improving efficiency by ~20%
2	Cavendish House	Barnet	2 Bed	Mid	Flat	1980s	Triple panel convector	B	2.1	10.2	36°C	Upgrade to triple panel convector radiators reduces required flow temp to 36°C, potentially improving efficiency by ~40%
3	Sherwin House	Lewisham	2 Bed	Ground	Flat	1930s	Single panel	C	3.7	9.8	44°C	Upgrade to triple panel convector radiators reduces required flow temp to 44°C, potentially improving efficiency by ~28%
4	Northcote Road	Wandsworth	3 Bed	Top	Maison ette	1890s	Four column heritage style radiators	D	7.2	15.3	48.0	Installing double glazing, other energy efficiency and air tightness measures could reduce heat loss to 7.2kW. Combined with upgrading heat emitters to large four column radiators enables a required flow temp of 48°C
5	Aldenham Drive	Hillingdon	2 Bed	Terraced	House	1980s	Double panel, double convector	C	3.6	11.2	41°C	No upgrades required.
6	Surrey Road	Southwark	3 Bed	Semi	House	1960s	Double panel, single convector	B	4.8	19.6	37°C	Upgrade to triple panel convector radiators reduces required flow temp to 37°C, potentially improving efficiency by ~20%
7	Mowbray Road	Croydon	3 Bed	Detached	House	1930s	Double panel	D	6.9	27.8	38°C	Improving air tightness and insulation could reduce heat loss to 6.9kW/ Combined with upgrading heat emitters to underfloor heating and triple panel convector radiators enables a required flow temperature of 38°C
8	Albany Road	Newham	3 Bed	Terraced	House	Pre 1919	Single panel	D	4.8	15.6	40°C	Improving air tightness and insulation could reduce heat loss to 4.8kW. Combined with upgrading heat emitters to triple panel convector radiators enables a required flow temperature of 40°C
9	Tradescant Road	Lambeth	5 Bed	Terraced	House	Victorian	Single panel	E	4.3	23.0	35°C	A whole house deep retrofit could reduce heat loss to 4.3. Combined with triple panel convector radiators could reduce flow temperatures to 35°C

6.6 High temperature heat pumps

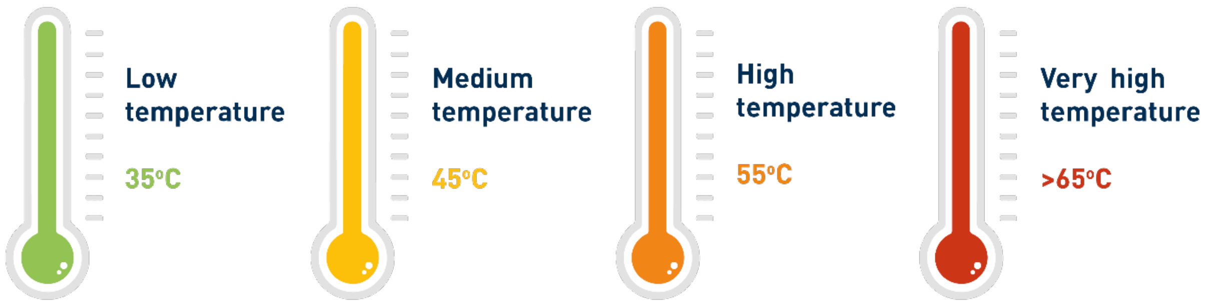
Standard heat pumps are designed to operate at lower flow temperatures of around 35-55°C, compared to gas boiler flow temperatures of 60-80°C. However, the maximum available flow temperatures of each model of heat pump will vary according to the specific design[66].

There are a number of heat pumps that are specifically designed to deliver higher flow temperatures of up to 80°C. These include:

- Products with optimised design for specific refrigerants that can deliver higher temperatures (such as propane, ammonia or CO_2)
- Sequential systems with multiple separate refrigeration cycles or multiple separate heat pumps that increase temperature in steps (e.g. 10-35°C then 35°-70°C)
- Enhanced Vapour Injection (EVI) heat pumps

The definitions of what constitutes 'high temperature' are sometimes contradictory. The situation is confused by the fact that designs of 'standard' heat pumps are increasingly being improved to reach 60-65°C at reasonable efficiency (although the efficiency of all heat pumps will be lower at higher temperatures).

For heat pumps generating hot water, BS EN 14511 (BSI Standard for air conditioners, liquid chillers and heat pumps) uses the following definitions.



However, these definitions are not used consistently by manufacturers in reference to products on the market. It is anticipated that the definitions above will be updated in future revisions to the BS EN 14511 standard.

[66] It is also important to remember that heat pump maximum flow temperatures will vary according to the available source temperature i.e. the flow temperature output will be lower at -5°C than it is at 15°C. Manufacturers typically provide flow temperature data for a range of different source temperatures as part of standard product documentation.

In this document we have used the following definitions which more closely reflect the terminology used for different product types in the heat pump market:

Low temperature heat pump:	Designed to operate between 35°C and 45°C but capable of achieving up to 55°C.
Standard heat pump:	Designed to operate primarily within the 35-55°C range, but with the capability to deliver 60-65°C at the extreme for periodic heating of hot water or occasional heating of a building from cold. This may include systems with in-line direct electric elements or immersion heaters.
High temperature heat pump:	Designed to operate predominantly in the 55-80°C range but that typically have the capability to modulate output to below 55°C where lower temperatures are sufficient.

High temperature heat pump costs

High temperature heat pumps make up a very small proportion of the overall market. A Carbon Trust review for BEIS in 2016[67] estimated that annual sales were approximately 2% of total heat pump sales, numbering a few hundred units per year. The same study found that installed costs of a high temperature heat pumps would typically be 10-20% higher than the costs of standard heat pumps.

It is also likely that maintenance costs will be higher for high temperature heat pumps due to the specialist nature of servicing the technologies and refrigerants involved.

High temperature heat pump efficiencies

Compared to standard heat pumps, there is a lack of large-scale field trial data. It is a growing technology sector and evidence of successful installations, delivering large CO_2 emissions savings is increasing. Reviews of manufacturer published data suggest that good efficiencies can be achieved, although these will typically be lower than efficiencies for low temperature and standard heat pumps.

As with all heat pumps, good system design is essential to ensure that flow temperatures are minimised to ensure a good efficiency. A well-designed inverter-drive high temperature heat pump, with a good control system, including weather compensation, will only deliver in excess of 75°C when absolutely necessary; otherwise it will modulate the heat pump to deliver lower temperature at better efficiencies.

[67] Carbon Trust for Department of Business, Energy and Industrial Strategy (2016). *Evidence gathering, low carbon heating technologies; Domestic High Temperature, Hybrid and gas Driven Heat Pumps.*

High temperature heat pump applications in London

High temperature heat pumps sound like an easy fix for many buildings in London that currently require higher flow temperatures. For example, inefficient buildings and existing communal and district heating schemes often operate at flow temperatures in excess of 70°C.

However, good practice design should always be to minimise flow temperatures first to achieve higher efficiencies. Furthermore, in order to meet overall sustainability goals, it is essential that overall demand for electricity is reduced. For this reason, high temperature heat pumps should generally be reserved for cases where options for reducing space heating demand and reducing flow temperatures do not exist, such as in heritage buildings.

Section C

Issues affecting heat pump deployment in London

The retrofit of heat pumps in to existing buildings in urban areas can present particular challenges. The noise levels of air source heat pumps, the space and access required for ground source borehole drilling or external fan units, and the floor area required for hot water cylinders and internal units can particularly impact technology choice and feasibility in densely populated inner cities.

However, heat pump technology is diverse and versatile, with various solutions to overcome these challenges, either within individual dwellings or through utilisation in heat networks. London benefits from an enviable array of heat sources alongside air and ground source including: ground water, aquifers, surface water, building waste heat, sewer heat, the London Underground and industrial waste heat. These can improve the efficiency of heat pumps, lower capital costs and enhance the case for heat pump retrofit, particularly at larger scales and in heat networks.

This section details some of the key issues relating specifically to the uptake of heat pumps in urban environments, and London in particular.

7. Summary of heat pump technology

To understand the issues impacting heat pump uptake in London, it is useful to be familiar with the core components and types of heat pump technology in use. Here we provide a brief overview of categories and core components of heat pump technology, ahead of exploring the practical considerations of deploying heat pumps in London.

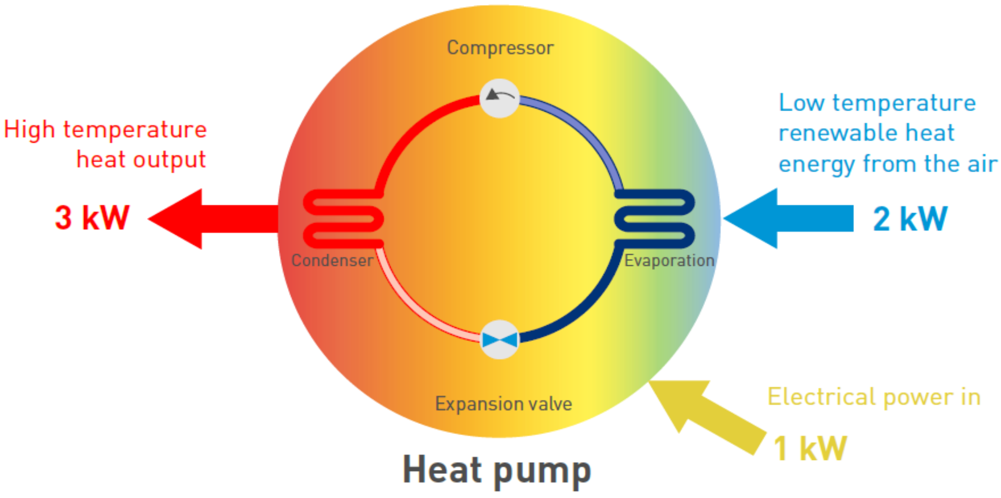
7.1 Key components of a heat pump

There are five essential components to a heat pump. How these components are configured is relevant to how they can be installed in buildings.

Five essential heat pump components

1. Evaporator	Extracts heat from the air, ground, water or other source and transfers it to the refrigerant, causing the refrigerant to turn in to a gas.
2. Compressor	Compresses the gas thereby raising its temperature.
3. Condenser	Transfers the heat in to the building's heating system.
4. Expansion valve	Lowers the pressure of the refrigerant, enabling the cycle to start again.
5. Refrigerant	Circulates heat pump system, changing between a liquid and a gas state, rising and falling in temperature and transferring the heat between the heat source and the building.

Figure 22: Example of an air source heat pump system
Source: Carbon Trust Heat Pumps Guide



7.2 Methods of collecting heat

The means of collecting heat will differ depending on the source and the technology. There are three main types of heat collectors:

Heat collector	Description	Applicable heat sources
External fan unit	Heat is extracted from air drawn across the evaporator by a fan.	• Air • Exhaust air or other air-based waste heat
Closed loop systems	A closed loop of pipe containing water and antifreeze is buried or submerged within the heat source. This could either be horizontally or vertically in boreholes. The liquid inside the closed loop is pumped through the evaporator to transfer the heat to the refrigerant.	• Ground • Ground water and aquifers • Surface water • Sewer heat • Liquid or solid waste heat
Open loop systems	In an open loop system, liquid (usually water) is drawn from the source and pumped directly through the evaporator in the heat pump.	• Ground water and aquifers • Surface water • Some liquid based waste heat

7.3 Heat pumps at different scales

The following taxonomy for heat pumps in London was developed in the Etude report for the GLA: Heat Pumps in London[68].

Scale	Description
Small scale/individual heat pumps (0-20kW)	These heat pumps are individual installations (e.g. in each dwelling). They are the heat pump equivalent of an individual gas boiler.
Medium scale/communal heat pumps (20-170kW)	These heat pumps can be the heating system of a non-domestic building (e.g. school or office building) or the communal heating system of an apartment block. They include individual heat pumps working off a shared ground loop.
Large scale/district heat pumps (>170kW)	These heat pumps can serve large non-domestic buildings (e.g. office buildings) or be integrated into the energy centre of a district heating network.

[68] Etude for Greater London Authority (2018). *Low Carbon Heat: Heat Pumps in London*

8. Heat sources in London

8.1 A wide range of alternative heat sources are possible in urban settings

Air source heat pumps are the most common form of heat pump technology, particularly outside of urban areas where sound and lack of space is less of a problem. High quality air source heat pumps in well-designed systems can achieve high year-round efficiencies.

However, because average winter air temperatures are lower than other available sources, such as the ground, ground water and waste heat, there are significant advantages to be gained by utilising other sources where possible. Furthermore, there can be barriers to the deployment of air source heat pumps in dense urban environments (such as blocks of flats) which make exploration of alternative heat sources a necessity.

Every degree of additional source temperature can lead to an efficiency gain in the heat pump system operation. The chart below demonstrates the potential value of utilising wider sources of heat in London with higher temperatures.

Table 9: Secondary heat sources in London (shading indicating environmental and secondary heat sources (Source: London's zero carbon energy resource: Secondary heat).[69]

Source	Description	Potential temperatures
Air source	The most widely available source for heat pumps is also the most variable with large seasonal fluctuations.	**-5-35°C**
Ground source	Stable year-round temperatures although shallow trenches will be subject to seasonal variation. The level of heat obtainable will depend on local geological conditions.	**12-14°C**
Ground water source	In suitable areas, shallow aquifers or quantities of water within gravel deposits and loose rock within the ground can be accessed either by closed loop or open loop systems.	**13-14°C**
Surface water (e.g. river)	London has particularly good potential for accessible surface water heat, from the River Thames for example.	**5-20°C**

[69] Greater London Authority (2013). *London's zero carbon energy resource: Secondary heat*

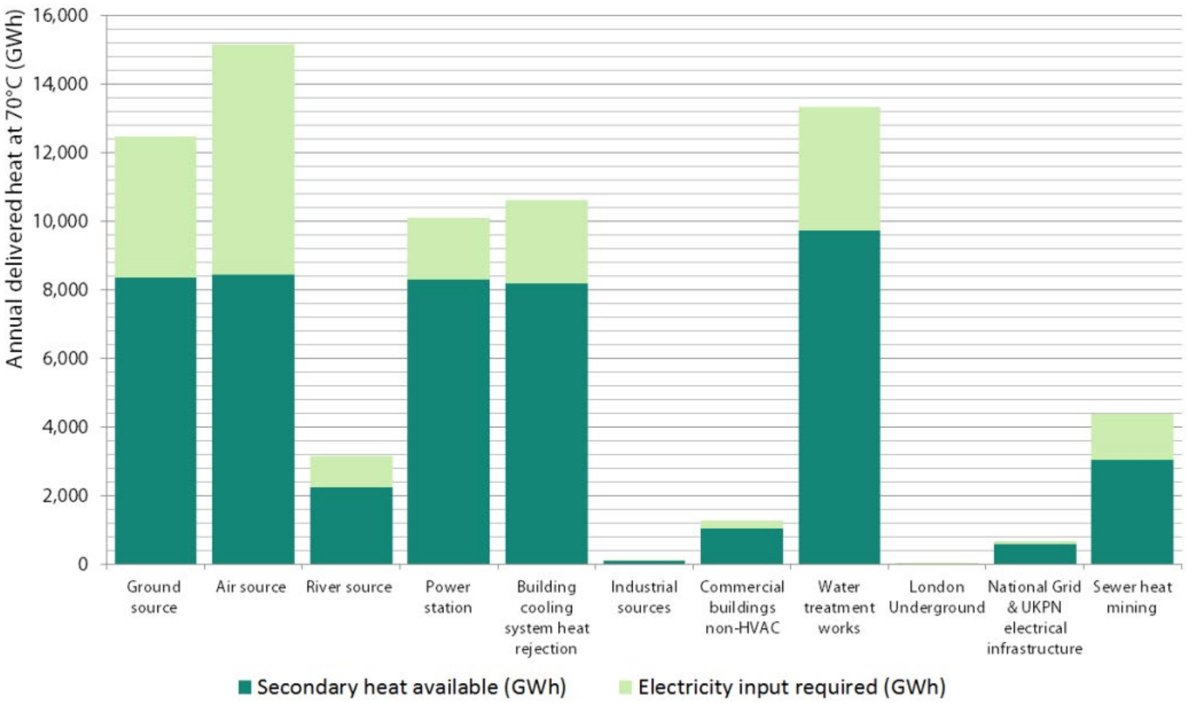
Power station rejection	Considerable energy is lost in the form of waste heat that can be utilised for heating buildings when upgraded by a heat pump.	**35-70°C**
Building cooling system heat rejection	Air and water cooled chillers reject heat at low temperatures that can be utilised for heat in buildings.	**~28°C**
Industrial sources	A number of industrial processes lead to the generation of waste heat such as food production and waste incineration.	**35-70°**
Commercial buildings non-HVAC	A number of buildings produce waste heat from non-heating and cooling systems, such as data centres and supermarket refrigeration.	**32-40°C**
Water treatment works	Low grade heat is generated due to the biological activity associated with waste water treatment.	**14-22°C**
Underground tunnels (e.g. London underground)	Waste heat is typically rejected through ventilator shafts but could be accessed for use in buildings.	**12-29°C**
UKPN/National Grid electrical infrastructure	Waste heat associated with the cooling of transformer coils.	**~50°C**
Sewer heat mining	Waste heat from large sewers underneath built up areas in London can be tapped in to in a similar way to the extraction of heat from the ground or rivers.	**14-22°C**

Fortunately, London has a wealth of other environmental and secondary heat sources. A study for the Greater London Authority in 2013[70] quantified the available heat resource in London, identifying that 71,300 GWh per year could be supplied by the combination of secondary heat sources and heat pumps in London, enough to meet London's current heat demand.

The chart below shows the estimated potential heat sources that could be supplied to future district heating networks in London with the energy available from the secondary source in dark green and the electricity required to drive the heat pumps in light green.

[70] Greater London Authority (2013). *London's zero carbon energy resource: Secondary heat*

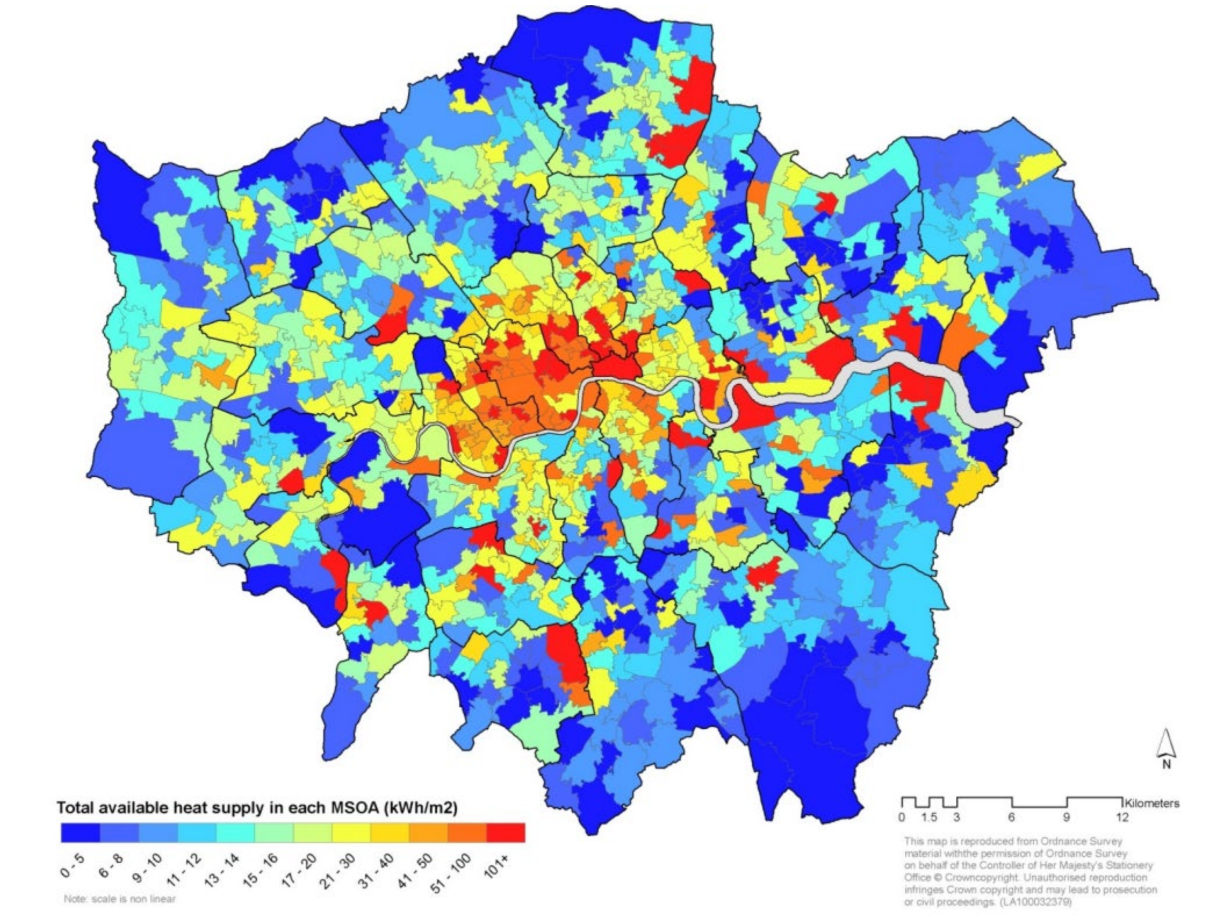
Figure 23: Estimated levels of secondary heat available for future district heating schemes in London. Source (London's zero carbon energy resource: Secondary heat)



This demonstrates that, alongside air source, ground source (including ground water), water treatment works, building cooling heat rejection and power station waste heat show the highest overall potential for utilisation by heat pumps. Sewer heat mining and river source also show considerable potential. For individual projects, the profile of potential available heat sources will be unique and should involve consideration of all potential sources. However, it is important to consider that this chart applies to utilisation of heat in heat networks only. For individual buildings; air and ground source are likely to be more dominant but with potential roles for other sources.

The 2013 Secondary Heat Study[71] also provides the map below indicating areas of high heat availability. In the centre of the city, this arises from building heat rejection, while in the outskirts, significant amounts of heat could be extracted from the ground or point sources such as power station condensers, river and waste water abstraction sources and large air source heat pumps located near electricity sub-stations.

Figure 24: Greater London Authority: 2013 Secondary Heat Study



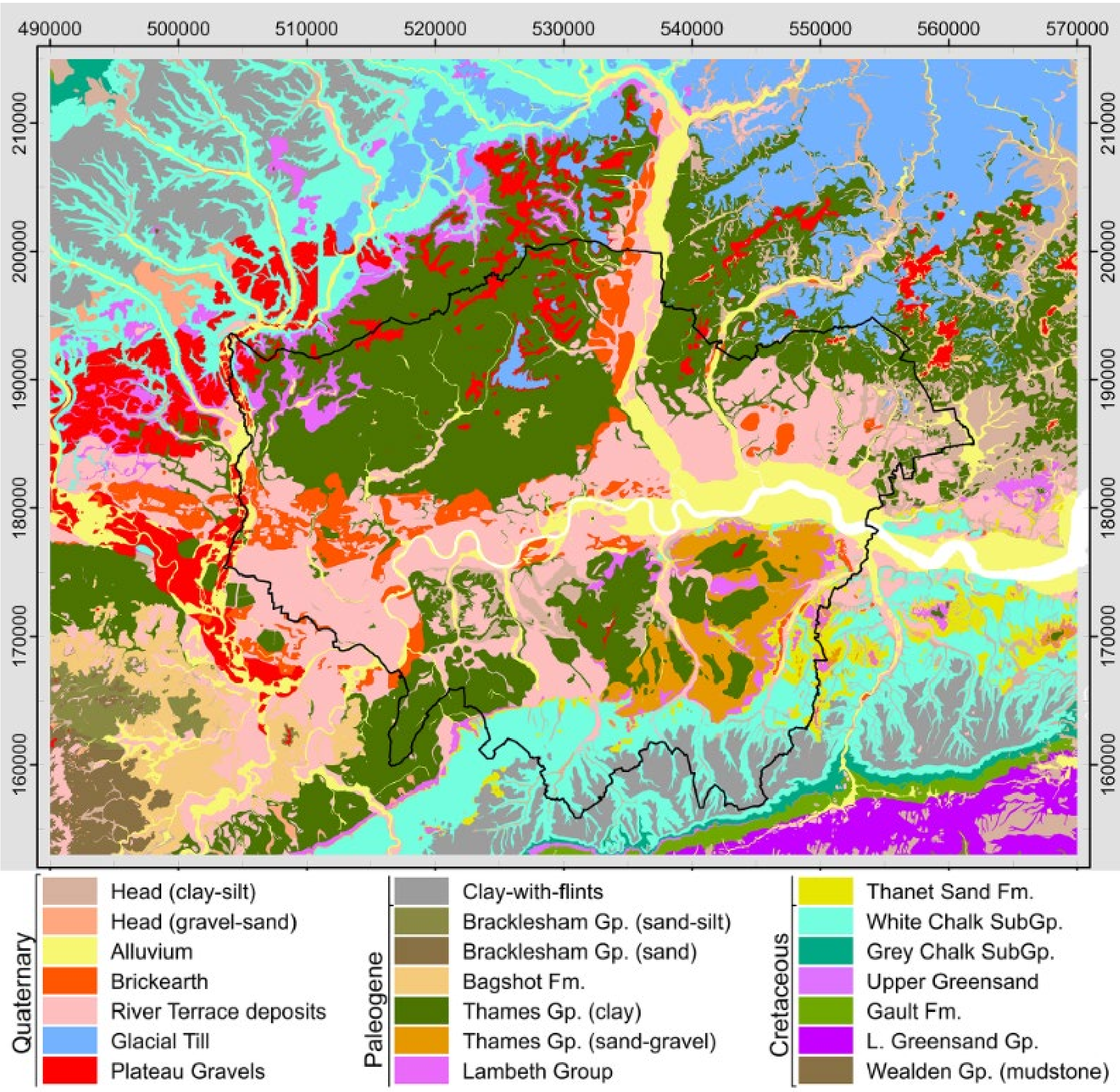
[71] Greater London Authority (2013). *London's zero carbon energy resource: Secondary heat* [71]

8.2 Geological conditions in London

The potential for ground and water source heat pumps is highly dependent on local geological conditions.

London's geology is highly varied (as shown by the map below) and so the specific location of a project within London will have a major bearing on the ground and groundwater heat sources available.

Figure 25: British Geological Survey: London Geology Atlas[72]



[72] British Geological Survey (2005). *London Geology Atlas*

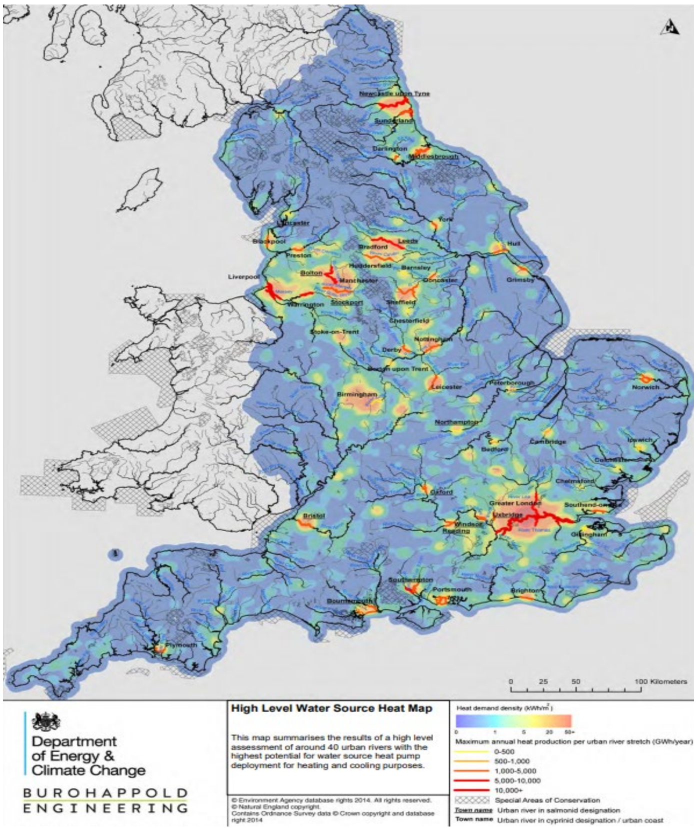
Ground source heat pumps have very stable temperatures. For larger buildings, open loop systems which exchange heat with surface water sources or shallow aquifers in the ground can make for a very strong financial case due to the lower drilling costs and high efficiencies achievable. London has particularly good potential for both shallow aquifer and surface water sources.

The map from the British Geological Survey shows the extensive covering of Alluvium (loose, unconsolidated sand, gravel and soil) and river terrace deposits (shallow river sand and gravel) within the Thames Basin associated with the River Thames itself and the Rivers Kennet, Ock and Lee. These sand gravel deposits provide a large storage volume of water than can potentially be accessed for use in closed or open loop water source heat pumps. These high yielding aquifers tend to exist at only a few metres depth meaning that drilling and extraction costs can be lower than for other forms of aquifer or ground drilling. Furthermore, due to an urban heat island effect, temperatures can be warmer than alternative ground water sources. The Ernest Dence Estate example in the Options appraisal (building 10) considers a shallow aquifer source heat pump.

Surface water potential in London

Regarding surface water potential; in 2014, the UK government commissioned a study of the high-level water source potential from around 40 urban rivers. The River Thames and its tributaries are considered to have some of the greatest potential in the UK (444MW of heat capacity in London)[73].

Figure 26: Water source heat potential from 40 Urban rivers in the UK. Source: BEIS



[73] Department for Energy and Climate Change (2015). *National Heat Map: Water Source Heat Map Layer*

Case Study

Utilising heat from London Underground: Bunhill Heat and Power Network

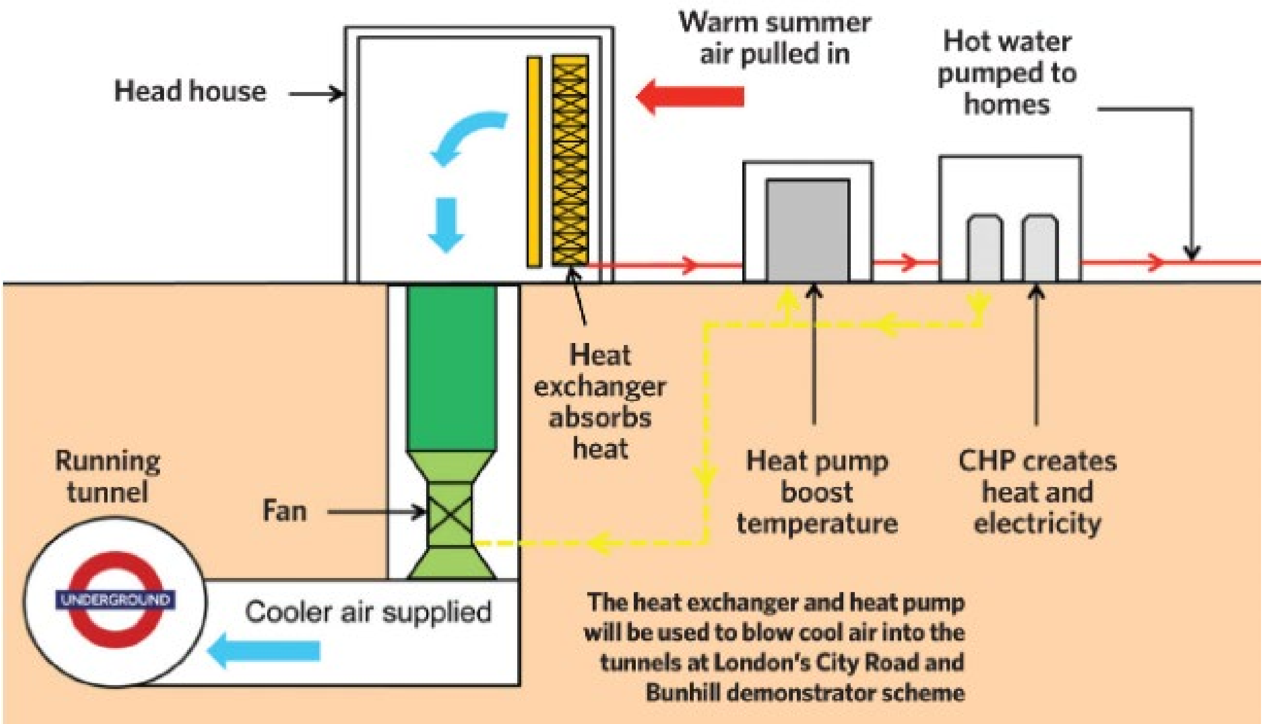
Islington Council's Bunhill Heat and Power Network (BHPN) is the first scheme in the world to take waste heat from an underground train network and use it to provide lower cost, greener heat to local homes, a school and leisure centres.

The Bunhill 2 Energy Centre is placed in the disused London Underground station of City Road, Islington. It features an underground two-metre fan which extracts warm air from tunnels on the Northern Line train route. The warm air is used to heat water that is pumped across the local neighbourhood through a new 1.5km network of underground pipes. It uses one of the ventilation shafts that carry hot air from the Underground tunnels up to ground level in order to help control the temperature on the network.

Warm air created by trains and machinery in the Underground network goes up the ventilation shaft and is pushed by a fan through a heat pump. The heat pump captures heat from the warm exhausted air, via a closed loop water circuit in the ventilation shaft. This is used to heat a gas, which is then put through a compressor, converting it into a very hot liquid and making the pipes that hold it very hot as well.

These hot pipes are used to heat the water that runs in the pipes of the Bunhill Heat and Power Network so that they can heat the buildings connected to the network. The pipe network is very well insulated to minimise the amount of heat lost on the way to the buildings.

In addition, the fan in the ventilation shaft has the potential to be reversed in the summer to provide cooling to the Underground network, helping to make journeys more comfortable. This scheme could be replicated in other locations across London making use of the numerous ventilation shafts that are already in place to cool the Underground.



9. Space, positioning and installation constraints

Heat pumps will typically require more space, both internally and externally than gas boilers or conventional electric heating. This is a key consideration for heat pump retrofit, particularly in London where internal space in dwellings is valued in excess of £6,000 per m^2.[74]

Also, as heat pumps typically do not provide instant hot water, space is generally required for a hot water cylinder in domestic properties or a larger thermal store in non-domestic and communal applications. This can pose a barrier to their use in small flats or buildings with limited size plant rooms available.

In this section, we look at some typical space requirements for different types of heat pump system and how this could affect their suitability for different building types in London.

Closed ground loop (trenches)

The length of pipe required for an individual ground trench will vary depending on the local ground conditions and heat pump size and efficiency. However, based on a range of manufacturer guidelines, a ground loop of between 60 and 100 metres of pipe is recommended per kW of installed capacity. A coiled pipe (known as a slinky coil) could reduce this figure by 60-75%.

For a domestic dwelling, a large garden would therefore be required with suitable access for light machinery for digging the trench.

For medium and large-scale commercial buildings, the amount of land required for ground trenches will almost certainly be prohibitive in London.

Closed ground loop (boreholes)

Compared to digging trenches, vertical boreholes offer a relatively discreet and compact solution, requiring little space and are possible with relatively minor disruption provided there is suitable access for the machinery. Boreholes can be dug in virtually any patch of land adjoining a building, with car parks, fields and gardens all able to be fully restored following installation.

In a borehole arrangement, a closed loop is placed vertically in the borehole to extract heat from the ground. Borehole depth will vary depending on energy requirement, local geological conditions and the thermal conductivity of the ground. However, depths of 60m and 100m are common. The boreholes are relatively small in diameter, typically less than 150mm. A borehole at this depth may provide 3-5kW of extractable heat. Much deeper drilling to 200-400 metres is also possible, producing higher yields of extractable heat.

[74] Rightmove (2020) Available at: https://www.rightmove.co.uk/news/articles/property-news/values-per-square-metre-of-houses-in-england-and-wales-revealed/

When coupled to a heat pump providing both heating and cooling, the seasonal efficiency can increase as summer cooling recharges the ground with heat that can increase yield in the winter. For example, one metre of vertical borehole will typically deliver 140kWh of useful heating and 110kWh of cooling per annum, although this will depend on hours run and length of heating and cooling seasons

To avoid boreholes extracting too much heat from the ground (leading to a reduced yield from each borehole), they are generally placed at 5-10 metres apart depending on ground conditions.

Boreholes can be located very close to buildings (although a minimum distance of 2-3 metres is kept to avoid any interference with building foundations) provided that access is available for machinery. The boreholes are typically placed within 25 metres of the property.

Borehole drilling is a specialist activity typically undertaken by expert companies, who are responsible for ensuring that the drilling process will avoid gas, electricity, water or sewage pipes or any other underground infrastructure. Whilst borehole drilling is undoubtedly more difficult in London than other areas, it is regularly undertaken safely and does not pose a major barrier for most London sites.

The primary constraint with borehole drilling is therefore cost rather than practical considerations. The economics of borehole drilling will tend to mean they are most viable for larger applications where the shared cost of drilling multiple loops improves the cost effectiveness. The supply chain for drilling boreholes is distinct from the heat pump installation supply chain and is already relatively mature so the potential for drilling costs to reduce may be limited, although uptake of heat pumps at mass scale could introduce new players and new efficiencies in to the supply chain.

Water source (open loop)

Open loop systems involve the direct abstraction of water for use in the heat pump. In the case of ground water or aquifers, water is abstracted via one or more boreholes. Depending on the depth of the available ground water aquifer, these boreholes can typically be much shallower than closed loop ground source boreholes at between 10-100 metres in depth. This can result in lower drilling costs. The number of boreholes will depend on the potential yield of the water source. However, it is common for fewer boreholes to be required than for closed loop systems. Even in some large applications, a single abstraction borehole and a single return borehole can be sufficient to deliver sufficient water flow for the heat pump.

Open loop systems can therefore be a better option where space for multiple boreholes is limited.

Various environmental permits are required from the Environment Agency for the abstraction and return of water to aquifers and open water sources. A heat pump installer will be able to advise on the necessary permissions.

A further consideration is that open loop systems can require greater maintenance than closed loop, meaning that there is a greater need for access to filters and for general maintenance.

Shared ground loops versus traditional heat networks

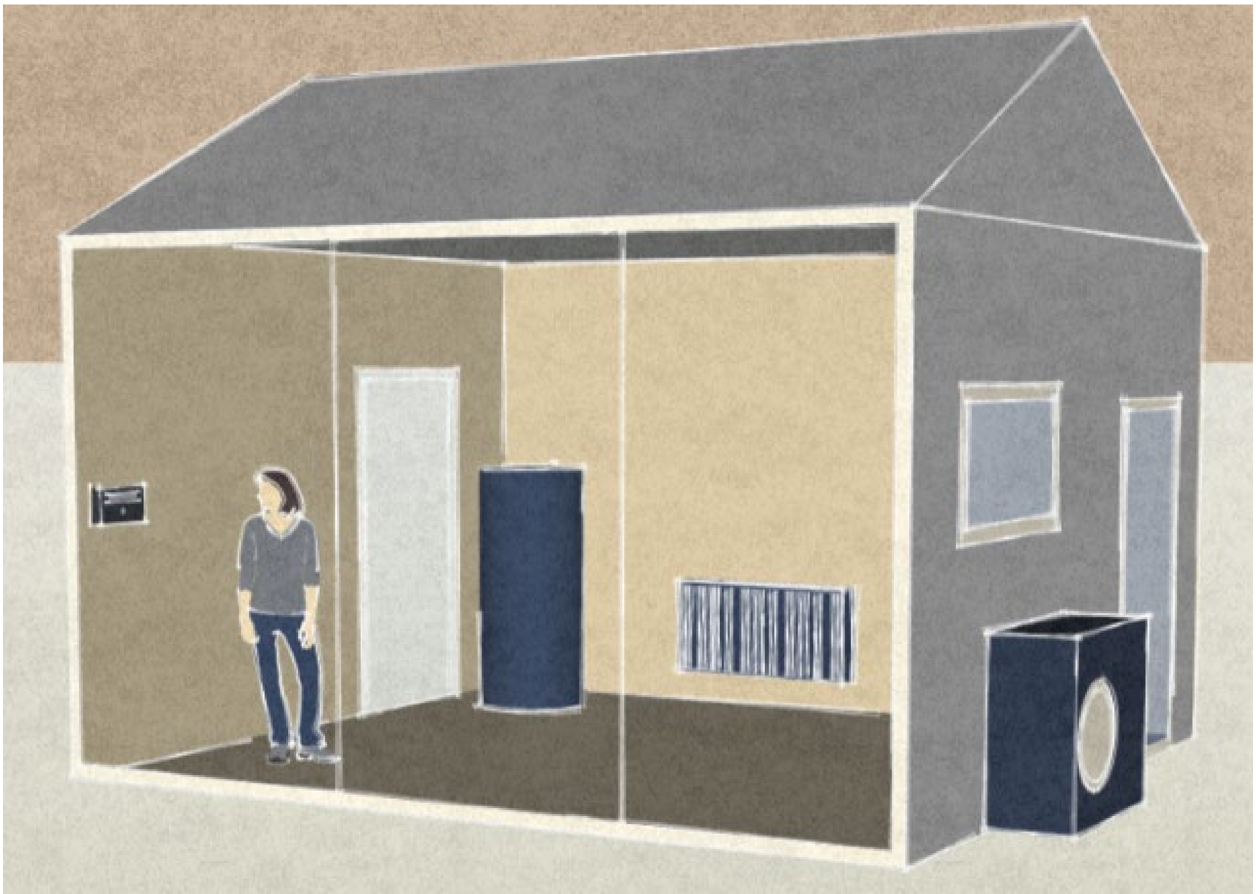
A shared ground loop is the name given to a heat pump configuration where two or more properties have individual heat pumps connected to one shared ground loop. In this way, shared loops can be considered a form of district heating. However, the loop itself contains ambient temperature heat from the ground (as opposed to high temperature water or steam) hence they are also referred to as 'ambient loops'. A shared loop will typically require a series of boreholes to be drilled according to the combined demand of the buildings connected.

Shared ground loops offer a number of advantages:

- **Lower cost of drilling:** Sharing the cost of borehole drilling can make it more viable for many projects.
- **Lower cost of heat distribution:** Compared to traditional heat networks, shared ground loop pipes are smaller and less expensive to install than high temperature insulated pipes containing hot water. This also makes them relatively easier to retrofit in to existing building service ducts where space is limited.
- **Lower system losses:** As the heat being distributed around the building is at ambient temperature, heat losses are essentially eliminated in the transition to the property. In fact, the heat exchange that occurs as the pipes pass through the ground and the building can be beneficial.
- **Independence:** Each building has control over its own heat pump and therefore pays its own energy bill i.e. there is no need for a separate energy services company, heat metering or Heat Interface Units.
- **Scope for expansion:** It is relatively easy to expand shared ground loop systems through the addition of further boreholes and further individual heat pumps in buildings.
- **Resilience:** When a fault develops with one heat pump, this does not affect other heat pumps on the system and the faulty head pump can be individually replaced.
- **Sharing heat:** Buildings with excess heat can discharge that heat to the ground loop, providing an efficient method of cooling and enabling other buildings on the loop to benefit from the higher temperature heat available. This can lead to highly efficient annual efficiency with excess heat from buildings in summer re-charging the ground with heat to be extracted in winter in a process referred to as Inter-seasonal Heat Transfer.
- **Non-domestic RHI:** Shared ground loops currently benefit from some of the more generous rates of funding under the non-domestic RHI. The non-domestic RHI is due to close in 2022.
- However, compared to traditional heat networks, shared ground loops may:
- **Be higher cost:** Shared ground loops can be more expensive overall as multiple individual heat pump units are required as opposed to one or two larger heat pumps serving multiple buildings.
- **Have lower capacity:** The total capacity of heat pump equipment required is also lower in traditional heat networks. As it is unlikely that peak heat loads will occur across all dwellings simultaneously, the overall heat pump system capacity can be smaller.
- **Require mores space:** Whilst shared loops require less space for centralised plant, traditional heat networks offer the advantage of not requiring space for a heat pump within the individual building itself. This can be a major advantage is space constrained buildings such as small flats.

Monobloc air to water heat pump

Figure 27: Scale illustration of 8kW monobloc external heat pump (*right*) feeding radiator (*centre*) and hot water cylinder (*back left corner*) with control unit (*front left corner*).



In a monobloc arrangement, all of the core heat pump components are contained in the external unit. Hot water pipes for radiators and the hot water cylinder pass directly from the unit in to the building.

Monobloc heat pumps require more external but less internal space than other ASHP configurations.

For small scale domestic applications (3-20kW) an individual unit is typically used ranging in size from the equivalent of a small fridge to a large double fridge freezer. Units are commonly placed in rear gardens, passageways or any other external wall provided there is a free flow of air.

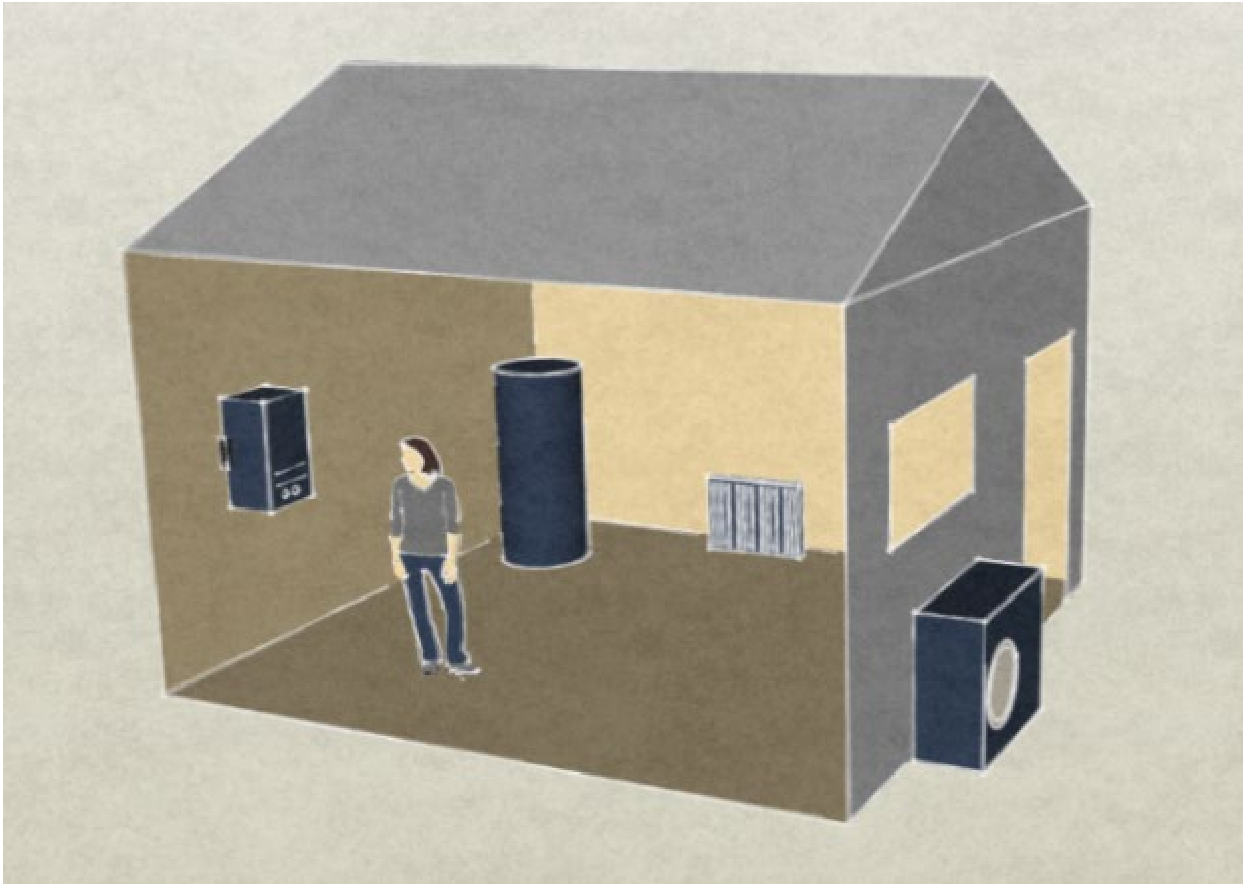
It is less common to use monobloc ASHPs on the outside of blocks of flats, due to a lack of suitable external wall space and the difficulty of accessing units for maintenance. However, it is possible to mount them on the roof with pipework running to the flat through service risers.

For medium and large applications, multiple units can be banked together to form systems over 1MW in size with the only real constraint being the amount of available space. Units are often located on the roofs of non-domestic buildings, or on dedicated ground adjacent to the building.

Monobloc heat pumps can be quicker and easier to install than other arrangements as only standard electricity and water connections are required (i.e. there is no need for F-Gas qualifications on installation, as there may be for split systems).

Split air to water heat pump

Figure 28: scale illustration of 8kW split air to water heat pump external unit (*right*), internal unit (*front left*), feeding radiators (centre) and a hot water cylinder (*back left corner*).



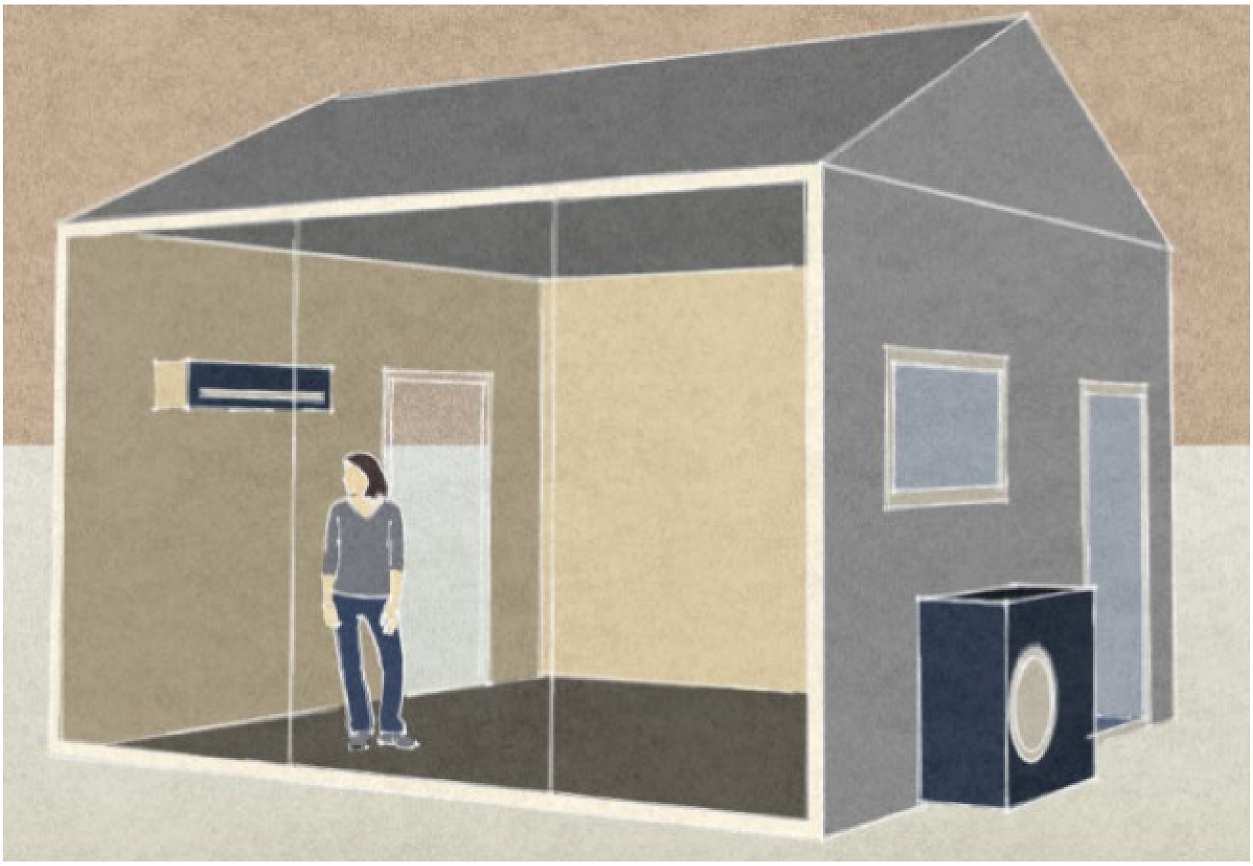
Split systems consist of two separate units: an indoor unit and outdoor unit. The outdoor unit contains the evaporator; the indoor unit contains the compressor and condenser with refrigerant passing between the two. To limit the amount of refrigerant required, it is desirable to locate the external and internal units as closely as possible although it is possible for the two units to be up to 50 metres apart or more in some applications.

This configuration typically requires a smaller outdoor unit than a monobloc arrangement which may enable a greater choice of locations in retrofits where outdoor space is limited. However, a suitable space for the internal unit, plus space for the hot water cylinder is required. For domestic installations (3-20kW) this can range in size from the equivalent of a wall-hung gas boiler to an under-counter fridge. It is common for split systems to combine the indoor unit with an integrated hot water cylinder, creating a combined unit the size of a tall fridge freezer. For non-domestic installations, this may require internal space in a plant room. The amount of space will vary but is likely to be larger than existing gas boiler plant. At this scale, additional plant such as buffer tanks and thermal stores are also likely to need accommodating.

Split systems may require a greater amount of time to install than monobloc systems and installers require an additional F-Gas qualification. This is because the external heat exchanger is connected to the internal unit with pipes containing refrigerant.

Split air to air heat pump

Figure 29: scale illustration of split air to air heat pump with external unit (*right*) connected to internal fan coil unit (*top left*). No radiators and no hot water.



Split air to air heat pumps consist of an exterior condenser unit which is connected via refrigerant pipes to interior fan coil units that provide heating or cooling directly through blown air. Air to air split units are a common form of air conditioning in buildings. They do not provide hot water.

In a retrofit context, air to air heat pumps can provide a solution for smaller dwellings or small office buildings where energy demand has been reduced to very low levels through energy efficiency and where the layout supports good air flow around the building to ensure all areas are sufficiently heated.

Variable Refrigerant Flow (VRF) heat pump

VRF heat pump systems are a type of inverter driven split air to air heat pump, where the flow of refrigerant can be modulated to supply varying demand to different indoor units. Heating and cooling can often be provided simultaneously depending on the requirements of different zones within the buildings. In the case of blocks of flats, the indoor units could be small individual internal heat pumps units; in the case of commercial buildings, the indoor units are more likely to be fan coil units (FCUs) providing warm air to zones within the building.

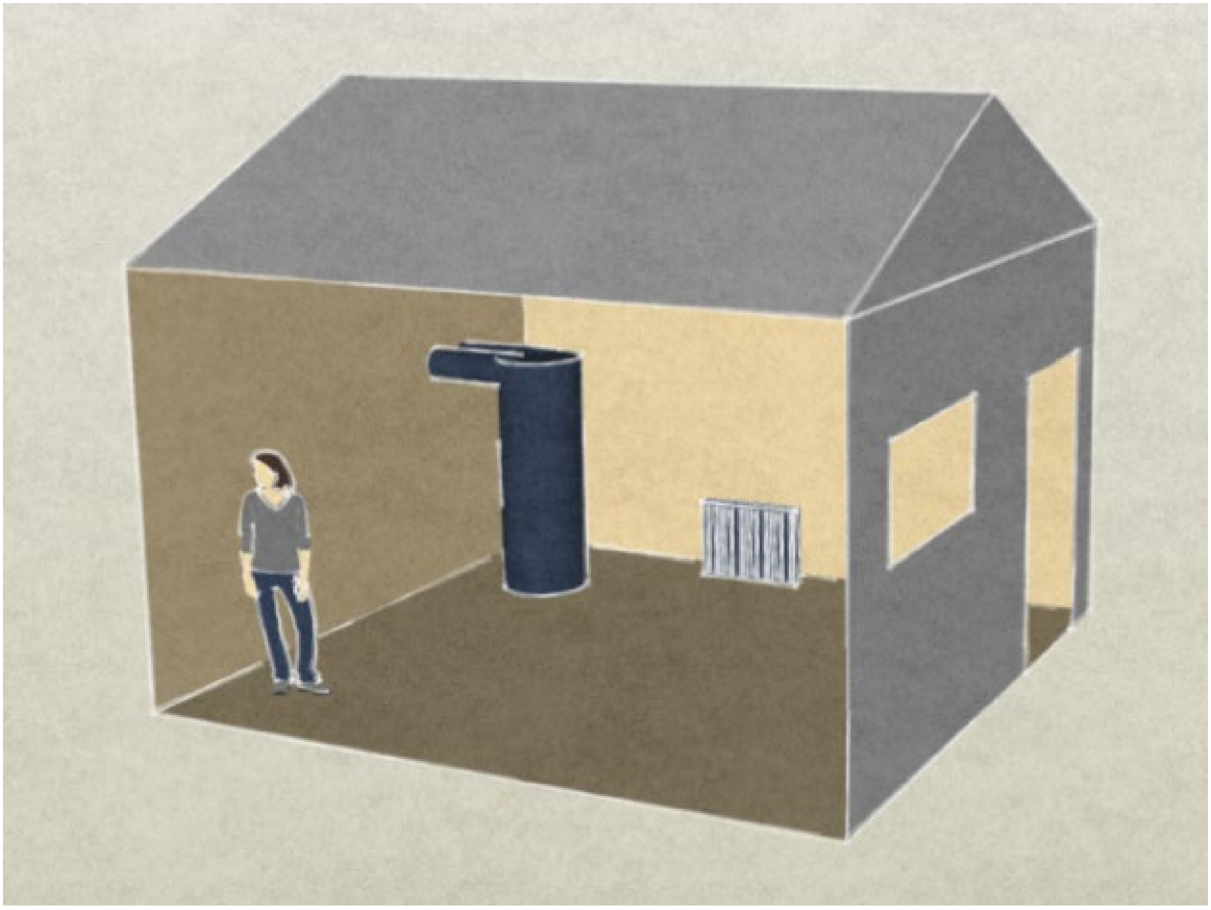
The ability to control the amount of refrigerant to the indoor units located throughout a building makes VRF technology ideal for applications with varying loads or where zoning is required. VRF is therefore a common system application for commercial buildings and offices.

Each fan coil unit or Heat Interface Unit (HIU) can operate independently, drawing down heat as required from the central heat pump circuit. Depending on the application, the installation of a VRF system can be a cost-effective alternative to traditional systems that require ductwork or large pipe sizes, pumps and boilers.

VRF systems can be more expensive to install than standard heat pump systems supplying hot water around the building although efficiencies can be higher. They can be more disruptive to install and so lend themselves better to situations where a deep retrofit of the building is taking place. VRF systems require less space as there is no central plant. The production of heating and cooling is decentralised within the individual fan coil units or heat pump units within the dwellings, rooms or heating zones.

Internal air to water heat pump

Figure 30: (*left*) scale illustration of 3kW internal heat pump with integrated hot water cylinder (*back left*) also feeding radiators (*centre*). With air ducts to external wall (*back left*).



In a fully internal heat pump, the evaporator is installed inside the building. The exterior air is brought into the unit via air ducts through the external wall. This technology can be combined with heat recovery from air-handling units or other waste sources by ducting exhaust air from the waste heat source in to the unit. These units are commonly provided as an integrated package with a hot water cylinder. This technology is typically found at smaller scales of 1-5kW.

This configuration can provide a solution for flats without a suitable space for an external fan unit.

The full heat pump and cylinder combination can take up less than 0.7m^2 of floor space and a height of approximately 1.8m, small enough to fit enough in a small airing cupboard[75]. Units can be provided pre-plumbed, reducing the labour requirement for on-site installation and potentially improving installation quality. Due to the small size of the heat pump, internal noise can be kept to low levels.

Exhaust air heat pump (combined ventilation heat pump and hot water unit)

Exhaust air heat pumps utilise the outgoing air from a building ventilation system as the heat source for the evaporator. They can come with an integrated hot water cylinder and plumbing for space heating. Fresh air is supplied to the ventilation system from outside via ducting, thereby providing a combined solution for ventilation and heating.

An appropriate ventilation system and ducting are required, therefore retrofit installation of these is typically impractical unless a major refurbishment of the inside of the building is taking place.

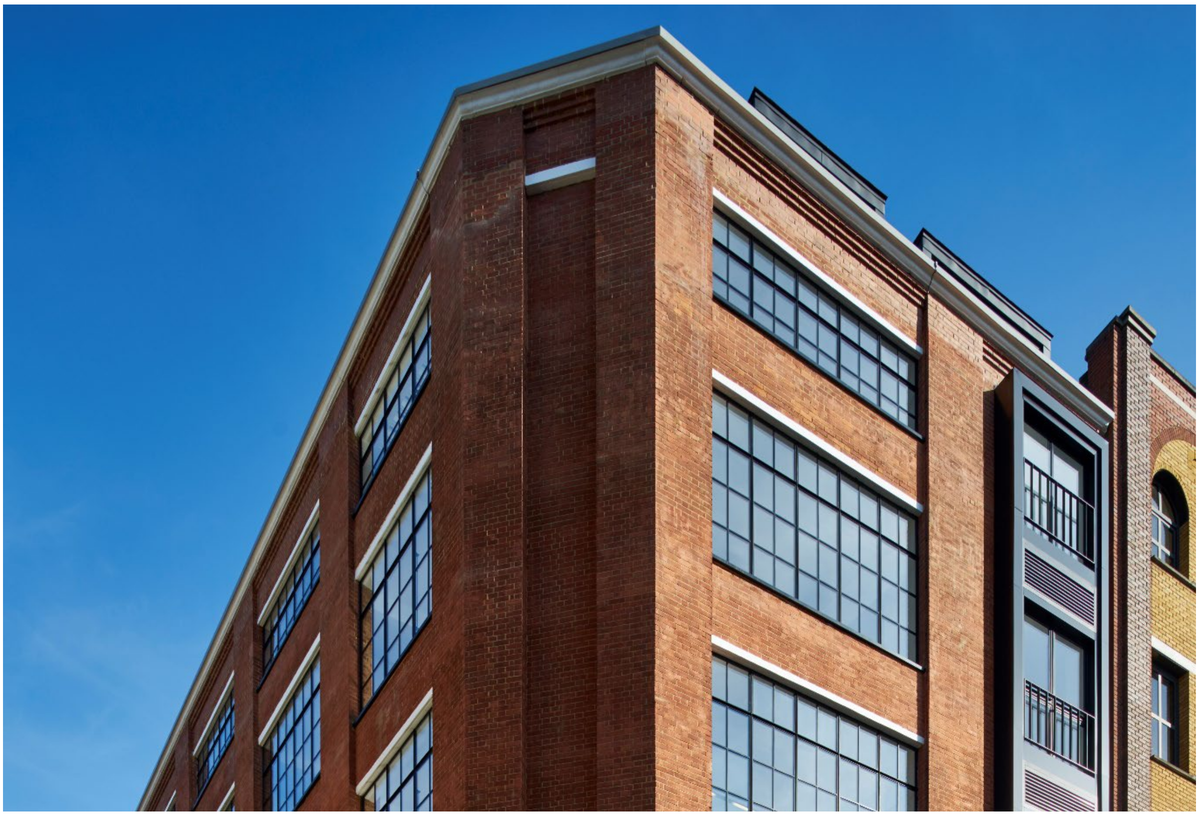
Also, output is generally limited to the volume of exhaust air flowing through the ventilation system which limits the overall kW output.

For that reason, these heat pumps are best suited to new build properties where ventilation is being installed at the same time, although there will be applications for them in deep retrofits of existing buildings where very low levels of space heating demand are required (e.g. 25-50kWh per m^2 per year).

[75] See, for example GroundSun GS 200: https://www.groundsun.co.uk/small-home-and-apartment-heat-pumps/

Case study

Air source heat pump case study: Central London office building refurbished through the Low Carbon Workplace partnership programme



Heat pumps

Mitsubishi Electric VRF air-cooled heat pump system provides all of the space heating and cooling requirements for the building. The seven roof-mounted City Multi PURY-EP-YLM units are capable of delivering a total cooling output of 380kW and a total heating output of 427kW for total electrical inputs of 121kW and 129kW respectively. In 2019 the energy monitoring system has shown that the total maximum input of electricity to the system has been 80kW. Refrigerant from the roof level units is distributed via branch controllers on each floor that allow both heating and cooling to be delivered simultaneously and for energy to be redistributed across the system, rather than rejected via outdoor units. Ceiling-mounted concealed fan coil units (FCU) heat and cool fresh air and recirculated air in the office spaces, air is extracted via heat recovery ventilation units on each floor allowing for individual control.

Heat emitters and controls

Mitsubishi Electric City Multi concealed ceiling-mounted fan coil units with max outputs ranging between 2.8kW-12.5kW. The heating and cooling are controlled by the central Building Management System (BMS), with building-wide temperature set points and the capability to control individual FCU temperatures. The operation of the heating and cooling is integrated with passive infrared (PIR) occupancy detectors that automatically implement a 'set-back' control routine reducing the temperature and fresh air demand on the FCUs and ventilation in that area if it is unoccupied. The window contact sensors switch off FCUs and ventilation in the immediate area if the window is opened, to reduce energy losses.

Energy efficiency

As part of the refurbishment, improvements were made primarily to the windows and the roof. The existing building was single glazed throughout, which was completely replaced with high performance double glazing; the double height units at ground floor and at roof extension level had a maximum U-Value of 1.4W/m^2.k, while the Crittal windows on floors one to four have a maximum U-Value of 1.8W/m^2.k. The replacement of the crittal windows allowed for openable windows incorporating sensors that integrated with the VRF and FCU controls. The refurbishment included a new flat roof level extension, with a U-Value of 0.18W/m^2.k. The brickwork construction was retained and did not undergo any changes to thermal performance.

10. Planning, noise and aesthetic constraints

For domestic and non-domestic heat pumps, installations are generally considered as permitted development, subject to the installation complying with a range of guidelines. For ground and water source heat pumps these guidelines are typically straightforward to comply with. Once ground and water source heat pumps have been installed they typically have no externally visible elements and very low noise levels. They are therefore generally viewed very favourably by planners.

However, for air source heat pumps, many of the permitted development guidelines will constrain their potential in London where blocks of flats and rows of terraced housing are prevalent. The two primary issues are the noise and the aesthetic impact of the external fan unit.

Full details of the permitted development requirements for buildings can be found on the Planning Portal website[76]. A summary is provided below.

Planning permission for ground and water source heat pumps:

Domestic

The installation of a ground source heat pump or a water source heat pump on domestic premises is usually considered to be permitted development with no need for planning permission. However, those living in a listed building or a conservation area should contact their local authority to check on local requirements.

Planning permission for ground and water source heat pumps:

Non-domestic Installing a ground or water source heat pump in the grounds of a non-domestic building is likely to be considered 'permitted development' with no need for planning permission provided the following conditions are observed

- When no longer required, the heat pump should be removed and the land restored to its original condition.
- The total area of excavation must not exceed 0.5 hectares.
- The heat pump must be located within the curtilage of the building and only one ground source heat pump is located within the curtilage of the building. Any more than one will require planning permission.

[76] Planning Portal (2020). *Permitted Development Rights.* Available at: https://www.planningportal.co.uk/info/200187/your_responsibilities/37/planning_permission/2

Planning permission for air source heat pumps: Domestic

The installation of an air source heat pump in domestic premises is considered to be permitted development with no need for planning permission. However, this is contingent on a range of guidelines being met, many of which will restrict the applicability of air source heat pumps in urban areas.

To qualify as permitted development, the following rules apply:

- All parts of the ASHP must be at least one metre from the property boundary.
- Installations on pitched roofs are not permitted development.
- Permitted development rights do not apply to listed buildings or scheduled monuments.
- On land within a Conservation Area or World Heritage Site, the ASHP must not be installed on a wall or roof which fronts a highway.
- On land not within a Conservation Area or World Heritage Site, the ASHP must not be installed on a wall if that wall fronts a highway and any part of that wall is above the level of the ground storey.
- The heat pump must be used solely for heating purposes.
- It must be removed as soon as reasonably practicable when it is no longer needed.
- It must be sited, as far as is practicable, to minimise its effect on the external appearance of the building and the amenity of the area.

Furthermore, all guidelines in Microgeneration Certification Scheme (MCS) 020 'Planning standards for permitted development installations of wind turbines and air source heat pumps on domestic premises'[77] must be followed.

Air source heat pump noise limits

MCS 020 sets out minimum requirements for MCS Certified Products and the MCS Contractor Standard MIS 3005. However, a primary focus of MCS 020 is to provide a calculation procedure for ensuring that air source heat pump installations comply with a maximum sound pressure level of 42dB(A) when assessed one metre away from the neighbours nearest window or door of a habitable room.

Heat pump noise levels are typically assessed and quoted in two ways:

1. Sound power level dB(A)

Sound power is the total acoustic energy emitted by a sound source and is an absolute value, irrespective of the environment or location of the listener. You will typically find sound power ratings provided in heat pump specification documents from manufacturers. The sound power level is also the level provided on the heat pump energy label for both the internal and external unit. Sound power levels can range widely between 40 and 80dB(A) for different makes and model of heat pump.

[77] Microgeneration Certification Scheme. *Planning standards 020.*

2. Sound pressure Level dB

Sound pressure is what we hear. It is determined not just by the sound power of the source but also by the specific surroundings and the distance from the source to the point at which the sound is heard. For example, sound pressure increases with the number of reflecting surfaces but can be reduced by obstacles to acoustic path. The 42dB limit applies to sound pressure.

An MCS certified installer will undertake a detailed noise assessment as part of the design, installation and commissioning of a heat pump to ensure that the necessary standard is met.

In the context of heat pump retrofit in London, the sound pressure level requirements represent a real constraint on situations where an air source heat pump may be suitable. For example, in dense blocks of flats, it may not be possible to meet the sound pressure requirements.

However, with careful choice of technology and placement to minimise sound pressure it may be possible to install ASHPs even in very dense settings. There is a wide range in the sound performance of heat pumps on the market, with the sound power of models on the market ranging between 30 and 80 Db(A). Premium heat pump models with very low levels of noise will enable far more choice in the positioning of heat pumps. Likewise, careful positioning away from inhabited rooms and reflecting surfaces can mean that relatively noisier heat pumps are still able to meet noise requirements.

In summary, the potential for air source heat pumps in flats and other densely populated areas is likely to be limited and other solutions such as ground source, shared ground loops or, in some cases internal or premium heat pumps with very low noise levels are likely to be required.

11. Connection constraints

For the majority of heat pump installations, payment to connect to the local electricity network is not required.

There is a standard notification process for connecting small scale heat pumps to the electricity network than can be accessed online[78]. The Energy Networks Association (ENA) maintains a database of approved equipment that can be connected to the network under this standard connection process. All DNOs will assess heat pump notifications within 10 working days.

In some cases, installing heat pumps may involve upgrading the electricity supply to a building.

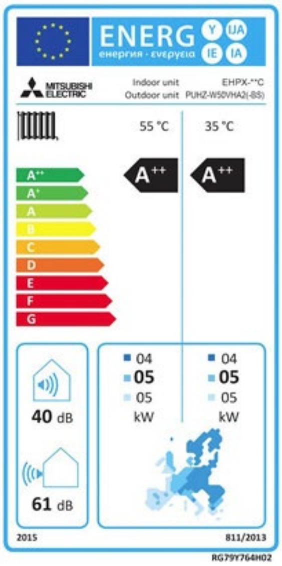
UK Power Networks (UKPN) provides the following advice to customers:

- Where connection requires upgrading the fuse from 30/60 to 80/100 amps, UKPN provides the fuse upgrade free of charge.
- Larger installations may require the upgrade of the electricity supply from single phase to three phase. In these circumstances the customer is required to pay for an upgrade. UKPN will provide customers with a cost for this upon application[79].
- For very large applications, such as if a whole block of flats were converted from gas to heat pumps, an electrician will be required to make a load assessment for the property and any required upgrades to the network will be charged to the building owners.
- For clustered groups of houses (such as in social housing) undertaking upgrades at the same time, any reinforcement costs are likely to be covered by the DNO.

The above information has been provided by UKPN for most of the London area. Building owners considering large heat pump retrofit projects across multiple buildings are encouraged to book a 'Distribution Energy Resources Surgery' from UKPN to discuss the viability of projects before making an application.

Information on how to book a surgery can be found at https://www.ukpowernetworks.co.uk/electricity/distribution-energy-resources/der-surgeries

Similar guidance for SSEN customers (SSEN covers parts of West London) can be found on the SSEN website: https://www.ssen.co.uk/Connections/SmallProjects/



[78] Energy Networks Association. Available at: http://www.energynetworks.org/electricity/futures/electric-vehicles-and-heat-pumps.html
[79] UK Power Networks. Available at: https://www.ukpowernetworks.co.uk/electricity/upgrade-reduce-electricity

12. Summary of potential heat pump solutions in urban areas

There are a number of factors that can make heat pump retrofit more challenging in urban areas than elsewhere. For example, large sections of the building stock remain energy inefficient and require high flow temperatures (which cause heat pumps to run less efficiently) and air source heat pumps can pose challenges for blocks of flats or dense urban areas where strict noise limits apply and space is at a premium.

However, heat pump technology is diverse and solutions exist to overcome a number of these challenges. As the UK heat pump sector develops, systems are increasingly being designed and manufactured to overcome the specific challenges of the UK market – for example high temperature heat pumps, heat pumps for small flats and low noise air source heat pumps.

Table 10: examples of some potential solutions for common building archetypes in London.

Building types	Barriers	Potential heat pump solutions
Individually heated flats	Many individual flats (particularly those above the ground floor) have limited or no suitable space for an air source heat pump external unit. Internal space for a hot water cylinder is at a premium. Strict noise limits apply to air source heat pumps that may limit their potential in flats.	• Fully internal air source heat pumps offer a potential low noise solution without the need for an external fan unit. These can be installed on a flat by flat basis. • In some cases, roofs, roof terraces, balconies or walkways may provide a suitable location for an external heat pump unit and hot water cylinder. • Shared ground loops with individual heat pumps in each dwelling offer a viable solution for flats. These are already being retrofitted to blocks of flats in London. These systems also have the potential to provide cooling for buildings that overheat in summer (an increasing problem in London). • Air source heat pumps with Variable Refrigerant Flow (VRF) can be used in blocks of flats, with small individual units within each flat capable of providing heating and cooling. • Individual heat pumps with integrated hot water cylinders can take up small amounts of floor space.
Individually heated houses	Houses in dense urban areas (e.g. terraced housing) can be limited in choice of location for both air source heat pumps	• Air source heat pumps with advanced acoustic dampening are capable of meeting noise limits even in very dense settings with sensitive installation. • When undertaken alongside upgrades to the thermal fabric and air tightness, heat loss can be reduced. By also

	and ground source heat pumps. The London housing stock is particularly inefficient with high heat loss, often requiring high flow temperatures.	upgrading radiators, flow temperatures can be reduced to make for an efficient heat pump installation. • For some homes, hybrid heat pumps or high temperature heat pumps may be an appropriate solution.
Offices and other non-domestic buildings	Heating systems in commercial and non-domestic buildings tend to be more varied meaning that systems are more site specific.	• At this scale, a wide range of heat sources become financially viable. Larger ground source heat pumps are the most common and have been installed in many buildings across London. London also has excellent potential from other sources such as shallow aquifers (where drilling costs can be lower and source temperatures higher), the River Thames, data centres, the London Underground, waste treatment facilities and commercial building waste heat. • At individual locations, any one of these sources may provide a source of heat that makes for a highly efficient heat pump installation. • Many non-domestic buildings already use lower temperature heat emitters such as fan coil units which are well suited to heat pumps. • Energy efficiency improvements can reduce flow temperatures and overall space heating demand. • Non-domestic buildings with high demand for cooling can gain huge benefits from 'passive cooling' offered by reversible ground or water source heat pumps. • In larger buildings, air source VRF systems can move heat from one part of the building to another to balance temperatures at very high efficiencies.
Blocks of flats with communal heating and larger scale district heating schemes	London has a high number of flats heated by one central plant room. Many of these are ageing and have inefficient gas boilers. Heat distribution systems are typically high temperature and can often be inefficient with high system losses.	• Large scale heat pumps can replace gas boilers. Heat pumps at this scale can be highly efficient, leading to overall reductions in fuel bills with good design, installation and operation. • Higher temperature heat pumps, while typically less efficient can provide high temperature heat to work with existing distribution systems. • Where distribution systems are being upgraded anyway, this presents an ideal opportunity for installing lower temperature compatible systems. • District heating schemes have the potential to tap into multiple sources of heat across an area.

RAG assessment of heat pump retrofit options for different building types

The following chart provides an assessment of the feasibility of different technology options for different building types in London.

- (Dark blue) Major barriers are likely to preclude this technology/building type combination.
- (Light blue) Barriers present but not for all buildings
- (Green) The technology is ideally suited to the building type with few barriers to installation

<table>
<tr><th>Property type</th><th>Existing heating system</th><th>Individual air source</th><th>Individual ground or water source</th><th>Shared ground loop with individual heat pumps or Air source Variable Refrigerant Flow (VRF) type system serving multiple flats</th><th>Centralised communal heat pumps distributing heat via hot water pipes</th></tr>
<tr><td rowspan="3">Blocks of flats</td><td>Individual electric heating</td><td rowspan="2">Significant barriers to individual ASHPs in flats due to noise and space constraints and lack of suitable position for external unit.
Fully internal ASHPs provide a potential solution for some.</td><td rowspan="2">Cost of installing individual GSHP prohibitive for small flat.</td><td>Can have a strong financial case for moving to individual electric heat pumps on shared ground loop. External space required for boreholes.
VRF ASHP also a viable option. Careful siting and attention to noise levels required.</td><td rowspan="2">Where existing low carbon heat networks exist nearby, flats could be retrofitted to connect to them.
However, levels of cost and disruption may favour less invasive work (e.g. shared ground loops)</td></tr>
<tr><td>Individual gas boilers</td><td>As above. Weaker financial case when replacing gas but higher lifetime carbon savings. Can also meet landlord desire to remove gas from high rise buildings.</td></tr>
<tr><td>Communal gas or gas CHP heating</td><td colspan="2">More efficient and cost effective to install communal heat pumps, utilising the existing or upgraded pipework, rather than install individual heat pumps.</td><td>Financial case likely to be stronger for maintaining centralised heat distribution and replacing central boiler with heat pump.
Decentralised systems provide an option for building owners wanting to remove centralised heating without installing gas.</td><td>Large carbon and fuel bill savings when replacing ageing existing communal systems.
Strong financial case when upgrades are required to existing heat distribution system in any case. Lower capital cost and higher efficiency than multiple individual heat pumps.</td></tr>
<tr><td rowspan="2">Converted flats</td><td>Electric heating</td><td colspan="2">Ground floor flats may have good potential and a strong financial case where noise issues can be overcome. In mid and top floor flats there is often a lack of suitable external space for heat pumps. Deep energy efficiency retrofit combined with smart on peak electric heating may be required.</td><td rowspan="2">Rows of terraces/ estates/neighbourhoods could potentially utilise shared ground loops but significant subsidy required to cover cost of ground loops. Major barriers to securing buy-in from multiple private individuals, although social housing areas could provide an anchor load.</td><td rowspan="2">Existing heat networks could be expanded to include new neighbourhoods but this is unlikely to be cost effective with low density housing.</td></tr>
<tr><td>Gas heating</td><td colspan="2">As above but with the additional barrier that significant subsidy levels required to make financial case compelling.</td></tr>
</table>

<table>
<tr><td rowspan="2">Houses</td><td>Individual electric heating</td><td>Very strong financial case for ASHP retrofit. Larger houses have strongest financial case and more options for suitable siting to avoid noise issues.</td><td rowspan="2">Unlikely to be viable for individual houses except for cases with very large heat demand.</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Individual gas heating</td><td>Good feasibility but subsidy required to make financial case compelling relative to gas boiler replacement, particularly where energy efficiency improvements required.</td></tr>
<tr><td rowspan="2">Medium sized office and non-domestic buildings</td><td>Electric heating</td><td colspan="2">Excellent technical and financial feasibility for heat pump retrofit.</td><td rowspan="4">Potential for building to be included in expandable fifth generation district heating programmes with surrounding buildings.</td><td rowspan="4">Potential for buildings to join neighbouring district heating networks.</td></tr>
<tr><td>Gas heating</td><td colspan="2">The financial case for heat pump retrofit is generally weak as the costs of replacement gas boilers are significantly lower.</td></tr>
<tr><td rowspan="2">Large office and non-domestic buildings</td><td>Electric heating and cooling</td><td>Excellent technical and financial feasibility for heat pump retrofit. Financial case can be improved further with addition of Solar PV.</td><td>Excellent technical and financial potential. The possibility of providing passive cooling enhances business case further.</td></tr>
<tr><td>Gas heating and electric cooling</td><td colspan="2">The financial case for heat pump retrofit is generally weaker due to the cost of replacement gas boilers being significantly lower. However, the ability to provide cooling at lower cost and avoid capital expenditure on separate heating and cooling systems can make cases more attractive. Subsidy required to make financial case compelling.</td></tr>
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Section D

CO_2 savings, fuel bill and costs analysis

In this section, we explore the potential CO_2 savings, capital costs, operating costs and lifetime costs of ownership of heat pump retrofit, through the context of the 15 example London buildings.

As previously noted, heat pump retrofit cannot be separated from the issues of energy efficiency, flexible time of use tariffs and good system design. The practical constraints for each location and building type also need to be considered.

Therefore, the packages that we appraised often include energy efficiency measures and heat emitter upgrades and were chosen specifically for each building in light of the available heat sources and practical constraints.

As such, this analysis is specific to these 15 buildings and should be extrapolated to wider buildings with caution. However, the analysis does contain valuable insights for heat pump retrofit in London in general and highlights a number of issues that are likely to be applicable across other buildings.

Every attempt has been made to identify accurate costs for the technologies specified and a range of quotes and feedback was received from heat pump installers and manufacturers active in London. However, these are estimates of cost and should be treated as indicative rather than exact.

Full details of each of the buildings, the options appraisals, cost breakdown and the methodology can be found in the accompanying document: Options appraisal for heat pump retrofit in 15 London buildings.

13. Potential CO_2 savings from heat pump installation

Table 11: Percentage CO_2 savings relative to BAU scenarios: domestic dwellings (cumulative CO_2 savings by 2030 and 2050)

Package	Building		BAU	BAU kg CO_2 2030	BAU kg CO_2 2050	Retrofit package	CO_2 saving 2030	CO_2 saving 2050
4b	Northcote Road	Maisonette	Gas	50,887	143,410	Hybrid	28%	34%
9b	Tradescant Road	House	Gas	61,778	174,102	Hybrid	35%	42%
5b	Aldenham Drive	House	Electric	14,230	20,487	ASHP	62%	62%
5c	Aldenham Drive	House	Electric	14,230	20,487	GSHP	64%	64%
7b	Mowbray Road	House	Gas	52,525	148,026	ASHP	67%	83%
1b	Lymington Road	Flat	Gas	15,347	43,251	ASHP & Rads	68%	84%
6b	Surrey Road	House	Gas	22,462	63,301	ASHP	68%	84%
2b	Cavendish House	Flat	Gas	11,231	31,650	ASHP & Rads	69%	84%
8b	Albany Road	House	Gas	38,263	107,832	ASHP & Rads	69%	84%
1c	Lymington Road	Flat	Gas	15,347	43,251	GSHP & Rads	70%	85%
3b	Sherwin House	Flat	Gas	14,737	41,532	ASHP & Rads	70%	85%
4c	Northcote Road	Maisonette	Gas	50,887	143,410	ASHP, Rads & EE	70%	85%
6c	Surrey Road	House	Gas	22,462	63,301	ASHP & Rads	72%	86%
7c	Mowbray Road	House	Gas	52,525	148,026	ASHP, Rads & EE	72%	86%
9c	Tradescant Road	House	Gas	61,778	174,102	ASHP, Rads & EE	79%	89%
8c	Albany Road	House	Gas	38,263	107,832	ASHP, Rads & EE	80%	90%
8d	Albany Road	House	Gas	38,263	107,832	GSHP, Rads & EE	82%	91%
4d	Northcote Road	Maisonette	Gas	50,887	143,410	ASHP, Rads & Deep retrofit	87%	93%
9d	Tradescant Road	House	Gas	61,778	174,102	ASHP, Rads & Deep retrofit	89%	94%
7d	Mowbray Road	House	Gas	52,525	148,026	ASHP, Rads & Deep retrofit	90%	95%

The potential impact of heat pump retrofit on CO_2 emissions was assessed in the 15 example buildings in London. In all cases heat pump retrofit was technically feasible and had the potential to deliver large CO_2 emissions savings relative to a business as usual (BAU) scenario.

All CO_2 savings are relative to the BAU scenario. The BAU scenario in all cases was the replacement of the existing heating system with a like-for-like modern, efficient replacement. In the majority of cases this was an A-rated gas boiler, apart from building 05 where the BAU was replaced with a new electric boiler. No heat emitter or energy efficiency upgrades were assumed in the BAU scenario.

According to this analysis:

- Homes installing heat pumps alongside full **deep retrofit** (achieving space heating demand of 25-50kWh per m^2 pa) would achieve the highest CO_2 savings of **88-90% by 2030**, increasing to 93-95% by 2050[80].

- Homes undertaking **energy efficiency measures** (not including deep retrofits) were predicted to achieve CO_2 emissions savings of between **70-83% by 2030** and 85-91% by 2050. For example, in property 08, improved energy efficiency through enhanced air tightness and insulation resulted in an additional 10% CO_2 savings over the heat pump only option.

- **Upgrading radiators** typically generated additional CO_2 savings. For example, in building 06 an **additional 4% CO_2 saving** resulted from the extra efficiency of the heat pump with upgraded radiators[81]. However, in the majority of cases upgrading radiators was essential to enable flow temperatures below 55°C. So, the value of upgraded radiators is more critical than this figure suggests. See Chapter 8.5 for further details of this.

- CO_2 savings are relatively lower when **replacing electric heating** than when replacing gas heating, but still substantial. For example, in building 05 (a two-bedroom terraced house) CO_2 savings were **62-64% by 2030** (the lowest for the standard heat pump solutions). As the grid decarbonises, CO_2 savings from heat pumps will increase relative to gas but stay static in percentage terms relative to electric heating.

- **Hybrid heat pumps** achieved the lowest CO_2 savings in our analysis at **29%-30% by 2030**. In these buildings it was assumed that the heat pump element of the hybrid is delivering 60% of the overall heat demand[82].

- **Ground source heat pumps** typically achieved marginally better efficiencies and **2-3% higher CO_2 savings that air source heat pumps** in this sample.

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[80] As the grid is predicted to further decarbonise over time, the CO_2 savings from heat pumps are predicted to increase relative to gas boilers.

[81] See Chapter 7 for an explanation of why and how upgraded radiators can improve the efficiency of heat pumps.

[82] While the heat pump element could deliver a higher percentage of overall heating demand in some cases, in our sample, hybrids were only specified where standard heat pumps would be unable to deliver the high flow temperatures required i.e. these buildings were by definition poorly suited to heat pump operation and so a lower level of heat pump operation was assumed from the hybrid.

Table 12: Percentage CO_2 savings relative to BAU scenarios: medium and large-scale dwellings (cumulative savings by 2030 and 2050)

Package	Building		BAU	BAU kg CO_2 2030	BAU kg CO_2 2050	Retrofit package	CO_2 saving 2030	CO_2 saving 2050
11b	Tower Block	50 flats	Electric	567,252	816,697	GSHP & Rads	64%	64%
14b	Docklands Road	Vary large office	Gas & Electric	3,963,735	10,462,773	ASHP & Chillers	62%	79%
12b	Gifford House	Small office	Gas	143,220	403,621	ASHP	64%	82%
13b	Billet Road	Medium office	Gas	751,728	2,118,506	ASHP	67%	83%
15b	Wimbledon Library	Library	Gas	335,505	945,513	High-temp ASHP	67%	83%
15c	Wimbledon Library	Library	Gas	335,505	945,513	ASHP & Rads	69%	84%
12c	Gifford House	Small office	Gas	143,220	403,621	ASHP & Rads	70%	85%
13c	Billet Road	Medium office	Gas	751,728	2,118,506	GSHP & Rads	70%	85%
10b	Ernest Dence Estate	95 flats	Gas	2,194,500	6,184,500	ASHP & upgraded distribution	70%	85%
12d	Gifford House	Small office	Gas	143,220	403,621	GSHP & Rads	74%	87%
10c	Ernest Dence Estate	95 flats	Gas	2,194,500	6,184,500	WSHP & upgraded distribution	76%	88%
15d	Wimbledon Library	Library	Gas	335,505	945,513	ASHP, Rads & EE	76%	88%
14c	Docklands Road	Vary large office	Gas & Electric	3,963,735	10,462,773	WSHP	77%	88%
10d	Ernest Dence Estate	95 flats	Electric	2,194,500	6,184,500	WSHP, upgraded distribution & deep retrofit	89%	94%
13d	Billet Road	Medium office	Gas	751,728	2,118,506	GSHP, Rads & Deep retrofit	90%	95%
14d	Docklands Road	Vary large office	Gas & Electric	3,963,735	10,462,773	WSHP & Solar PV	100%	100%

This table shows the range of CO_2 savings for each of the packages in each of the medium and large-scale buildings. According to this analysis:

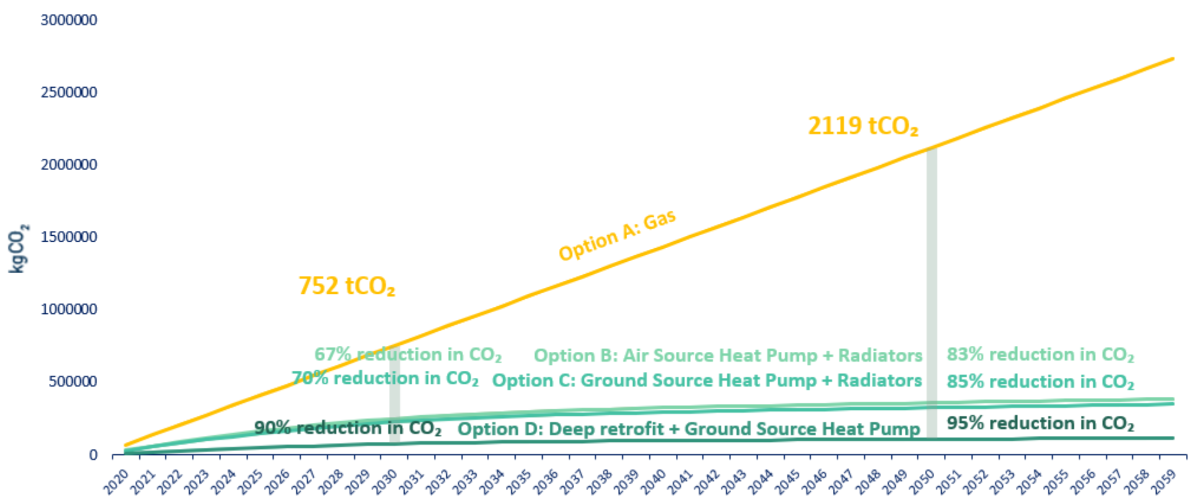
- The large office (building 14. Docklands Road) with high cooling demand was able to achieve the highest CO_2 emissions reductions by combining a reversible water source heat pump (WSHP) with Solar PV.
- **Using the heat pump for heating and cooling resulted in additional CO_2 savings**. For example, in building 14 (large office building), an additional 10% CO_2 emissions were saved by using the WSHP for cooling as opposed to standard electric chiller units.
- Buildings undertaking deep retrofit, alongside heat pump installation achieved the highest CO_2 savings of **89-90% by 2030** and **94-95% by 2050**.
- **Upgraded heat emitters contributed an additional 3-6% to the CO_2 savings of heat pumps by 2030.**

CO_2 savings from four example large scale buildings 2020-2060

Illustrative CO_2 savings from four of the buildings are provided below.

In Building 13, (a medium-sized office building), three options were compared to the BAU scenario of a replacement gas boiler. By 2030, cumulative CO_2 savings ranged from 67% for the air source heat pump to 90% for a ground source heat pump, plus a full deep retrofit of the building fabric. As the carbon intensity of grid electricity reduces further over time, so the CO_2 savings relative to gas increase to 83%-95% for Option B, C and D in 2050[83].

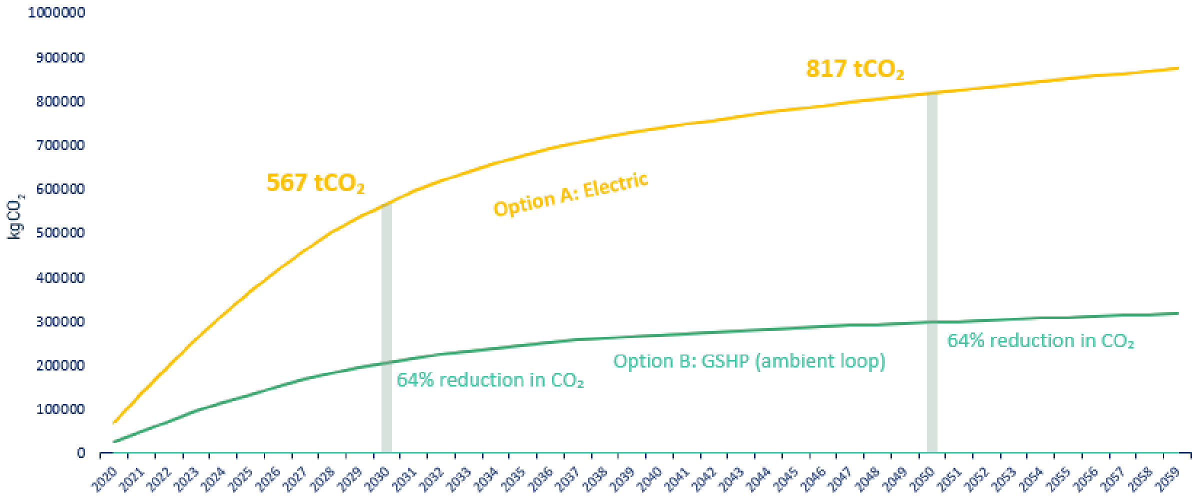
Figure 31: 13. Billet Road (Medium sized office building) Cumulative CO_2 emissions 2020 - 2060



[83] In reality, the carbon intensity does fluctuate marginally from year to year as the make up and source of gas in the grid changes year on year. However, we have assumed a flat carbon intensity 0.21kg CO_2 per kWh, in line with Treasury Green Book forecasts.

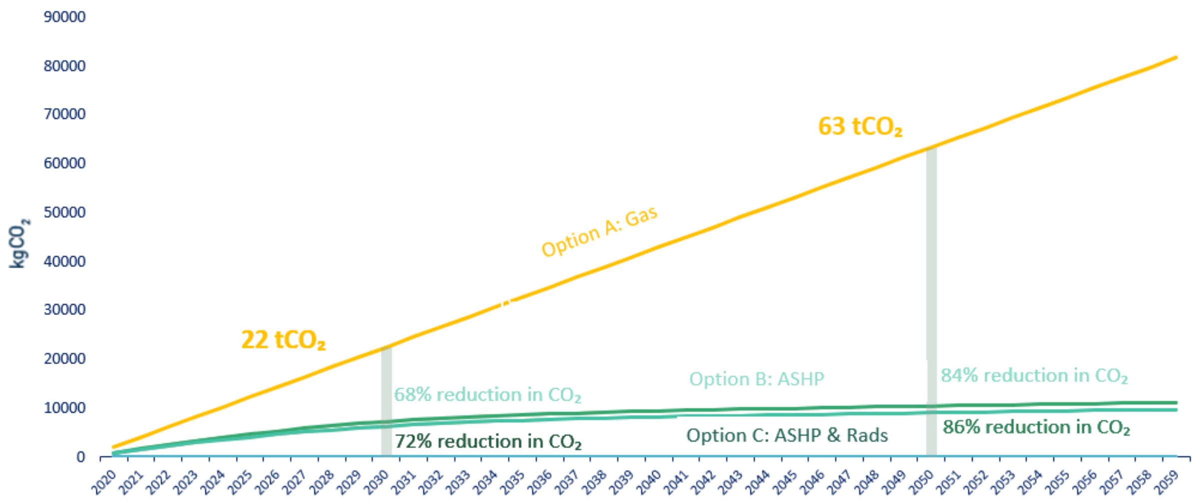
In building 11, an electrically heated block of 50 flats, the CO_2 emissions saving from a ground source shared ambient loop with individual heat pumps in each flat are around 64% by 2030 and 2050.

Figure 32: 11. Tower Block (50 flats) Cumulative CO_2 emissions 2020 - 2060



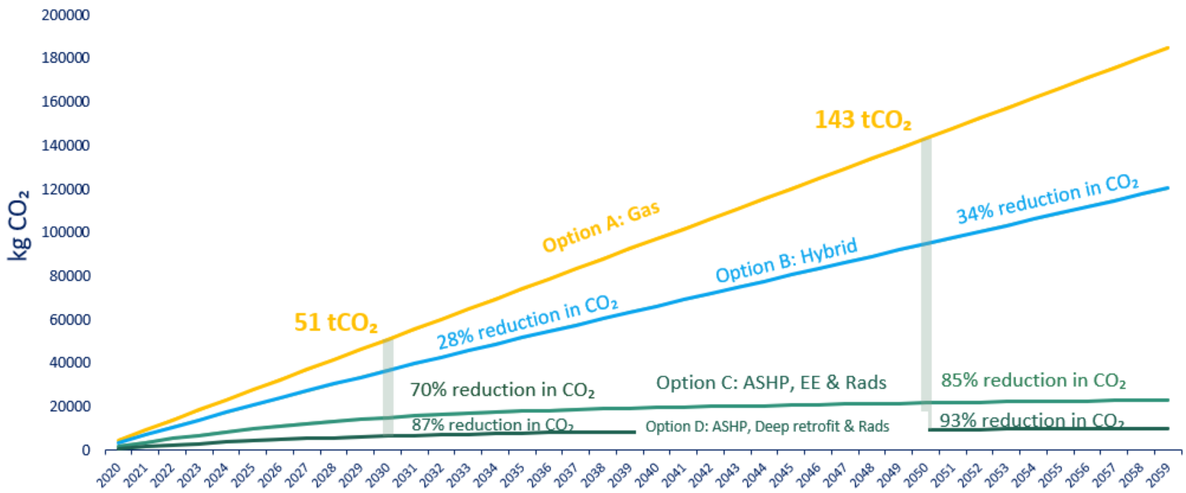
In building 06 (a small terraced house), the air source heat pump options result in predicted CO_2 savings of 68-70% by 2030, increasing to 84-86% in 2050, relative to a replacement gas boiler.

Figure 33: 06. Surrey Road: Cumulative CO_2 emissions 2020 - 2060



In building 04, a two-storey Victorian maisonette, the hybrid heat pump option results in a lower CO_2 saving of 28% by 2030 and 34% by 2050. The deep retrofit option in this Victorian mid-terrace maisonette achieves only an additional 8% CO_2 emissions reduction by 2050 over the lighter energy efficiency measures. This appears to make the deep retrofit option unattractive due to the high costs involved (*see Section 16*). However, the delivery of an overall low carbon energy system is predicated on large space heating demand reduction across the building stock. Because some building types will find it more difficult than others to reduce space heating demand, deep retrofit will be essential on some buildings to account for lesser space heating demand reductions in others.

Figure 34: 04. Northcote Road: Cumulative CO_2 emissions 2020 - 2060



14. Heat pump capital costs

The up-front capital costs for heat pumps, were calculated for each of the 15 example buildings, including the costs of installing hot water cylinders, thermal stores and the associated costs of upgraded heat emitters and energy efficiency.

Heat pump cost sources

The following sources were used to inform an assessment of costs in our options appraisals for the 15 example buildings in London:

1. The development of bottom-up quotations using equipment price lists from wholesale retailers and manufacturers and installers.
2. Estimated days for design, installation and commissioning directly from heat pump manufacturers and installers.
3. Average day rates for heating system design, installation and commissioning using quotes from installers and standard rates from Spon's Mechanical and Electrical Services Price Book 2020.
4. Indicative cost estimates for different systems in each of the 15 examples provided by manufacturers and installers – used to sense check and adjust the bottom up quotes (1.).
5. Specific detailed quotes for specific projects or details of historic scheme costs where the installation had already taken place – provided by installers. In a number of cases, these were used directly.
   - Indicative average figures for projects at different scales, e.g. rates of £1,800 per kW for design, supply, installation and commissioning of a large GSHP project, or £1,150 for large ASHP – provided by installers. These were used to sense check the bottom up pricing estimates.
   - It was assumed all space and water heating demands were met through the heat pump system. Where this included immersion heaters for the top-up provision of heat or hot water, these costs were included in the overall system costs. The costs of hot water cylinders and thermal stores were also included in the heat pump capital cost.

Project costing is as realistic as possible. However, it should be noted that heat pump costs can vary significantly from case to case and so the estimates provided here are unique and not necessarily indicative of other similar buildings.

Heat pump costs can vary significantly based on the specific details of the installation, availability of source heat, ancillary works required and the specific technology chosen. Heat pumps of the same type and size can still vary substantially in terms of efficiency, build quality, applications, features, brand, noise and aesthetics. Due to these factors, these cost estimates should be treated with caution in terms of general applicability, particularly for larger schemes where there is likely to be higher variability in cost.

14.1 Potential routes to reducing heat pump capital costs

This chapter provides details of the capital costs of heat pump technologies, relative to the BAU scenarios, for the 15 example London buildings.

The costs for the heat pump retrofit scenarios are broken down in to three categories:

1. Heat pump costs (equipment costs and installation costs, including hot water cylinder or thermal store and any associated necessary pipework)[84]
2. Heat emitter upgrades (equipment plus installation)
3. Energy efficiency costs (equipment plus installation)

In this analysis, current heat pump prices were used and single installations were assumed in all cases. All costs are inclusive of VAT at current rates (typically 20% for equipment and 5% for installation). In reality there are a number of factors which could reduce heat pump costs over time, or when delivered at larger scales and these factors should be considered alongside the cost analysis here:

- A BEIS study from 2016 predicted that costs could reduce by 10-15% as heat pump sales reach mass market scale[85].
- London Boroughs, social landlords and commercial landlords can achieve discounts for economies of scale during procurement. Anecdotal evidence from this research suggests that discounts of 5-15% would be typical for larger scale procurements, relative to the costs used in this analysis.
- Subsidies: in recognition of up-front costs being a major barrier to heat pump uptake, BEIS has proposed up-front grants of £4,000 for domestic systems[86] after the closure of the domestic renewable heat incentive in 2022. At the time of writing, no subsidies are proposed for non-domestic heat pumps after the closure of the non-domestic renewable heat incentive in 2021.
- Heat pump installation in new build homes is zero rated for VAT. However, in retrofits, since October 2019, VAT applies to the purchase of heat pump equipment at 20% and to labour costs associated with installation at 5%. This is the case for all installations where the costs of all materials and equipment account for more than 60% of the overall costs (most air source heat pumps would fall in to this category). Any future changes to the rate of VAT on heat pump equipment could have a major impact on costs.

[84] As such these are intended to represent the full cost of the installation necessary to produce heating and hot water.
[85] Delta EE for Department of Energy and Climate Change (2016). *Potential cost reductions for air source heat pumps.*
[86] Department for Business, Energy and Industrial Strategy (2020). *Consultation on future support for low carbon heat.*

14.2 Small scale (domestic) capital cost analysis

Domestic heat pumps up-front costs

Figure 35: Heat pump equipment, design, installation and commissioning costs (including hot water cylinders and immersion heaters where appropriate and all associated costs). Excluding upgraded heat emitters. Small scale domestic (N.B. for ground source heat pumps the design, installation and commissioning of the ground loop is included in equipment cost).

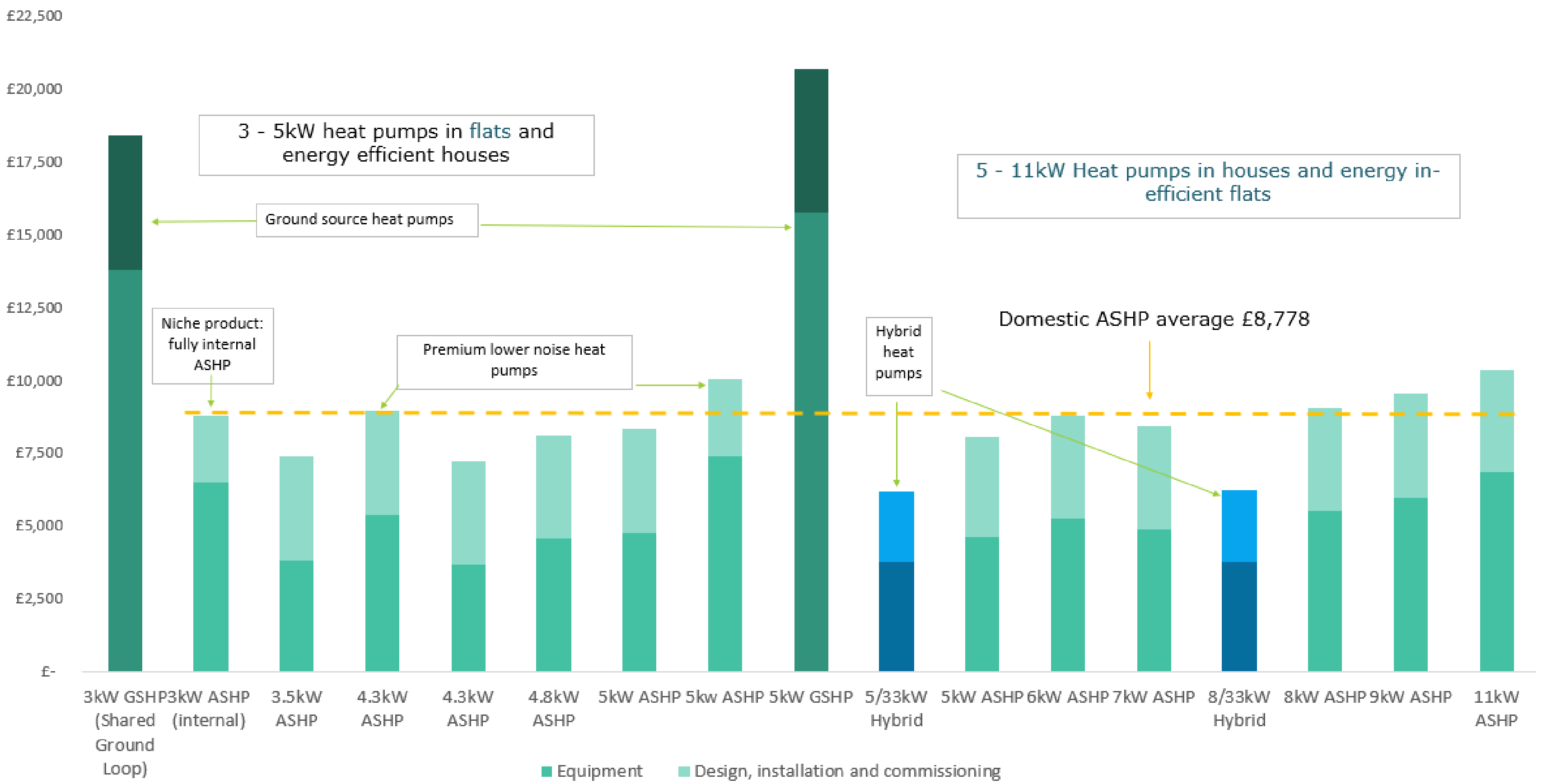


Table 13: Comparison of up-front costs for a BAU scenario versus heat pump, heat emitter and energy efficiency packages.

Package	Building		BAU package	BAU cost	Retrofit package	Heat pump & Cylinder cost	Heat emitter upgrade cost	Energy efficiency costs
9b	Tradescant Road	House	Gas boiler	£ 2,722	Hybrid	£ 6,196	£ -	£ -
4b	Northcote Road	Maisonette	Gas boiler	£ 2,672	Hybrid	£ 6,272	£ -	£ -
5b	Aldenham Drive	House	Electric boiler	£ 2,544	ASHP	£ 7,258	£ -	£ -
7b	Mowbray Road	House	Gas boiler	£ 2,672	ASHP	£ 9,588	£ -	£ -
1b	Lymington Road	Flat	Gas boiler	£ 2,219	ASHP & Rads	£ 8,151	£ 1,758	£ -
6b	Surrey Road	House	Gas boiler	£ 2,672	ASHP	£ 10,065	£ -	£ -
2b	Cavendish House	Flat	Gas boiler	£ 2,219	ASHP & Rads	£ 8,817	£ 2,226	£ -
3b	Sherwin House	Flat	Gas boiler	£ 2,219	ASHP & Rads	£ 8,965	£ 2,226	£ -
8b	Albany Road	House	Gas boiler	£ 2,672	ASHP & Rads	£ 8,826	£ 2,959	£ -
6c	Surrey Road	House	Gas boiler	£ 2,672	ASHP & Rads	£ 10,065	£ 3,346	£ -
8c	Albany Road	House	Gas boiler	£ 2,672	ASHP, Rads & EE	£ 8,151	£ 2,959	£ 3,400
7c	Mowbray Road	House	Gas boiler	£ 2,672	ASHP, Rads & EE	£ 8,470	£ 4,340	£ 3,700
5c	Aldenham Drive	House	Electric boiler	£ 2,544	GSHP	£ 18,426	£ -	£ -
1c	Lymington Road	Flat	Gas boiler	£ 2,219	GSHP & Rads	£ 18,426	£ 1,758	£ -
4c	Northcote Road	Maisonette	Gas boiler	£ 2,672	ASHP, Rads & EE	£ 9,098	£ 5,924	£ 11,450
8d	Albany Road	House	Gas boiler	£ 2,672	GSHP, Rads & EE	£ 20,715	£ 2,959	£ 3,400
9c	Tradescant Road	House	Gas boiler	£ 2,722	ASHP, Rads & EE	£ 10,354	£ 4,722	£ 17,200
7d	Mowbray Road	House	Gas boiler	£ 2,672	ASHP, Rads & Deep retrofit	£ 7,402	£ 4,160	£ 42,427
4d	Northcote Road	Maisonette	Gas boiler	£ 2,672	ASHP, Rads & Deep retrofit	£ 8,352	£ 5,924	£ 45,486
9d	Tradescant Road	House	Gas boiler	£ 2,722	ASHP, Rads & Deep retrofit	£ 8,113	£ 3,980	£ 56,658

The graph and table on the previous pages highlight several of the research findings regarding heat pump up-front costs.

Heat pumps have higher up-front costs than replacement gas boilers or electric heating systems

- Across the nine domestic examples in this study average costs were as follows:
    - Gas boiler or electric heating replacement £2,576
    - Air source heat pumps £8,778
    - Ground source heat pumps £19,189
    - Hybrid heat pumps £6,234[87]
- Where upgraded radiators were required this added, on average, an additional up-front cost of £3,517, making the average capital costs, including radiators:
    - £11,747 for air source
    - £20,761 for ground source
- Upgraded radiators were typically high output triple panel radiators. However, the average cost is increased by the high cost of heritage style four column radiators in building 04. None of the examples were deemed suitable for the retrofit of underfloor heating in this study, although we recommend that further research should be carried out to understand the feasibility and cost of this in existing buildings.
- The cost for the GSHP unit specified here for an individual dwelling was just over £20,000. The costs for shared ground loops in this sample were estimated to be between £14,000-£19,000 per dwelling[88]. N.B. This figure does not take in to account current RHI funding, which is particularly generous for shared ground source loops.
- Hybrid heat pumps tend to have lower installed costs than standard heat pumps. One reason for this is that there is no need for a hot water cylinder, resulting in a significant saving on both equipment and labour.

Small domestic heat pumps do not necessarily have lower up-front costs than larger ones

- The average installed cost for heat pump systems 5kW or less was £8,562. Average installed cost for ASHP systems between 6kW and 11kW was £9,302.
- One reason for this in our sample was that smaller heat pumps, for example in blocks of flats or small terraced houses, were more likely to require more specialist solutions, such as a premium heat pump with low noise levels, a shared ground loop or a fully internal heat pump. These all came a cost premium compared to what could be considered more mass-market ASHPs in the 5-16kW range.

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[87] Hybrid heat pump costs are for an integrated hybrid unit that contains both the heat pump internal unit and gas boiler in one box.

[88] This includes the example in building 11, assessed as part of the medium- and large-scale examples in the next section.

- A further reason is that smaller domestic heat pumps (3-8kW) do not require significantly less labour to install than larger ones (8-16kW).
- This indicates that heat pump capital costs in London could be higher than those elsewhere in the country, as London has a higher proportion of densely populated areas and blocks of flats where standard, lowest cost ASHP solutions are less likely to be viable.

Energy efficiency measure costs

- Where **energy efficiency measures** were required (excluding deep retrofit packages), this **added on average £10,783** to the cost of the retrofit package. This reflects that the homes most in need of energy efficiency were typically the older pre-1919 properties that required more expensive measures such as double-glazed sash windows and under-floor insulation. However, energy efficiency requirements will vary significantly between properties and need to be assessed on a case by case basis.
- In the properties where a **deep retrofit package** was specified (achieving space heating demands of 25=50kWh per m^2 per year) **the average cost was £48,190**. Again, this reflects the fact that the properties most in need of deep retrofit in our sample were often the pre-1919 properties where retrofit measures such as external solid wall insulation and heritage sensitive measures were required, increasing costs.

Energy efficiency costs: It is important to note that potential energy efficiency grants were not considered, nor was any spending on energy efficiency that would need to take place in any case. For example, it is likely that windows would need replacing within the 30-year timeframe considered here, but these costs were not included in this analysis.

Furthermore, as energy efficiency is required under all scenarios for achieving net zero carbon, these represent investments that must be made under all circumstances, rather than investment specifically relating to heat pumps.

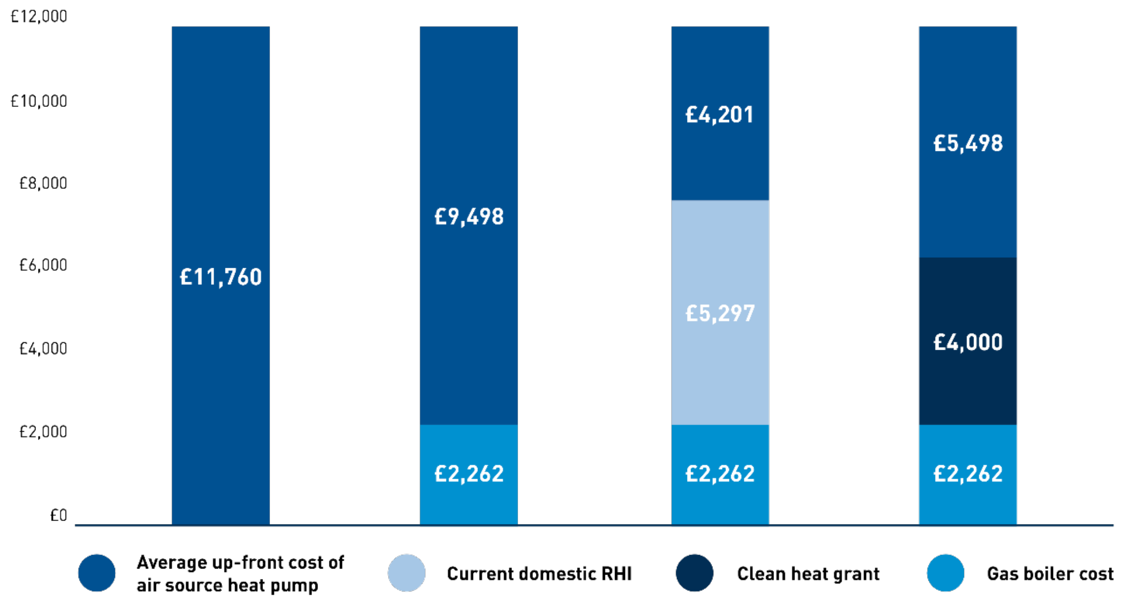
Finally, when fuel bill savings from energy efficiency are taken in to account, this can help to offset some of the additional capital cost of energy efficiency. See the section below on fuel bills and lifetime costs for further information.

Current and proposed grant levels do not fully cover the additional capital cost

Table 14: CAPEX for heat pump plus radiators & Additional CAPEX over BAU, against current RHI rates and proposed £4,000 Clean Heat Grant

Package	Building		BAU package	Additional CAPEX over BAU (heat pump, cylinder and radiators)	Current RHI	Proposed Clean Heat Grant
1b	Lymington Road	Flat	Gas boiler	£ 7,690	£ 2,899	£ 4,000
1c	Lymington Road	Flat	Gas boiler	£ 17,965	£ 9,946	£ 4,000
2b	Cavendish House	Flat	Gas boiler	£ 8,824	£ 2,170	£ 4,000
3b	Sherwin House	Flat	Gas boiler	£ 8,972	£ 2,892	£ 4,000
4b	Northcote Road	Maisonette	Gas boiler	£ 3,600	£ -	£ -
4c	Northcote Road	Maisonette	Gas boiler	£ 12,350	£ 7,715	£ 4,000
4d	Northcote Road	Maisonette	Gas boiler	£ 11,604	£ 4,711	£ 4,000
5b	Aldenham Drive	House	Electric boiler	£ 4,714	£ 2,733	£ 4,000
5c	Aldenham Drive	House	Electric boiler	£ 15,882	£ 5,486	£ 4,000
6b	Surrey Road	House	Gas boiler	£ 7,393	£ 4,243	£ 4,000
6c	Surrey Road	House	Gas boiler	£ 10,738	£ 4,534	£ 4,000
7b	Mowbray Road	House	Gas boiler	£ 6,915	£ 9,734	£ 4,000
7c	Mowbray Road	House	Gas boiler	£ 10,138	£ 8,139	£ 4,000
7d	Mowbray Road	House	Gas boiler	£ 8,889	£ 3,651	£ 4,000
8b	Albany Road	House	Gas boiler	£ 9,112	£ 7,392	£ 4,000
8c	Albany Road	House	Gas boiler	£ 8,438	£ 5,098	£ 4,000
8d	Albany Road	House	Gas boiler	£ 21,002	£ 9,065	£ 4,000
9b	Tradescant Road	House	Gas boiler	£ 3,475	£ -	£ -
9c	Tradescant Road	House	Gas boiler	£ 12,354	£ 7,734	£ 4,000
9d	Tradescant Road	House	Gas boiler	£ 9,372	£ 4,161	£ 4,000

Figure 36: Additional up-front cost of domestic air source heat pumps (including heat emitters and hot water cylinders) in this study relative to gas boiler replacement, domestic RHI and the proposed Clean Heat Grant



- For ASHPs, when taking in to account the cost of upgraded heat emitters and the heat pump itself, the average additional cost was £9,498 over the BAU scenario cost. Average current levels of RHI (pre-July 2020) are £5,297. This is higher than the proposed government Clean Heat Grant of £4,000 (although the Clean Heat Grant is paid up-front)
- For GSHP the average additional cost, including heat emitters, was £18,500 over BAU. This is considerably higher than the £8,165 average RHI and the proposed £4,000 Clean Heat Grant.

14.3 Medium and largescale heat pump capital costs analysis

Figure 37: Upfront capital costs: medium to large scale heat pumps in communal heating and non-domestic building (not including heat emitters or distribution)

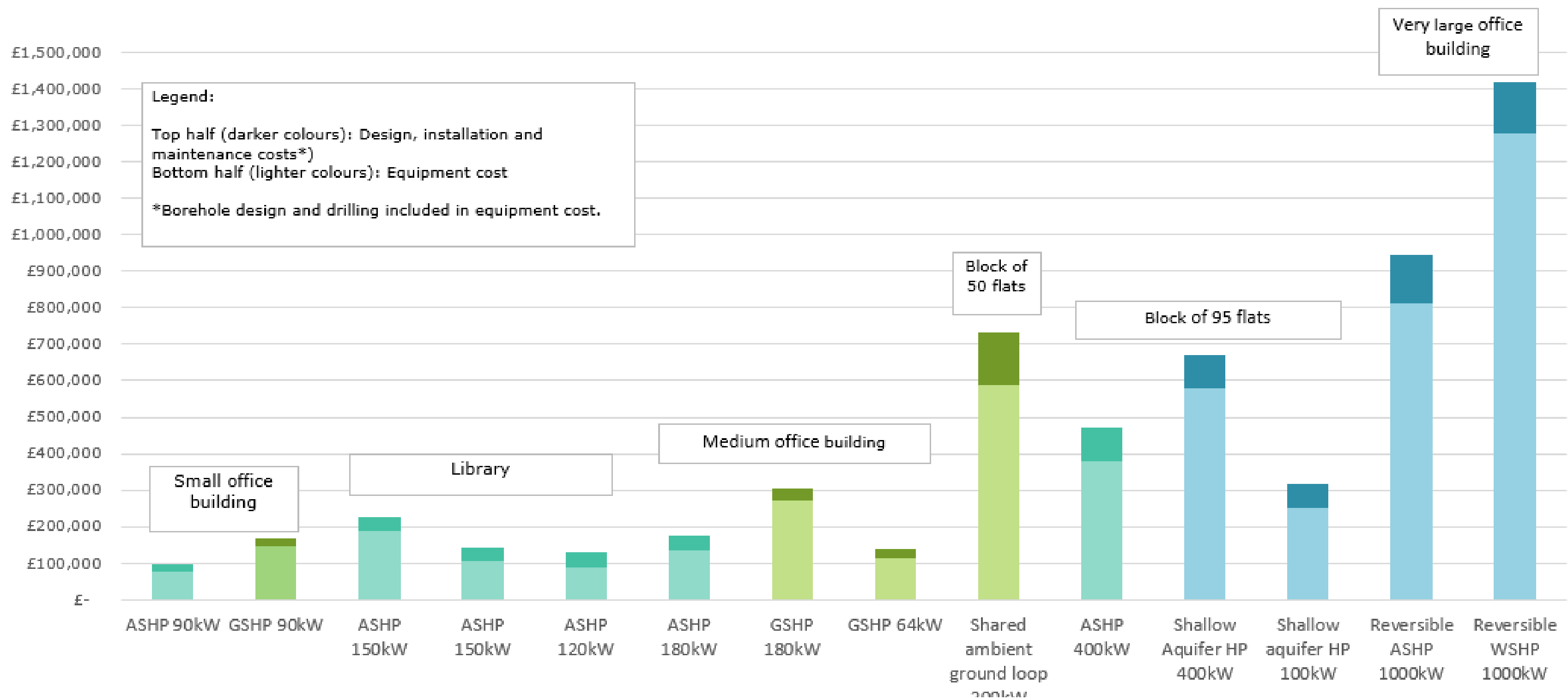


Table 15: Comparison of up-front costs for BAU versus heat pump, heat emitter and energy efficiency packages

Package	Building		BAU package	BAU up-front costs	Retrofit package	Heat pump & thermal store up-front costs	Heat emitter & distribution up-front costs	Energy efficiency up-front costs
10b	Ernest Dence Estate	95 flats	Communal Gas boiler	£ 50,500	ASHP & upgraded distribution	£ 471,560	£ 800,000	£ -
10c	Ernest Dence Estate	95 flats	Communal Gas boiler	£ 50,500	WSHP & upgraded distribution	£ 672,152	£ 800,000	£ -
10d	Ernest Dence Estate	95 flats	Gas boiler	£ 50,500	WSHP, upgraded distribution & deep retrofit	£ 317,449	£ 700,000	£ 1,818,300
11b	Tower Block	50 flats	Individual Electric heating	£ 212,500	GSHP & Rads	£ 734,745	£ 60,375	£ -
12b	Gifford House	Small office	Gas boiler	£ 10,601	ASHP	£ 97,369	£ -	£ -
12c	Gifford House	Small office	Gas boiler	£ 10,601	ASHP & Rads	£ 97,369	£ 21,225	£ -
12d	Gifford House	Small office	Gas boiler	£ 10,601	GSHP & Rads	£ 168,958	£ 21,225	£ -
13b	Billet Road	Medium office	Gas boiler	£ 21,910	ASHP	£ 175,096	£ 33,280	£ -
13c	Billet Road	Medium office	Gas boiler	£ 21,910	GSHP & Rads	£ 306,675	£ 33,280	£ -
13d	Billet Road	Medium office	Gas boiler	£ 21,910	GSHP, Rads & Deep retrofit	£ 139,198	£ 33,280	£ 104,000
14b	Docklands Road	Vary large office	Gas boiler & chillers	£ 110,223	ASHP & Chillers	£ 945,988	£ -	£ -
14c	Docklands Road	Vary large office	Gas boiler & chillers	£ 110,223	WSHP	£ 1,416,704	£ -	£ -
14d	Docklands Road	Vary large office	chillers	£ 110,223	WSHP & Solar PV	£ 1,416,704		£ 607,500
15b	Wimbledon Library	Library	Gas boiler	£ 14,859	High-temp ASHP	£ 226,334	£ -	£ -
15c	Library	Library	Gas boiler	£ 22,383	ASHP & Rads	£ 143,423	£ 44,080	£ -
15d	Wimbledon Library	Library	Gas boiler	£ 22,383	ASHP, Rads & EE	£ 129,419	£ 44,080	£ 104,000

Summary of up-front cost findings: (medium and large scale)

Due to the small sample size, the high level of diversity of the buildings and the highly specific nature of each installation, we have not attempted to draw conclusions about average capital costs. However, the following indications are suggested by the individual examples:

Higher up-front costs.

Heat pumps have higher up-front costs than BAU heating and cooling costs under all of the buildings in our sample. In our sample:

- Average BAU heating system replacement cost of sample: £111,000
- Average heat pump heating system cost of sample: £466,000

For gas only systems, the cost gap is bigger than in domestic dwellings.

The gap between heat pump costs and BAU costs is bigger in medium and large-scale buildings, than the gap in small domestic buildings. This is particularly the case where the heating system is a relatively straightforward gas boiler and radiator arrangement. In our analysis, for commercial buildings, the gas boilers were only marginally over-sized for the building heat loss, whereas in domestic properties the boilers were often over-sized[89]. Therefore, in an office building with 150kW heat demand, the boiler is only five times the size of a typical domestic gas system (five times 30kW) but 15 times the size of a heat pump system (15 times 10kW). In other words, gas boilers are relatively cheaper in larger buildings than in smaller ones.

For more complex heating systems, particularly those involving cooling, the cost gap is smaller.

However, where building heating and cooling systems are more complex, for example involving gas boilers, air handling units, fan coil units and electric chillers for cooling, the difference in up-front costs between the BAU and heat pump systems is smaller. For example, in building 14, the capital costs for the BAU scenario include the replacement of both the gas boilers and the electric chiller units. In contrast, in the heat pump scenarios, reversible heat pumps were able to provide both heating and cooling, resulting in a more economical solution.

[89] Domestic combi-boilers are typically found in sizes of 24kW and above – far higher than the typical heat loss of the homes.

Where upgrades are required to heat distribution systems in any case, the cost differential of heat pump retrofit is relatively smaller.

For example, in building 10 (block of 95 flats on communal heating), an estimated £800,000 upgrade is required to the heat distribution and heat emitters under both the BAU and the heat pump scenarios. Therefore, although the cost of replacement communal gas boilers is much lower than the heat pump cost, the difference between the overall packages is smaller than in buildings where upgrades to heating systems are not required.

Replacement communal heating systems have the potential for lower costs per dwelling than shared ground loops with individual heat pumps in each building.

Compared to the costs of replacement communal or district heating systems, the costs of individual heat pumps connected to a shared ground loop are higher because of the cost of multiple heat pumps units compared with one centralised plant. However, where existing heat distribution pipework does not exist, retrofitting an ambient ground source loop in to the building or neighbourhood is likely to be lower cost than retrofitting insulated hot water pipe. System losses are also likely to be lower because there is no need for hot water to piped around the building (the shared loop is at ambient temperature).

When comparing the two systems for blocks of flats, the shared ambient ground loop appears relatively expensive compared with the communal system. One reason for this is that, for the communal heating system, the proposed heat pump is feeding a central communal boiler and so no heating distribution system costs are included. In contrast, the shared ground loop up-front costs include the cost of the individual heat pumps within each of the flats and the distribution pipework within the flat. Therefore, in this case, the additional project costs for the shared ground loop are greater than for the communal system.

Higher cost for high temperature heat pumps but lower expenditure on heating system upgrades.

High temperature heat pumps (those designed to operate primarily between 55°C-80°C) are likely to have higher up-front costs than standard temperature heat pumps, although this is counter-balanced by lower costs for energy efficiency and heat pump upgrades. In our sample only one building (building 15, Wimbledon Library) was specified with a high temperature heat pump, so no conclusions can be drawn as to average additional costs.

Additional CAPEX relative to current levels of RHI (medium and large scale)

Table 16: CAPEX for heat pump and thermal store compared to levels of current RHI subsidy.

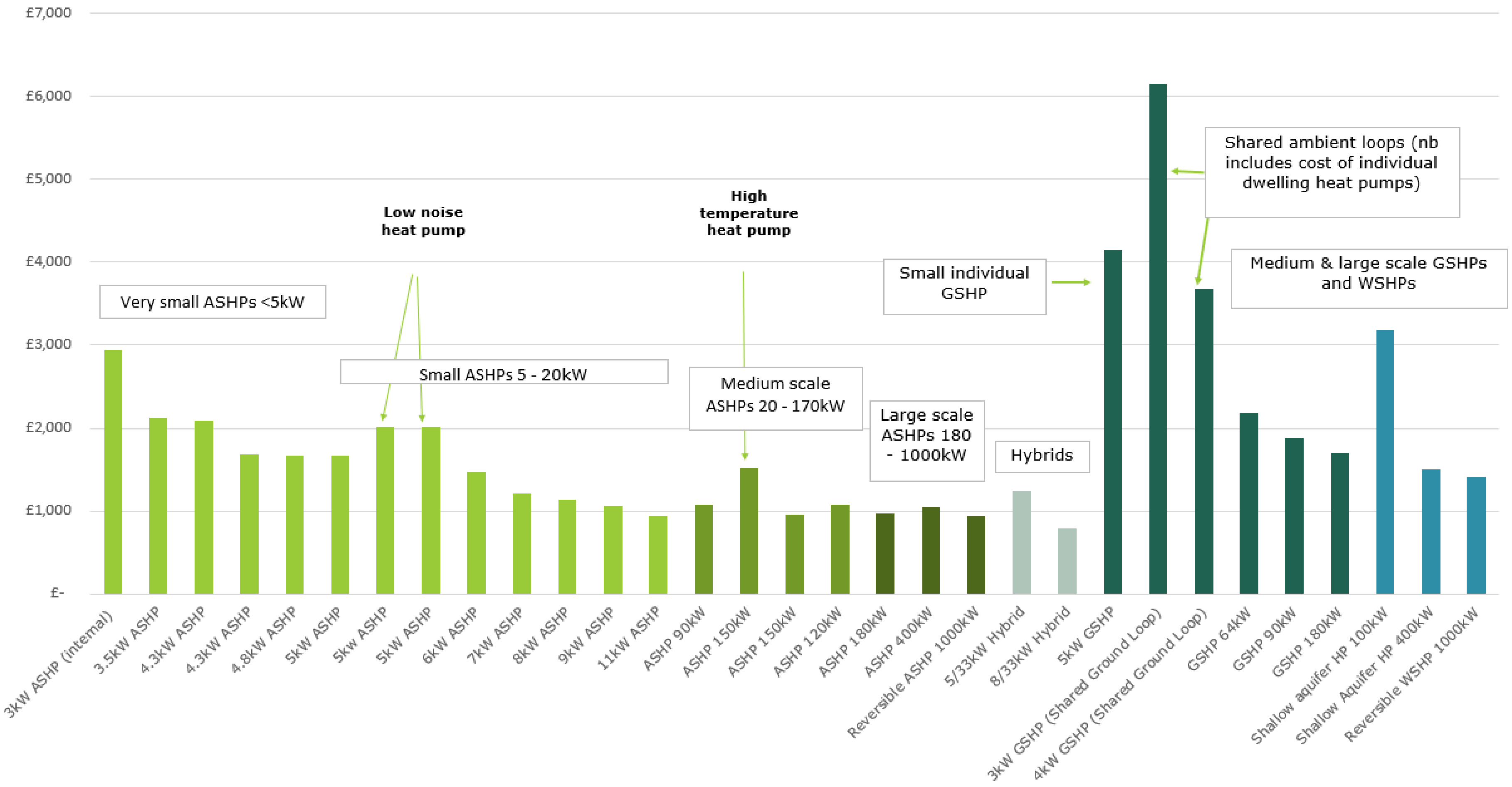
Package	Building		BAU package	Additional CAPEX over BAU (heat pump, thermal store, system and radiators)	Current RHI	RHI as a % of additional capital cost
10b	Ernest Dence Estate	95 flats	Gas boiler	£ 421,060	£ 458,271	109%
10c	Ernest Dence Estate	95 flats	Gas boiler	£ 621,652	£ 870,814	140%
10d	Ernest Dence Estate	95 flats	Gas boiler	£ 266,949	£ 229,162	86%
11b	Tower Block	50 flats	Electric heating	£ 582,620	£ 916,646	157%
12b	Gifford House	Small office	Gas boiler	£ 86,768	£ 31,828	37%
12c	Gifford House	Small office	Gas boiler	£ 107,993	£ 30,237	28%
12d	Gifford House	Small office	Gas boiler	£ 179,582	£ 94,504	53%
13b	Billet Road	Medium office	Gas boiler	£ 186,466	£ 158,706	85%
13c	Billet Road	Medium office	Gas boiler	£ 318,045	£ 391,866	123%
13d	Billet Road	Medium office	Gas boiler	£ 150,568	£ 146,663	97%
14b	Docklands Road	Vary large office	Gas boiler & chillers	£ 835,764	£ 766,771	92%
14c	Docklands Road	Vary large office	Gas boiler & chillers	£ 1,306,481	£ 2,322,890	178%
14d	Docklands Road	Vary large office	Gas boiler & chillers	£ 1,306,481	£ 2,322,890	178%
15b	Wimbledon Library	Library	Gas boiler	£ 211,475	£ 74,560	35%
15c	Wimbledon Library	Library	Gas boiler	£ 165,121	£ 74,560	45%
15d	Wimbledon Library	Library	Gas boiler	£ 151,116	£ 60,967	40%

The table above shows the additional capital costs of heat pump systems (including upgraded heat emitters and thermal stores) relative to the current levels of RHI payments[90]. In our small sample of buildings:

- Current RHI payments for this sample of buildings covered between 28% and 178% of the additional capital cost relative to the BAU costs.
- RHI Payments for GSHP and WSHP systems were equivalent to between 53% and 178% of additional capital costs.
- RHI payments for ASHP systems were equivalent to between 28% and 109% of the additional capital costs.
- The current non-domestic RHI is more likely to cover the cost gap between BAU and heat pumps for larger buildings.
- The current non-domestic RHI is more likely to cover the cost different between BAU and heat pumps for ground source and water source heat pumps than for air source, due to the more generous tariffs for these technologies.
- This suggests that current rates of RHI funding are sufficient to financially incentivise heat pump installation in larger buildings and for ground and water source technologies. But they are generally not sufficient to incentivise air source heat pump installations. The current non-domestic RHI is due to end in 2022 and at the time of writing it is unknown what future support there will be for non-domestic installations.

[90] Note that all payments are calculated under pre-July 2020 domestic RHI rates except for building 01 which is assumed to be on a shared ground loop and benefitting from the more generous non-domestic RHI payments.

Figure 38: Up-front capital costs per kW of installed capacity (small, medium and large-scale heat pumps). Not including heat emitters.



Looking at capital costs divided by kW capacity suggests the following:

- ASHP costs ranged between £900 and £2,900 per kW of installed capacity.
- Costs per kW for very small ASHP are higher than for larger heat pumps. This is primarily due to the fact that neither installation costs nor capital equipment costs are significantly lower for, for example, a 3kw heat pump versus an 8kW heat pump.
- GSHP and WSHP costs are typically more expensive per kW than ASHP costs, ranging between approximately £1,400 and £6,000 per kW of installed capacity.
- GSHPs have very high costs per kW when used for small installations (e.g. below 5kW) such as when shared ground loops are used. Although, in some of the cases specified, no other technology solution was considered feasible.
- For medium and large installations, this sample suggests that GSHP costs are 60-90% higher than air source.
- There is some evidence to suggest that water source heat pumps have a lower up-front capital cost per kW than ground source but the limited and specific nature of this sample makes it impossible to draw firm conclusions.

15. Heat pump impact on fuel bills

15.1 Heat pump impact on domestic fuel bills

Summary

The table on the following page shows that the following factors influence the impact of heat pump retrofit on fuel bills:

- Heat pumps replacing electric heating lead to the largest reductions in fuel bill savings. In example building 05 (a two-bed terraced house) the reduction was 64% increasing to 69% under a time of use tariff[91].
- Gas heated dwellings undergoing deep retrofit were predicted to have large fuel bill savings of 48-58%, increasing to 60-68% under a time of use tariff. Because of the high levels of energy efficiency of the property, a greater degree of load shifting of heat demand away from peak hours was possible in these examples.
- Gas heated dwellings undertaking energy efficiency measures (not including deep retrofit) alongside heat pumps were predicted to experience between a 32% saving and an 18% increase in fuel bills. This changed to between a 40% saving and a 1% saving under a time of use tariff.
- Gas heated dwellings not undertaking energy efficiency improvements were predicted to experience between an 11% saving and a 34% increase in fuel bills. This changed to between a 31% saving and 23% increase under a time of use tariff.
- Smaller dwellings (with lower fuel bills) were more likely to benefit from the switch to heat pumps than larger properties. One factor in this is the removal of the gas standing charge having a larger proportional effect on smaller dwellings. In addition to the per kWh rates, we assumed standing charges of £87.60 for gas and £73 for electricity per year. Where a gas boiler is being removed from a property, this can remove the need to pay the gas standing charge[92]. This has the biggest impact on small properties, where the gas standing charge accounts for a high proportion of the overall bill. In these cases, the removal of the gas standing charge can make the heat pump the lower cost option in terms of fuel bills, as the electricity standing charge is already being paid regardless of heating technology.
- Larger, gas heated dwellings installing heat pumps without any energy efficiency or heat emitter upgrades were the most likely to experience fuel bill increases. In building 07 (a three-bedroom house), this was a significant increase of 34% under a standard tariff.

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[91] However, in our analysis we did not look at the potential impact of time of use tariffs on the BAU scenario. In this case, as the BAU fuel type is electricity, a flexible time of use tariff could also have been applied to the direct electric heating.
[92] It may be necessary to replace gas hobs with electric induction hobs in order to fully remove gas from the property.

Table 17: comparison of fuel bills; BAU, standard tariff, flexible time of use tariff for different retrofit scenario

Package	Building		BAU package	Retrofit package	Fuel bills BAU	Fuel bills heat pump	% Increase in fuel bills	Fuel bills heat pump & TOUT	% Increase in fuel bills
1b	Lymington Road	Flat	Gas boiler	ASHP & Rads	£ 302	£ 311	3%	£ 261	-14%
1c	Lymington Road	Flat	Gas boiler	GSHP & Rads	£ 302	£ 291	-4%	£ 244	-19%
2b	Cavendish House	Flat	Gas boiler	ASHP & Rads	£ 245	£ 218	-11%	£ 169	-31%
3b	Sherwin House	Flat	Gas boiler	ASHP & Rads	£ 294	£ 276	-6%	£ 230	-22%
4b	Northcote Road	Maisonette	Gas boiler	Hybrid	£ 800	£ 949	19%	£ 949	19%
4c	Northcote Road	Maisonette	Gas boiler	ASHP, Rads & EE	£ 800	£ 947	18%	£ 790	-1%
4d	Northcote Road	Maisonette	Gas boiler	ASHP, Rads & Deep retrofit	£ 800	£ 413	-48%	£ 322	-60%
5b	Aldenham Drive	House	Electric boiler	ASHP	£ 895	£ 342	-62%	£ 287	-68%
5c	Aldenham Drive	House	Electric boiler	GSHP	£ 895	£ 325	-64%	£ 273	-69%
6b	Surrey Road	House	Gas boiler	ASHP	£ 402	£ 455	13%	£ 382	-5%
6c	Surrey Road	House	Gas boiler	ASHP & Rads	£ 402	£ 396	-2%	£ 332	-17%
7b	Mowbray Road	House	Gas boiler	ASHP	£ 823	£ 1,101	34%	£ 1,013	23%
7c	Mowbray Road	House	Gas boiler	ASHP, Rads & EE	£ 823	£ 911	11%	£ 765	-7%
7d	Mowbray Road	House	Gas boiler	ASHP, Rads & Deep retrofit	£ 823	£ 345	-58%	£ 267	-68%
8b	Albany Road	House	Gas boiler	ASHP & Rads	£ 623	£ 741	19%	£ 711	14%
8c	Albany Road	House	Gas boiler	ASHP, Rads & EE	£ 623	£ 492	-21%	£ 433	-31%
8d	Albany Road	House	Gas boiler	GSHP, Rads & EE	£ 623	£ 426	-32%	£ 375	-40%
9b	Tradescant Road	House	Gas boiler	Hybrid	£ 952	£ 1,133	19%	£ 1,133	19%
9c	Tradescant Road	House	Gas boiler	ASHP, Rads & EE	£ 952	£ 834	-12%	£ 751	-21%
9d	Tradescant Road	House	Gas boiler	ASHP, Rads & Deep retrofit	£ 952	£ 443	-53%	£ 364	-62%

15.2 Heat pump impact on medium and large-scale building fuel bills

Summary

For the analysis of fuel bills in medium and large-scale buildings, we used fuel bill data from the Treasury Green Book non-domestic central scenario for 2021[93].

The table on the following page shows that the following factors influence the impact of heat pump retrofit on fuel bills in medium and large-scale buildings:

- Heat pumps replacing electric heating were predicted to achieve the largest reductions in fuel bill savings. For example, in building 11 (a tower block of 50 flats heated by electricity), fuel bill savings of 64% were predicted.
- Building 14 (a very large office building) demonstrates the potential of combining heat pumps with solar PV in a building with a high summer cooling demand. In this example, the PV generation profile matches well with the demand for cooling, resulting in a 61% reduction in fuel bills.
- The deep retrofit (energy efficiency) of gas heated buildings alongside heat pump installation was predicted to lead to substantial fuel bills savings of 55% (medium sized office building) and 48% (block of 95 flats).
- Where heat pumps were installed without energy efficiency or heat emitter upgrades, the highest increases in fuel bills were predicted of between 51%-63%. This reflects the relatively poor efficiency of the heat pumps with the higher flow temperatures required in these buildings.
- Where heat pumps were installed without energy efficiency upgrades, but with heat emitter upgrades, the packages were predicted to increase fuel bills by between 11% and 51%.
- Our analysis looked at heat pumps in comparison to a new 90% efficient gas boiler. In comparison to some less efficient existing gas boilers, heat pumps can deliver significant fuel bill savings. For example, a 300% efficient heat pump would have the same fuel bills as a 65% efficient gas boiler under standard tariffs. Therefore, existing buildings with poorly performing gas boilers (e.g. ageing heat networks) would be able to realise fuel bill savings through a good practice heat pump retrofit, even before additional benefits from time of use tariffs and energy efficiency are applied.

[93] Department for Business, Energy and Industrial Strategy (2020). *Green Book Supplementary Guidance: valuation of energy use and greenhouse gas emissions for appraisal.*

Flexible time of use tariffs

For medium and large-scale buildings, we did not individually model the capacity of each building to accommodate flexible shifting of heat load. Instead we applied assumptions that:

- Blocks of flats would be capable of achieving a 7.5% reduction in fuel bills relative to the Treasury Green Book rates through applying dynamic time of use tariffs.
- Non-domestic buildings would be capable of achieving a 12.5% reduction in fuel bills relative to the Treasury Green Book rates through applying a dynamic time of use tariffs.
- In practice, larger savings could be possible. Also, larger buildings are able to benefit from other payments for flexibility services. However, modelling these was outside the scope of this work. Our assumptions for reducing operating costs through payments and savings for flexibility services are therefore highly conservative.

Table 18: comparison of fuel bills; BAU, standard tariff, flexible time of use tariff for different retrofit scenarios.

Package	Building		BAU package	Retrofit package	Fuel bills BAU	Fuel bills heat pump	% Increase in fuel bills	Fuel bills heat pump & TOUT	% Increase in fuel bills
10b	Ernest Dence Estate	95 flats	Gas boiler	ASHP & upgraded distribution	£ 27,618	£ 37,459	36%	£ 34,649	25%
10c	Ernest Dence Estate	95 flats	Gas boiler	WSHP & upgraded distribution	£ 27,618	£ 30,735	11%	£ 26,125	-5%
10d	Ernest Dence Estate	95 flats	Gas boiler	WSHP, upgraded distribution & deep retrofit	£ 27,618	£ 14,270	-48%	£ 13,200	-52%
11b	Tower Block	50 flats	Electric heating	GSHP & Rads	£ 32,584	£ 11,849	-64%	£ 10,960	-66%
12b	Gifford House	Small office	Gas boiler	ASHP	£ 1,802	£ 2,929	63%	£ 2,563	42%
12c	Gifford House	Small office	Gas boiler	ASHP & Rads	£ 1,802	£ 2,472	37%	£ 2,163	20%
12d	Gifford House	Small office	Gas boiler	GSHP & Rads	£ 1,802	£ 2,138	19%	£ 1,870	4%
13b	Billet Road	Medium office	Gas boiler	ASHP	£ 9,461	£ 14,315	51%	£ 12,525	32%
13c	Billet Road	Medium office	Gas boiler	GSHP & Rads	£ 9,461	£ 12,973	37%	£ 11,351	20%
13d	Billet Road	Medium office	Gas boiler	GSHP, Rads & Deep retrofit	£ 9,461	£ 4,294	-55%	£ 3,757	-60%
14b	Docklands Road	Vary large office	Gas boiler & chillers	ASHP & Chillers	£ 135,568	£ 165,497	22%	£ 144,810	7%
14c	Docklands Road	Vary large office	Gas boiler & chillers	WSHP	£ 135,568	£ 131,549	-3%	£ 115,106	-15%
14d	Docklands Road	Vary large office	Gas boiler & chillers	WSHP & Solar PV	£ 135,568	£ 52,329	-61%	£ 45,788	-66%
15b	Wimbledon Library	Library	Gas boiler	High-temp ASHP	£ 4,222	£ 6,389	51%	£ 5,590	32%
15c	Wimbledon Library	Library	Gas boiler	ASHP & Rads	£ 4,222	£ 5,977	42%	£ 5,229	24%
15d	Wimbledon Library	Library	Gas boiler	ASHP, Rads & EE	£ 4,222	£ 4,591	9%	£ 4,017	-5%

16. Heat pump lifetime costs

The lifetime costs of a technology are particularly important to building portfolio owners considering how to invest over a 10 to 30-year timeframe. In this regard, there are some considerations that should be taken when comparing heat pumps with traditional forms of heating:

- Heat pumps are generally assumed to have a longer service life than a condensing gas boiler. In this report, the following lifetimes were assumed based on a literature review and feedback from industry:
  - Gas boiler: 12 years
  - Air source heat pump 15 years
  - Ground source heat pump 20 years (ground loop 50 years)
- In this analysis, it was assumed that all technologies would require annual servicing to ensure optimal performance. Our research suggests that heat pump servicing costs are currently higher than gas boiler servicing in the current market:
  - Domestic gas boiler annual service plan: £109
  - Domestic air source heat pump annual service plan: £182
  - Domestic ground source heat pump annual service plan: £182
- The market for gas boiler servicing is highly mature and competitive whereas the market for heat pump servicing is nascent. As the market for heat pump servicing matures, there is good potential for heat pump servicing costs to reduce. However, in this report, we applied the current market rates over the full 40-year analysis timeframe.
- In this analysis it was assumed that gas boilers will be able to carry out their full-service life. However, in practice it is possible that legislation targeted at reducing CO_2 emissions in existing buildings could require gas boilers to be removed from buildings before their end of life.

16.1 Domestic buildings: Lifetime costs of heat pump retrofit

30-year costs of ownership: no subsidies

Table 19: 30-year costs of ownership of BAU and retrofit scenarios (no grants).

Package	Building		BAU package	Retrofit package	BAU 30 year cost	Retrofit scanrio 30 year cost	% increase in costs relative to BAU (30 years)
1b	Lymington Road	Flat	Gas boiler	ASHP & Rads	£ 20,040	£ 33,600	68%
1c	Lymington Road	Flat	Gas boiler	GSHP & Rads	£ 20,040	£ 40,500	102%
2b	Cavendish House	Flat	Gas boiler	ASHP & Rads	£ 18,080	£ 32,550	80%
3b	Sherwin House	Flat	Gas boiler	ASHP & Rads	£ 19,750	£ 33,840	71%
4b	Northcote Road	Maisonette	Gas boiler	Hybrid	£ 38,270	£ 55,620	45%
4c	Northcote Road	Maisonette	Gas boiler	ASHP, Rads & EE	£ 38,270	£ 71,610	87%
4d	Northcote Road	Maisonette	Gas boiler	ASHP, Rads & Deep retrofit	£ 38,270	£ 86,970	127%
5b	Aldenham Drive	House	Electric boiler	ASHP	£ 37,550	£ 30,690	-18%
5c	Aldenham Drive	House	Electric boiler	GSHP	£ 37,550	£ 38,980	4%
6b	Surrey Road	House	Gas boiler	ASHP	£ 24,770	£ 42,620	72%
6c	Surrey Road	House	Gas boiler	ASHP & Rads	£ 24,770	£ 44,100	78%
7b	Mowbray Road	House	Gas boiler	ASHP	£ 39,040	£ 60,290	54%
7c	Mowbray Road	House	Gas boiler	ASHP, Rads & EE	£ 39,040	£ 59,640	53%
7d	Mowbray Road	House	Gas boiler	ASHP, Rads & Deep retrofit	£ 39,040	£ 77,740	99%
8b	Albany Road	House	Gas boiler	ASHP & Rads	£ 32,270	£ 50,030	55%
8c	Albany Road	House	Gas boiler	ASHP, Rads & EE	£ 32,270	£ 43,930	36%
8d	Albany Road	House	Gas boiler	GSHP, Rads & EE	£ 32,270	£ 51,460	59%
9b	Tradescant Road	House	Gas boiler	Hybrid	£ 43,580	£ 53,040	22%
9c	Tradescant Road	House	Gas boiler	ASHP, Rads & EE	£ 43,580	£ 70,230	61%
9d	Tradescant Road	House	Gas boiler	ASHP, Rads & Deep retrofit	£ 43,580	£ 91,210	109%

The table above shows the 30-year cost of ownership for the BAU and heat pump scenarios, taking in to account all capital costs (including replacement installations within the 30 years) and operating costs, including fuel bills and annual servicing[94].

- In our analysis (when no grant is included and standard tariffs are used), over a 30-year timeframe, all retrofit packages, except for one have higher 30-year costs.
- 30-year costs were between 18% lower and 127 % higher than BAU costs over 30 years.
- The retrofit of heat pumps in to buildings with electric heating had the lowest lifetime costs. When replacing electric heating with an air source heat pump, an 18% saving was achieved. When replacing electric heating with a ground source heat pump (on a shared ground loop) the increase in costs was only 4%. This reflects the high fuel bill savings when replacing electric heating.
- Where cost effective energy efficiency measures were available e.g. building 08 (three bed Victorian terrace) this improved the 30-year financial case for heat pump retrofit.
- However, more expensive energy efficiency measures (for example double glazed sash windows in building 09 (five bed Victorian terrace) did not pay for themselves in fuel bill savings over 30 years.
- Similarly, homes undertaking deep retrofit did not repay the initial up-front capital investment through reduced fuel bills. However, this analysis does not take in to account money that would need to be spent on the building in any case. Particularly where deep retrofit occurs, this can off-set other planned maintenance expenditure and reduce emergency repair to work to buildings.
- In our sample, ground source heat pumps have higher 30-year lifetime costs than air source heat pumps. The marginally lower fuel bills associated with ground source did not repay the additional up-front capital investment. However, in all these cases, factors other than cost could drive a decision in favour of ground source heat pumps (for example, the lack of available space for air source heat pump external units).

[94] We included the capital costs of replacing equipment within the 30-year time frame. For air source heat pumps this typically involved a full replacement of the heat pump equipment at 15 years and for ground source heat pumps this typically involved a replacement of equipment (not including the ground loop) at 20 years. We took account of the fact that installation costs for heat pumps would typically be lower the second time around as much of the ancillary work and changes to pipework would not need to be repeated. However, we did not take in to account general reductions in the cost of heat pump equipment due to market maturity. In this sense, our estimates of cost could be seen as conservative relative to the potential for cost reduction in the market. However, a report by Delta EE for BEIS in 2016 suggests that the scope for heat pump cost reductions is relatively limited at 15-20% when the heat pump market reaches full scale.

30-year costs of ownership with current RHI

Table 20: 30-year costs of ownership of BAU and retrofit scenarios (current RHI)

Package	Building		BAU package	Retrofit package	BAU 30 year cost	Retrofit scenario 30 year cost with RHI	% increase in costs relative to BAU (30 years) Including RHI
1b	Lymington Road	Flat	Gas boiler	ASHP & Rads	£ 20,040	£ 30,700	53%
1c	Lymington Road	Flat	Gas boiler	GSHP & Rads	£ 20,040	£ 30,550	52%
2b	Cavendish House	Flat	Gas boiler	ASHP & Rads	£ 18,080	£ 30,380	68%
3b	Sherwin House	Flat	Gas boiler	ASHP & Rads	£ 19,750	£ 30,950	57%
4b	Northcote Road	Maisonette	Gas boiler	Hybrid	£ 38,270	£ 55,620	45%
4c	Northcote Road	Maisonette	Gas boiler	ASHP, Rads & EE	£ 38,270	£ 63,900	67%
4d	Northcote Road	Maisonette	Gas boiler	ASHP, Rads & Deep retrofit	£ 38,270	£ 82,260	115%
5b	Aldenham Drive	House	Electric boiler	ASHP	£ 37,550	£ 27,960	-26%
5c	Aldenham Drive	House	Electric boiler	GSHP	£ 37,550	£ 33,490	-11%
6b	Surrey Road	House	Gas boiler	ASHP	£ 24,770	£ 38,370	55%
6c	Surrey Road	House	Gas boiler	ASHP & Rads	£ 24,770	£ 39,560	60%
7b	Mowbray Road	House	Gas boiler	ASHP	£ 39,040	£ 50,560	30%
7c	Mowbray Road	House	Gas boiler	ASHP, Rads & EE	£ 39,040	£ 51,500	32%
7d	Mowbray Road	House	Gas boiler	ASHP, Rads & Deep retrofit	£ 39,040	£ 74,090	90%
8b	Albany Road	House	Gas boiler	ASHP & Rads	£ 32,270	£ 42,640	32%
8c	Albany Road	House	Gas boiler	ASHP, Rads & EE	£ 32,270	£ 38,830	20%
8d	Albany Road	House	Gas boiler	GSHP, Rads & EE	£ 32,270	£ 42,390	31%
9b	Tradescant Road	House	Gas boiler	Hybrid	£ 43,580	£ 53,040	22%
9c	Tradescant Road	House	Gas boiler	ASHP, Rads & EE	£ 43,580	£ 62,500	43%
9d	Tradescant Road	House	Gas boiler	ASHP, Rads & Deep retrofit	£ 43,580	£ 87,050	100%

- When current rates of RHI are applied, the 30-year financial cases change relative to the BAU, ranging from 26% lower to 115% higher than BAU costs. However, for the majority of buildings the current RHI is not sufficient to make heat pumps the cheaper technology over 30 years.
- The RHI penalises retrofit scenarios that include energy efficiency because RHI payments are linked to the kWh of heating demand. This dis-incentivises reducing thermal demand.

30-year costs of ownership with £4,000 Clean Heat Grant and a 20% CAPEX reduction

Table 21: 30-year costs of ownership of BAU and retrofit scenarios (20% CAPEX reduction plus Clean Heat Grant)

Package	Building		BAU package	Retrofit package	BAU 30 year cost	Retrofit scenario 30 year cost with £4,000 grant and 20% CAPEX reduction	Retrofit costs as a % of BAU costs (30 years) Including £4,000 grant and 20% CAPEX reduction
1b	Lymington Road	Flat	Gas boiler	ASHP & Rads	£ 20,040	£ 22,880	14%
1c	Lymington Road	Flat	Gas boiler	GSHP & Rads	£ 20,040	£ 28,400	42%
2b	Cavendish House	Flat	Gas boiler	ASHP & Rads	£ 18,080	£ 22,040	22%
3b	Sherwin House	Flat	Gas boiler	ASHP & Rads	£ 19,750	£ 23,070	17%
4b	Northcote Road	Maisonette	Gas boiler	Hybrid	£ 38,270	£ 44,500	16%
4c	Northcote Road	Maisonette	Gas boiler	ASHP, Rads & EE	£ 38,270	£ 53,290	39%
4d	Northcote Road	Maisonette	Gas boiler	ASHP, Rads & Deep retrofit	£ 38,270	£ 65,570	71%
5b	Aldenham Drive	House	Electric boiler	ASHP	£ 37,550	£ 20,550	-45%
5c	Aldenham Drive	House	Electric boiler	GSHP	£ 37,550	£ 27,180	-28%
6b	Surrey Road	House	Gas boiler	ASHP	£ 24,770	£ 30,090	21%
6c	Surrey Road	House	Gas boiler	ASHP & Rads	£ 24,770	£ 31,280	26%
7b	Mowbray Road	House	Gas boiler	ASHP	£ 39,040	£ 44,230	13%
7c	Mowbray Road	House	Gas boiler	ASHP, Rads & EE	£ 39,040	£ 43,710	12%
7d	Mowbray Road	House	Gas boiler	ASHP, Rads & Deep retrofit	£ 39,040	£ 58,200	49%
8b	Albany Road	House	Gas boiler	ASHP & Rads	£ 32,270	£ 36,030	12%
8c	Albany Road	House	Gas boiler	ASHP, Rads & EE	£ 32,270	£ 31,140	-4%
8d	Albany Road	House	Gas boiler	GSHP, Rads & EE	£ 32,270	£ 37,170	15%
9b	Tradescant Road	House	Gas boiler	Hybrid	£ 43,580	£ 42,430	-3%
9c	Tradescant Road	House	Gas boiler	ASHP, Rads & EE	£ 43,580	£ 52,190	20%
9d	Tradescant Road	House	Gas boiler	ASHP, Rads & Deep retrofit	£ 43,580	£ 68,970	58%

For each building a hypothetical scenario combining the proposed £4,000 Clean Heat Grant with a 20% reduction in all capital costs (including heat pumps, radiators and energy efficiency measures) was modelled. This scenario was chosen to represent a 'best case scenario' for social landlords who may be able to benefit from economies of scale. The 20% reduction could also arise from additional grant or government action, such as removing VAT on heat pumps in retrofit.

Under this scenario, the 30-year cost of heat pump ownership is much closer to BAU, ranging between a 45% saving and a 71% increase.

- Under this scenario, electrically heated buildings would have a very strong financial incentive to transition to heat pumps.
- In addition, some buildings with cost effective energy efficiency measures and potential for air source heat pumps would experience 30-year cost savings relative to BAU.
- For the majority of buildings, the heat pump option would be more expensive over 30 years. However, for scenarios not involving deep retrofit or ground source heat pumps, this difference was only 16%-26%.
- This scenario was modelled using standard electricity tariffs. Flexible time of use tariffs could potentially reduce lifetime costs further.

16.2 Medium and large-scale buildings: Lifetime costs of heat pump retrofit

30-year costs of ownership: no subsidies[95]

Table 22: 30-year costs of ownership of BAU and retrofit scenarios (no grants)

Package	Building		BAU package	Retrofit package	BAU 30 year cost	Retrofit scenario 30 year cost	% increase in costs relative to BAU (30 years)
10b	Ernest Dence Estate	95 flats	Gas boiler	ASHP & upgraded distribution	£ 2,493,850	£ 3,459,220	39%
10c	Ernest Dence Estate	95 flats	Gas boiler	WSHP & upgraded distribution	£ 2,493,850	£ 3,314,720	33%
10d	Ernest Dence Estate	95 flats	Gas boiler	WSHP, upgraded distribution & deep retrofit	£ 2,493,850	£ 3,897,420	56%
11b	Tower Block	50 flats	Electric heating	GSHP & Rads	£ 1,490,570	£ 1,850,710	24%
12b	Gifford House	Small office	Gas boiler	ASHP	£ 135,570	£ 343,770	154%
12c	Gifford House	Small office	Gas boiler	ASHP & Rads	£ 135,570	£ 350,240	158%
12d	Gifford House	Small office	Gas boiler	GSHP & Rads	£ 135,570	£ 353,270	161%
13b	Billet Road	Medium office	Gas boiler	ASHP	£ 472,400	£ 974,260	106%
13c	Billet Road	Medium office	Gas boiler	GSHP & Rads	£ 472,400	£ 1,096,340	132%
13d	Billet Road	Medium office	Gas boiler	GSHP, Rads & Deep retrofit	£ 472,400	£ 1,145,990	143%
14b	Docklands Road	Vary large office	Gas boiler & chillers	ASHP & Chillers	£ 6,152,590	£ 7,737,750	26%
14c	Docklands Road	Vary large office	Gas boiler & chillers	WSHP	£ 6,152,590	£ 7,870,320	28%
14d	Docklands Road	Vary large office	Gas boiler & chillers	WSHP & Solar PV	£ 6,152,590	£ 2,905,420	-53%
15b	Wimbledon Library	Library	Gas boiler	High-temp ASHP	£ 266,670	£ 757,910	184%
15c	Wimbledon Library	Library	Gas boiler	ASHP & Rads	£ 266,670	£ 589,720	121%
15d	Wimbledon Library	Library	Gas boiler	ASHP, Rads & EE	£ 266,670	£ 616,040	131%

[95] At the time of writing, it is unknown what support there will be for non-domestic buildings following the closure of the non-domestic RHI in 2022.

The table below shows the 30-year cost of ownership for the BAU and heat pump scenarios, taking in to account all capital costs (including replacement installations within the 30 years) and operating costs including fuel bills and annual servicing.

This analysis suggests that:

- Buildings matching a high cooling demand with reversible heat pump installation and Solar PV can achieve very low lifetime costs. In our example building 14 (very large office), this combination of measures resulted in a 53% cost saving over 30 years relative to BAU. However, it should be noted that this includes export tariff and avoided electricity costs from a 640kWP solar installation and so represents an extreme example of the potential benefits here.

- Where heat pumps are replacing electric heating, as in building 11 (tower block of 50 flats), the fuel bill savings did not quite repay the additional up-front investment of the shared ground loop and individual heat pumps. However, the 30-year lifetime costs are only 24% higher. When current levels of RHI are taken in to account (see next section) this makes for an attractive financial case for heat pump retrofit.

- Where the BAU scenario also includes upgrades to the wider heating and cooling system, the cost gap between the heat pump scenario and the BAU scenario is relatively smaller. For example, in building 14 (very large office) the BAU scenario included replacement of the electric chiller units as well as the gas boiler. By replacing these with a single technology (reversible heat pump) capital cost savings were achieved that lowered lifetime costs to only 26-28% more than BAU.

- Similarly, in building 10 (block of 95 flats), the BAU scenario included the refurbishment of the communal heating pipework and Heat Interface Units (HIUs) at an estimated cost of £800,000. In this building, the additional 30-year cost of heat pump retrofit was only 33%-56% greater than the BAU scenario.

- Where the BAU scenario involved the relatively straightforward replacement of a gas boiler with a like-for-like replacement, the additional cost of heat pump retrofit over 30 years was much greater. For example, in building 12 (small office), building 13 (medium office) and building 15 (library), the additional costs of heat pump retrofit over BAU ranged from 106% to 184%. In these cases, capital costs were significantly higher for the heat pump, fuel bills were typically greater and service costs higher. N.B. scenarios for these buildings do not take in to account time of use tariffs or other payments for flexibility, nor RHI or potential CAPEX reductions.

30-year costs of ownership with current RHI (the current situation until 2022)

Table 23: 30-year costs of ownership of BAU and retrofit scenarios (current non-domestic RHI)

Package	Building		BAU package	Retrofit package	BAU 30 year cost	Retrofit scenario 30 year cost with RHI	% increase in costs relative to BAU (30 years) Including RHI
10b	Ernest Dence Estate	95 flats	Gas boiler	ASHP & upgraded distribution	£ 2,493,850	£ 3,000,940	20%
10c	Ernest Dence Estate	95 flats	Gas boiler	WSHP & upgraded distribution	£ 2,493,850	£ 2,276,490	-9%
10d	Ernest Dence Estate	95 flats	Gas boiler	WSHP, upgraded distribution & deep retrofit	£ 2,493,850	£ 3,543,930	42%
11b	Tower Block	50 flats	Electric heating	GSHP & Rads	£ 1,490,570	£ 934,060	-37%
12b	Gifford House	Small office	Gas boiler	ASHP	£ 135,570	£ 311,940	130%
12c	Gifford House	Small office	Gas boiler	ASHP & Rads	£ 135,570	£ 320,000	136%
12d	Gifford House	Small office	Gas boiler	GSHP & Rads	£ 135,570	£ 258,760	91%
13b	Billet Road	Medium office	Gas boiler	ASHP	£ 472,400	£ 815,550	73%
13c	Billet Road	Medium office	Gas boiler	GSHP & Rads	£ 472,400	£ 673,420	43%
13d	Billet Road	Medium office	Gas boiler	GSHP, Rads & Deep retrofit	£ 472,400	£ 985,090	109%
14b	Docklands Road	Vary large office	Gas boiler & chillers	ASHP & Chillers	£ 6,152,590	£ 6,970,980	13%
14c	Docklands Road	Vary large office	Gas boiler & chillers	WSHP	£ 6,152,590	£ 5,547,430	-10%
14d	Docklands Road	Vary large office	Gas boiler & chillers	WSHP & Solar PV	£ 6,152,590	£ 698,670	-89%
15b	Wimbledon Library	Library	Gas boiler	High-temp ASHP	£ 266,670	£ 683,350	156%
15c	Wimbledon Library	Library	Gas boiler	ASHP & Rads	£ 266,670	£ 515,150	93%
15d	Wimbledon Library	Library	Gas boiler	ASHP, Rads & EE	£ 266,670	£ 555,080	108%

- When current rates of non-domestic RHI are applied, the 30-year financial cases for heat pump retrofit change relative to the BAU ranged between 89% lower and 156% higher cost than BAU over 30 years.
- For the very large office building (building 14) the RHI subsidies were sufficient to make the heat pump options cheaper than BAU over 30 years.
- However, for the majority of buildings the current non-domestic RHI was not sufficient to make heat pumps the cheaper technology over 30 years.
- Non-domestic RHI payments for ground and water source are more generous than those for air source. In building 10 (block of 95 flats) this made the water source heat pump scenario lower cost than the BAU scenario over 30 years.
- For scenarios involving ground and water source heat pumps (not including PV), the additional costs over BAU ranged between a 37% saving and a 91% increase. For scenarios involving air source heat pumps, the additional costs over BAU ranged from a 13% increase to a 156% increase.
- The non-domestic RHI penalises retrofit scenarios that include energy efficiency because payments are linked to the kWh of heating demand. This dis-incentivises reducing thermal demand.

30-year costs of ownership with grant and a 20% CAPEX reduction

Table 24: 30-year costs of ownership of BAU and retrofit scenarios (20% CAPEX reduction plus grant)

Package	Building		BAU package	Retrofit package	BAU 30 year cost		Retrofit scenario 30 year cost with grant and 20% CAPEX reduction		Retrofit costs as a % of BAU costs (30 years) including grant and 20% CAPEX reduction
10b	Ernest Dence Estate	95 flats	Gas boiler	ASHP & upgraded distribution	£	2,493,850	£	2,387,370	-4%
10c	Ernest Dence Estate	95 flats	Gas boiler	WSHP & upgraded distribution	£	2,493,850	£	2,655,680	6%
10d	Ernest Dence Estate	95 flats	Gas boiler	WSHP, upgraded distribution & deep retrofit	£	2,493,850	£	2,737,940	10%
11b	Tower Block	50 flats	Electric heating	GSHP & Rads	£	1,490,570	£	1,280,570	-14%
12b	Gifford House	Small office	Gas boiler	ASHP	£	135,570	£	268,850	98%
12c	Gifford House	Small office	Gas boiler	ASHP & Rads	£	135,570	£	276,350	104%
12d	Gifford House	Small office	Gas boiler	GSHP & Rads	£	135,570	£	203,490	50%
13b	Billet Road	Medium office	Gas boiler	ASHP	£	472,400	£	750,260	59%
13c	Billet Road	Medium office	Gas boiler	GSHP & Rads	£	472,400	£	585,500	24%
13d	Billet Road	Medium office	Gas boiler	GSHP, Rads & Deep retrofit	£	472,400	£	798,250	69%
14b	Docklands Road	Vary large office	Gas boiler & chillers	ASHP & Chillers	£	6,152,590	£	6,758,170	10%
14c	Docklands Road	Vary large office	Gas boiler & chillers	WSHP	£	6,152,590	£	5,244,160	-15%
14d	Docklands Road	Vary large office	Gas boiler & chillers	WSHP & Solar PV	£	6,152,590	£	276,600	-96%
15b	Wimbledon Library	Library	Gas boiler	High-temp ASHP	£	266,670	£	586,580	120%
15c	Wimbledon Library	Library	Gas boiler	ASHP & Rads	£	266,670	£	429,470	61%
15d	Wimbledon Library	Library	Gas boiler	ASHP, Rads & EE	£	266,670	£	462,560	73%

For each building a hypothetical scenario with a 20% reduction in all capital costs (including heat pumps, radiators and energy efficiency measures) was modelled.

For the blocks of flats (buildings 10 and 11) a £4,000 Clean Heat Grant for each flat[96] was added. For the non-domestic buildings, we added the non-domestic RHI at the current rates (N.B. the non-domestic RHI is currently scheduled to end in 2022)[97].

This scenario was chosen to represent a 'best case scenario' for building owners able to achieve economies of scale or capital cost reductions through other means. The 20% reduction could also arise from additional grant or government action such as removing VAT on heat pumps in retrofit.

- This analysis suggests that, for blocks of flats, a 20% reduction in CAPEX alongside a £4,000 grant per flat could be sufficient to make the 30-year costs of heat pump retrofit lower or equivalent to replacement gas heating (see building 10).
- However, this sample suggests even with a 20% CAPEX reduction added to current levels of non-domestic RHI, small- and medium-sized office buildings with gas heating systems would still experience a cost increase for heat pump retrofit compared to BAU over 30 years. In this sample of buildings, the heat pump retrofit scenarios remained 59%-120% more expensive than BAU over 30 years[98].

[96] At the time of writing, the published consultation for the Clean Heat Grant does not include support for blocks of flats with communal heating (e.g. building 10), however, we modelled the impact of an equivalent grant for communally heated buildings (£4,000 per flat) to identify the potential impact this would have on the financial case.
[97] At the time of writing, the government had yet to release plans for future support for non-domestic buildings.
[98] This assessment does not include potential additional benefits from time of use tariffs.

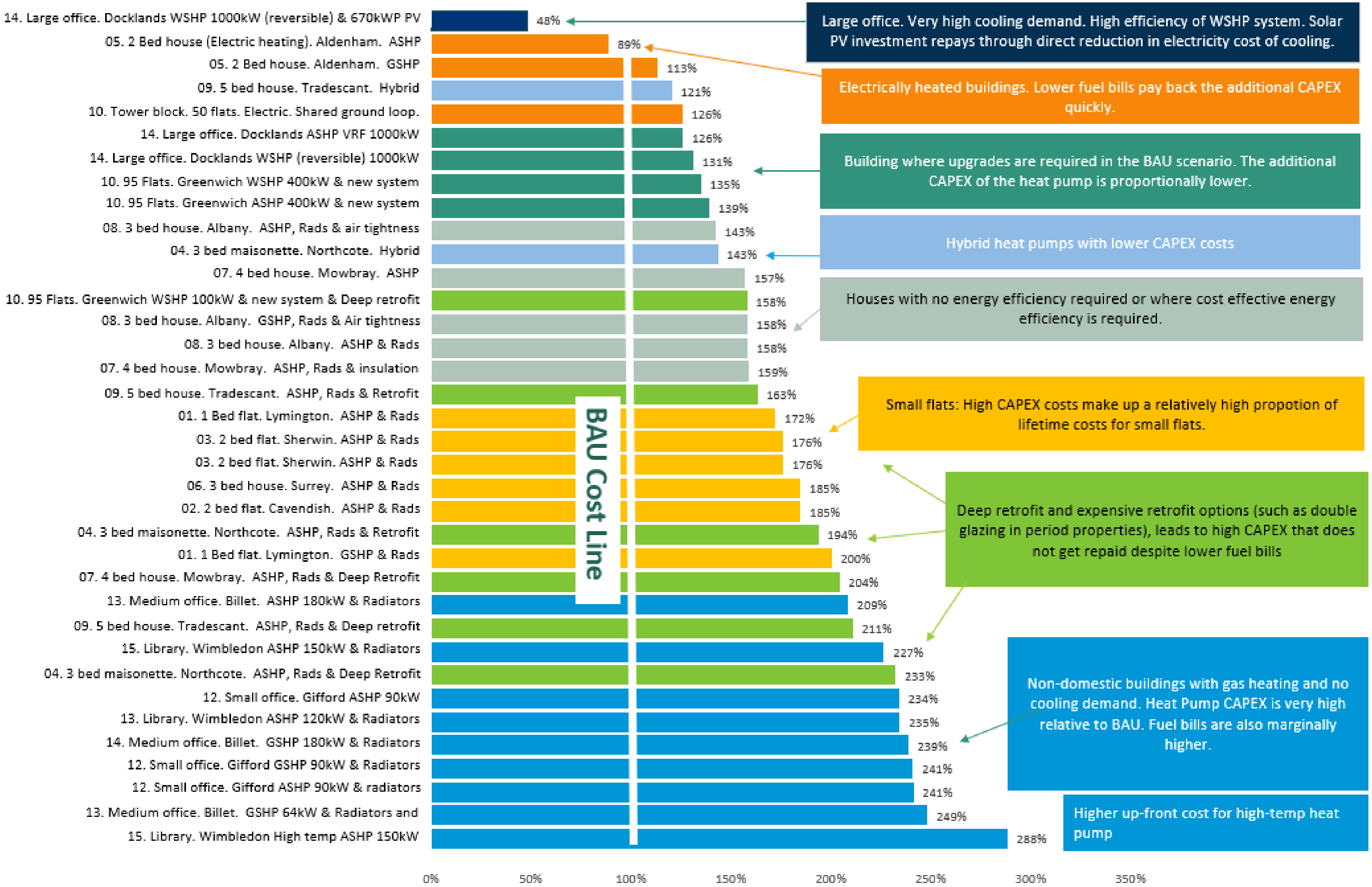
16.3 Summary of lifetime cost of ownership analysis

The following chart summarises the 30-year lifetime costs of the heat pump retrofit scenarios relative to the BAU scenario.

In this chart, the different heat pump scenarios are ranked according to the difference between 30-year BAU costs and 30-year heat pump retrofit scenario costs. The buildings at the top have the lowest 30-year costs relative to BAU and the buildings at the bottom are relatively the most expensive scenarios for heat pump retrofit. From this chart, the following ranking emerges of buildings with the strongest to weakest 30-year financial cases for heat pump retrofit (N.B. this does not take account of any current or future proposed subsidies or the 20% CAPEX reduction):

1. Buildings that have a combination of high electric cooling demand, high BAU costs (due to more complex existing energy systems needing replacing) and Solar PV installation.
2. Electrically heated buildings with potential for air source heat pumps.
3. Electrically heated buildings with potential for ground source heat pumps.
4. Buildings where BAU costs are high due to necessary building upgrades or replacement of expensive capital equipment.
5. Houses where no energy efficiency work is required or where cost effective energy efficiency is required.
6. Small flats: in our sample the small flats were generally energy efficient and did not require energy efficiency works, however, capital costs were relatively high making lifetime costs relatively more expensive.
7. Homes that required more expensive energy efficiency measures.
8. Non-domestic buildings where BAU costs are very low, such as simple gas boiler heating systems.

Figure 39: 30-year lifetime costs for all heat pump retrofit options as a percentage of BAU costs (without subsidies)



16.4 Summary of the cost of carbon reductions

The following chart looks at the relative costs of achieving a one tonne reduction in CO_2 emissions for each option in each building. This metric helps to understand the balance between the cost of the retrofit package and level of carbon savings achieved. Whilst this does not affect the financial case for heat pump retrofit in each case (in the current absence of a market for carbon such as the Carbon Reduction Commitment), this metric is a key guide to the relative societal benefit of each package.

This analysis suggests the following ranking of building types and retrofit packages as the most cost-effective ways of achieving CO_2 emissions reductions:

1. Electrically heated buildings that can install air source heat pumps. As these buildings will typically have lower lifetime costs than the BAU scenario (conventional electric heating) the cost of carbon reduction is negative. Where levels of grant are sufficient, electrically heated buildings utilising ground and water source heat pumps could also fall in to this category.

2. Buildings with a high electric cooling demand that can combine this with solar PV. As these buildings can achieve lower lifetime costs than BAU, the cost of carbon reduction is negative.

3. Hybrid heat pumps. Although hybrid heat pumps save a much lower level of CO_2 than standard heat pumps; due to their lower cost of installing hybrid heat pumps, they can save CO_2 at a lower cost per tonne.

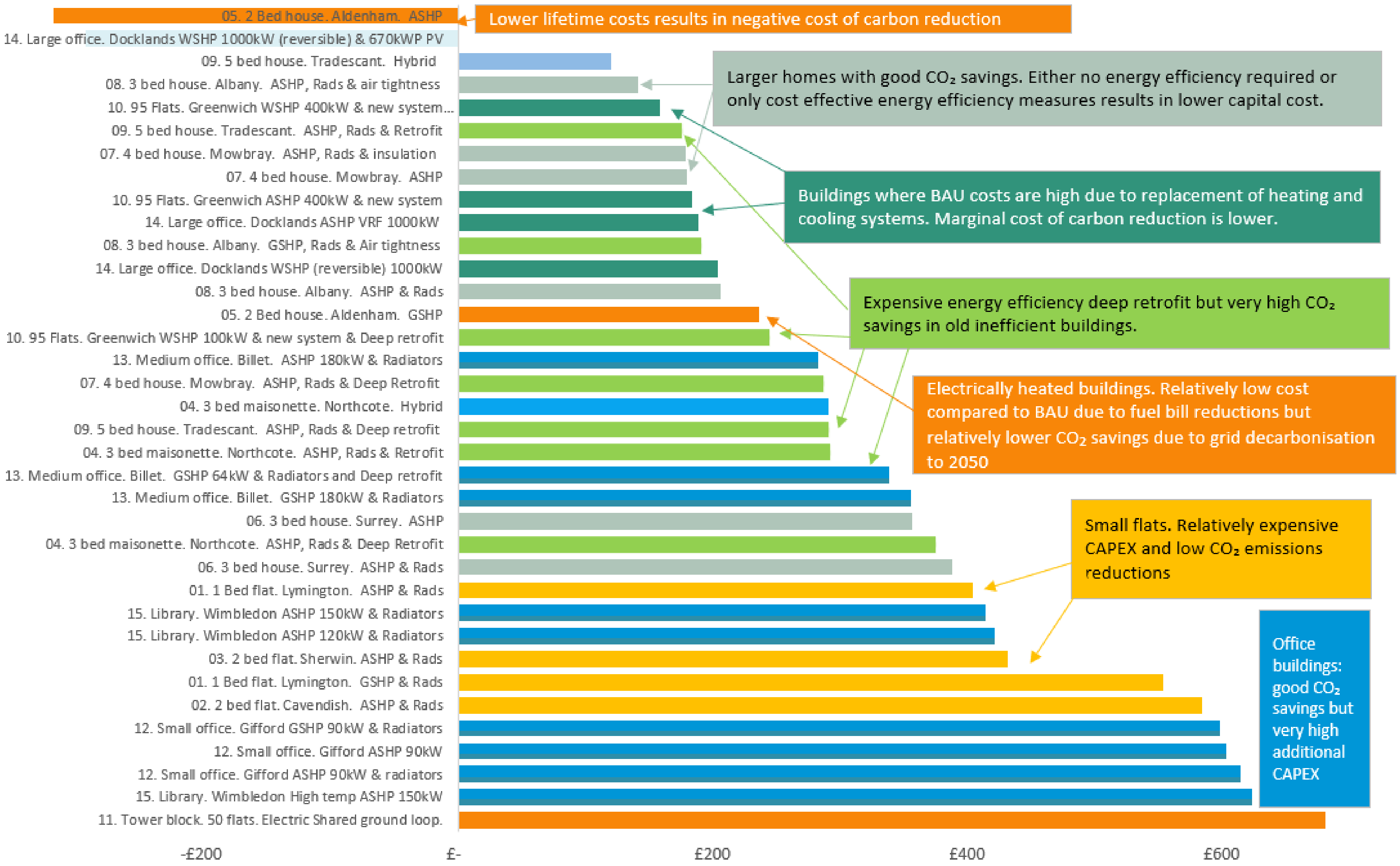
4. Large homes where no energy efficiency or only cost-effective energy efficiency measures are required. In larger homes, large CO_2 savings can be achieved by removing high gas usage. Where installations are lower cost (where less expensive energy efficiency measures are required) this can lead to a relatively low cost of carbon reduction.

5. Electrically heated homes with more expensive heat pump solutions. Where electrically heated homes require more expensive heat pump solutions (such as ground source heat pumps) the cost of carbon reduction is relatively higher. CO_2 emissions reductions are lower when replacing electricity than when replacing gas.

6. Small individual flats have a relatively high cost of carbon reduction. This is due to lower CO_2 savings and a relatively high up-front capital cost.

7. Non-domestic buildings with simple heating systems (e.g. gas boiler and radiators) have a higher cost of carbon reduction. While there are large CO_2 savings to be made in these building types, the lifetime costs are much higher than the BAU scenario. Therefore, the overall cost per tonne of CO_2 is high.

Figure 40: Cost of carbon reduction relative to BAU scenario. £ per tonne of CO_2 reduced (cumulative CO_2 emissions by 2050). Not including RHI.



Appendix

Appendix 1: Predicting heat pump efficiency in retrofit

In this report we have used percentages to represent predictions of both gas and heat pump efficiency over the course of a year under real world conditions. The percentages represent the kWh of heat energy output by the system divided by the kWh of gas or electricity input to the heating system. This enables a straightforward comparison between gas, direct electric, hybrid and pure heat pump based systems. The predicted percentage efficiency for heat pump systems in this report were based on the Building Research Establishment (BRE) Domestic Annual Heat Pump Efficiency Estimator methodology (further information below). Whilst presenting efficiency in percentage terms provides a straightforward basis for comparison, it is worth noting that this refers only to the quantity of heat output relative to the quantity of electricity or gas input. It is not thermodynamically possible to have an efficiency greater than 100% when all inputs (including the renewable heat sources) are taken in to account. For this reason, it is more common to see heat pump performance expressed as a Co-efficient of Performance (COP), Seasonal Co-efficient of Performance (SCOP) or Seasonal Performance Factor (SPF) rather than an efficiency rating. These terms are described below.

Co-efficient of performance (COP): a snapshot of efficiency

COPs quoted by manufacturers for heat pumps can often be as high as four or five. However, the COP is only a snapshot of performance under a specific set of test conditions[99] for specific source and flow temperatures. In reality, heat pump efficiency will vary across the year as temperatures change and test conditions may not apply, especially in a retrofit context. Therefore, COPs are not the most useful basis for assessing heat pump performance across the year in a real-world retrofit context.

Seasonal Performance Factor (SPF): actual performance over a year

The SPF is the ratio between the kW of heat delivered and the kW of electricity used to drive the heat pump over a year. Typically, an SPF should be based on metered data and will therefore consider the whole system efficiency accounting for the specific source and output temperature and the efficient of the heating system. This makes SPF the ideal criteria on which to assess real world heat pump performance. SPF data has been gathered for a range of field trials in the UK and across Europe. A summary of results from these trials was presented in the report Heat Pumps in London[100].

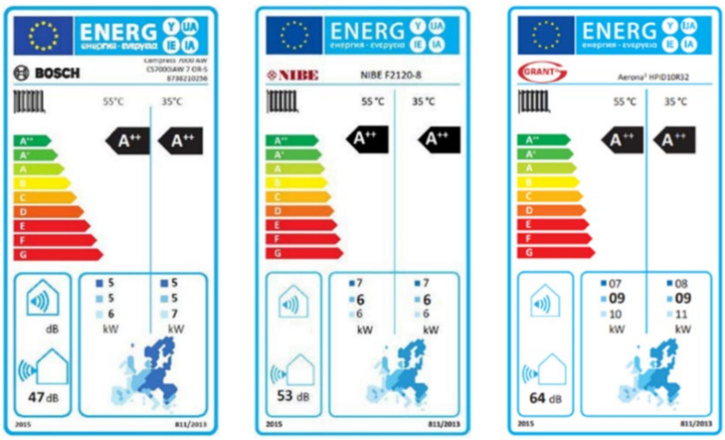
[99] Tested under EN14511:2013.
[100] Etude for Greater London Authority (2018). *Low carbon heat – heat pumps in London.*

Data Source	Heat Pump Type			Confidence
	Air-air	Air-water	Ground-water	
Field Trials				
EST Field Trials 1		1.20 – 2.20	1.55 – 3.47	*
EST Field Trials 2		2.00 – 3.60	2.00 – 3.82	**
RHPP Detailed Analysis Report*		2.33 – 2.95	2.81 – 3.14	**
Fraunhofer WP-Effizienz		2.50 - 3.60	3.00 – 5.20	***
Fraunhofer WP im Gebäudebestand		2.20 – 3.10	2.80 – 3.60	***
SEPEMO-Build	3.30 - 3.80	3.00+	4.00+	***

This review of SPFs suggests that heat pump performance in real world settings can vary significantly ranging between 1.20 to over 4.00. However, it should be noted that the field trials above represent an evolution in the understanding of heat pump system design, installation and operation. The early Energy Saving Trust (EST) field trials in 2009-2011 highlighted the potential negative consequences of poor system design, where flow temperatures were high and users were not instructed on how to operate heat pumps efficiently. Therefore, while data from historic schemes provides valuable insight, it is not the best basis for predicting future performance in different buildings with contemporary best practice design.

Seasonal Coefficient of Performance (SCOP): a prediction of annual performance

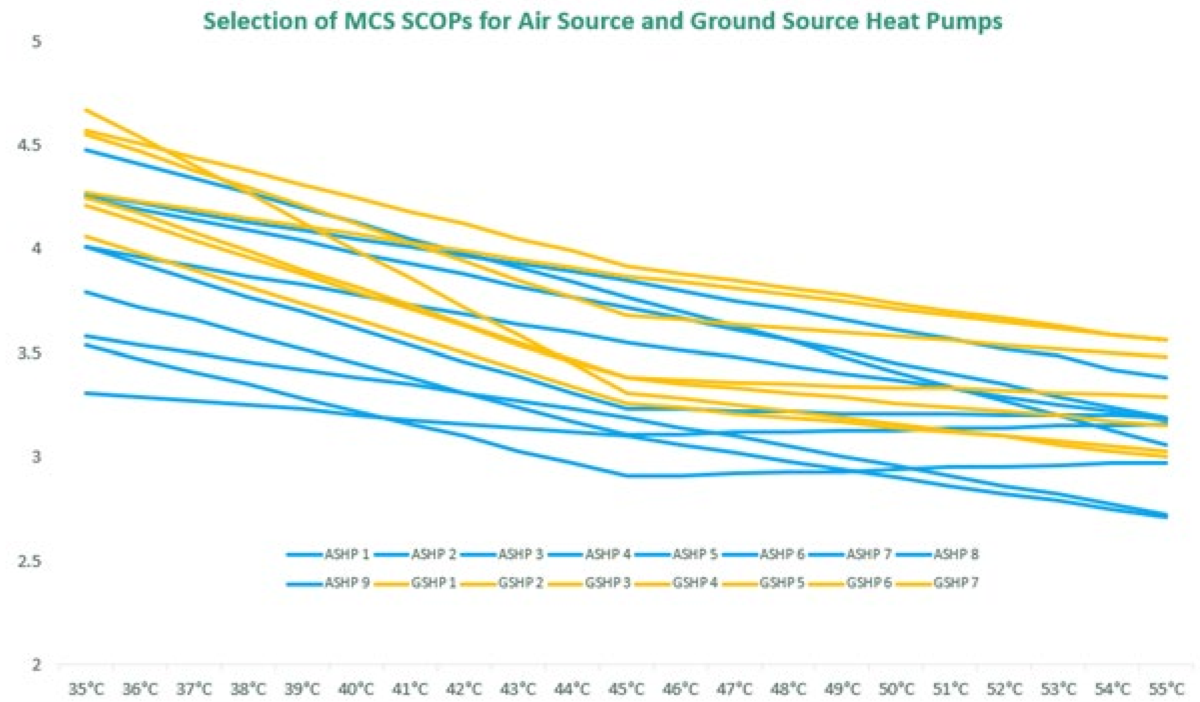
The SCOP is a test and calculation standard (EN 14825:2016) that simulates a wide range of temperature conditions across the year to calculate a 'deemed' year-round efficiency. The SCOP is a valuable basis for comparison of how different heat pumps could be expected to perform across a year.



The UK's Microgeneration Certification Scheme (MCS) has developed a SCOP calculator. Any heat pump commissioned after 25 March 2016 must achieve a minimum SCOP of 2.5 using the calculator in order to gain MCS certification and the SCOP value is recorded for individual products in the MCS Product Directory[101] and can be found indirectly via the EU energy labels for heat pumps

[101] Microgeneration Certification Scheme (2020). *Product Directory.* Available at: https://mcscertified.com/product-directory/

The SCOP is therefore a useful predictor of heat pump performance across the year.



The above graph shows a selection of SCOPs for a number of air and ground source heat pumps from the MCS Directory. This shows how heat pump predicted performance can differ significantly between products. But values between 2.8 and 4 are typical for ASHP while values between 3 and 4.5 are typical for GSHPs[102], although values for either technology can lie outside these ranges.

Other predictors of heat pump efficiency

Whilst the SCOP is a good basis for comparison of heat pump performance and reasonable guide to the predicted annual performance, there are a number of ways in which the performance of a heat pump could differ when installed in buildings, particularly in a retrofit context:

1. The SCOP does not take in to account the heat loss of the building in which the heat pump is to be installed. Heat pumps operate most efficiently when sized correctly for the heat loss of the building. Over-sized heat pumps will start and stop more frequently and spend less time operating at their most efficient setting.
2. The SCOP does not take in to account hot water heating. In the majority of London retrofit contexts, the heat pump would be required to provide both space and water heating.
3. The SCOP uses average European climate data rather than data specific to London or the UK.

[102] You will note here the extent to which heat pump efficiency reduces as the required flow temperature increases. This is a key element of efficient heat pump design which is discussed in detail in Chapter 8.

4. For inverter driven or modulating heat pumps (heat pumps that flex their power output relative to the level of demand vs outputting at a constant rate) the SCOP does not define the minimum heat output, meaning some heat pumps may cycle on/off more than others at identical temperature conditions.

5. The SCOP does not take in to account whole system annual efficiency including the use associated with back-up electric heaters and circulation pumps. This whole system efficiency is known as SPF_H4[103].

To address these issues the Building Research Establishment (BRE) has developed an annual efficiency calculation method that utilises the engineering standard EN 15316-4-2:2017. To estimate heat pump annual efficiency, an annual combined space and hot water heating duty cycle is used, which incorporates hourly space and hot water heat load and temperature assumptions, using average UK weather data (taken from the City of Leeds). Heat pump test data satisfying Eco-design regulation requirements (EN 14825:2016) is used as an input to the calculation.

Taking account of additional factors that will affect real world performance suggests that real world heat pump efficiencies can be marginally lower than those suggested by the SCOP, with values in the region of 2.40 to 3.85 for air source and 2.65 to 3.90 for ground source. With the lowest end of each ranges typically representing heat pumps that are over-sized for the level of building heat loss and operating at higher flow temperatures.

[103] BRE (2020). *Domestic Annual Heat Pump System Efficiency Estimator (DAHPSE)*. Available at: https://www.bregroup.com/heatpumpefficiency/index.jsp

Appendix 2: Useful Links

Greater London Authority

- Element Energy for Greater London Authority (2018). *London's Climate Action Plan WP3 Zero Carbon Energy Systems.*
- Etude for Greater London Authority (2018). *Low Carbon Heat: Heat Pumps in London*
- Greater London Authority (2016) *London Atmospheric Emissions Inventory, 2016.*
- Greater London Authority (2018). *1.5C compatible climate action plan.*
- Greater London Authority (2013); Secondary Heat Study: London's zero carbon energy resource
- Greater London Authority (2018). *London Environment Strategy.*

Committee on Climate Change

- Committee on Climate Change (2019). *Net zero technical report.*
- Committee on Climate Change (2016). *Biomethane Technical Note*.

Uk government

- Carbon Trust for Department of Business, Energy and Industrial Strategy (2016) *Evidence gathering, low carbon heating technologies; Domestic High Temperature, Hybrid and gas Driven Heat Pumps.*
- Carbon Trust and Imperial College for Department of Business, Energy and Industrial Strategy (2016): *Capturing the benefits of smart flexible energy system.*
- Delta EE for Department of Energy and Climate Change (2016). *Potential cost reductions for air source heat pumps.*
- Department for Business, Energy and Industrial Strategy (2020). *Consultation on future support for low carbon heat.*
- Department for Business, Energy and Industrial Strategy (2020). *Green Book Supplementary Guidance: valuation of energy use and greenhouse gas emissions for appraisal.*
- Department for Energy and Climate Change (2015). *National Heat Map: Water Source Heat Map Layer*
- HM Treasury 2020], A Plan for Jobs 2020
- HM Treasury (2020). *Budget Report: Delivering our promises to the British People.*
- UK Parliament Publications and Records (2019). Energy efficiency, building towards net zero

- GOV.UK (2020). *Tax on shopping and services.* Available at: https://www.gov.uk/tax-on-shopping/energy-saving-products

Other

- BRE (2020). *Domestic Annual Heat Pump System Efficiency Estimator (DAHPSE).* Available at: https://www.bregroup.com/heatpumpefficiency/index.jsp
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- Planning Portal (2020). *Permitted Development Rights.* Available at: https://www.planningportal.co.uk/info/200187/your_responsibilities/37/planning_permission/2
- Regulatory Assistance Project (2020). *Heating without the hot air: principles for smart heat electrification*
- Tado (2020). Available at: https://www.tado.com/t/en/uk-homes-losing-heat-up-to-three-times-faster-than-european-neighbours/
- UK Green Building Council (2019). *Energy performance targets for commercial offices.*

Appendix 3: Abbreviations used in this report

Organisations

- BEIS: Department of Business, Energy and Industrial Strategy
- CCC: Committee on Climate Change
- GLA: Greater London Authority
- BRE; Building Research Establishment
- CIBSE: Chartered Institute of Building Services Engineers
- BSI: British Standards Institute
- ENA: Energy Networks Association
- MCS: Microgeneration Certification Scheme
- UKPN: United Kingdom Power Networks
- SSEN: Scottish and Southern Energy Networks
- MEEF: Mayor of London's Energy Efficiency Fund
- HNDU: Heat Networks Delivery Unit
- HNIP: Heat Network Investment Project
- UKGBC: United Kingdom Green Building Council
- DNO: Distribution Network Operator
- DEEP: Decentralised Energy Enabling Project
- RIIO Revenue using Incentives to deliver Innovation and Outputs
- LAEI: London Atmospheric Emissions Inventory

Technical abbreviations

- COP: Co-efficient of Performance
- SCOP: Seasonal Co-efficient of Performance
- SPF: Seasonal Performance Factor
- DAHPSE: Domestic Annual Heat Pump Efficiency – Estimator
- VRF: Variable Refrigerant Flow

- DSR: Demand Side Response
- Solar PV: Solar Photo Voltaic panels
- EPC: Energy Performance Certificate
- TEDI: Thermal Energy Demand Intensity
- EUI: Energy Use Intensity
- CCS: Carbon Capture and Storage
- ASHP: Air Source Heat Pump
- GSHP: Ground Source Heat Pump
- WSHP: Water Source Heat Pump
- HVAC: Heating, Ventilation and Cooling
- FCU: Can Coil Units
- HIU: Heat Interface Unit
- BMS: Building Management System
- CHP: Combined Heat and Power
- NO_x Nitrogen Oxides

Other

- RHI: Renewable Heat Incentive
- Non-Domestic RHI: Non-Domestic Renewable Heat Incentive
- RAG (Red, Amber, Green)
- BAU: Business as Usual
- VAT: Value Added Tax
- CAPEX: Capital Expenditure

Appendix 4: Contributors to this report

We would particularly like to thank the following people for their contribution to this research;

London Boroughs

- Richard Neal and Corin Freshwater-Turner; London Borough of Merton
- Nimish Shah and Marie Modeste, London Borough of Waltham Forest
- Waseem Ishaq, London Borough of Newham
- Sarah Butler, Royal London Borough of Greenwich
- James Davies, London Borough of Camden
- Neil Luscombe, London Borough of Brent

Heat pump manufacturers, installers and industry representatives

- Mark Hewitt, ICAX Heat Pumps Ltd
- Bean Beanland and Jen Billings, Ground Source Heat Pump Association / Heat Pump Federation
- Kevin Lucas, Hitachi Heat Pumps
- Dan Large, Solaris Energy Ltd
- Mark Barson, Vaillant Group
- Tony Nash, Vital Energi UK Ltd
- Robert Carter, Geothermique
- Ieman Barmaki and Karl Drage, Kensa Heat Pumps Ltd
- Tom Cattell, Alto Energy Ltd
- Brian Connell, GroundSun Ltd
- Peter Konowalczyc, Centrica
- Stuart Laughton, SL Services (Southern) / Nilan UK ltd
- Isaac Ochipinti, EUA
- Martyn Cooper, FETA
- Martin Wright, Purmogroup
- Mark Bornhoft, Eigen Ventures
- Graham Wright, Daikin Air conditioning UK Ltd / Heat Pump Association
- Dave Pearson, Star Renewable Energy

Caveat

The information provided in this report is provided in good faith based on the best available information at the time of writing. However, prices will invariably change and all parties investigating the installation of heat pumps will need to undertake their own market assessment and due diligence to establish costs and benefits specific to their building stock. Neither the Carbon Trust nor GLA bear any responsibility for decisions made as a result of information presented in this guidance which is clearly marked as indicative.

We have consulted extensively with heat pump manufacturers and installers regarding costs and system specifications. However, these are indicative costings and should not be regarded as exact predictions of cost for different system types. Furthermore, system specifications and costs can differ significantly depending on the individual circumstances of each buildings.

The choice of technologies used has been designed to show a range of possible routes to heat pump retrofit, but does not necessarily represent best practice in each case and does not constitute an endorsement of one system type or particular technology over another.

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