Department for
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Energy Innovation Research Office (EIRO): Air-to-Air Heat Pumps

Literature Review

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1 Executive Summary

Air-to-air heat pumps are a particular type of air source heat pump, with unique advantages and disadvantages compared to other types. Instead of working with radiators (as air-to-water heat pumps do), they work with air blower units, which can also provide cooling, dehumidification, air filtration and smart control of individual room temperatures. These additional functions could increase the appeal of switching from fossil fuel-based heating to heat pumps, however the cooling ability could also increase energy consumption in summer. Little data is available on energy demand for domestic cooling in the UK.

Air-to-air heat pumps do not currently benefit from all of the incentives that air-to-water heat pumps do, such as the Boiler Upgrade Scheme. They are also excluded from permitted development in the planning system, and considered as a ‘last resort’ in building regulations. They face different challenges from “monobloc” air-to-water heat pumps around the refrigerants that can be used, which may make it more difficult to use refrigerants with very low global warming potential, and comply with tightening standards on refrigerants.

Air-to-air heat pumps are widely used for domestic heating in some European countries, but are currently very niche in UK homes. They are often used in combination with other heating systems, such as electric resistive heaters in bathrooms, or wood burners. Case studies of domestic installations in the UK show that they tend to be installed to deal with poor thermal properties of a specific part of a house, such as an extension with a large glazed area, rather than as a whole-house replacement for the central heating system.

There are far more installers qualified to install air-to-air heat pumps in the UK (50,000) than air-to-water (estimated at 7,000, with rapid growth in recent years), due to the widespread use of air-to-air in commercial buildings.

Literature is limited and contradictory on the comparative installation costs, operating costs, and energy efficiency of air-to-air systems for heating compared to air-to-water, and further studies and trials would improve this understanding.

The literature makes some suggestions of housing archetypes which may benefit from choosing air-to-air rather than air-to-water, such as flats (particularly those prone to overheating), homes with high heat losses, and homes without existing radiator pipework (such as those using storage heaters). Further study to better understand which characteristics make homes especially well-suited to air-to-air heat pumps rather than air-to-water would be valuable.

The following research questions were answered:

- *What is the current UK deployment of air-to-air heat pumps?*

In 2014 it was estimated that there were around 220,000[1] air-to-air heat pumps in domestic settings in the UK. Based on UK sales between 2018 and 2022, it is estimated that this figure is now around 225,000. This is a best estimate based on the assumption that sales during the period for which data is not available (2015-2018) grew in a linear way. This figure does not consider lifespan of air-to-air heat pumps, and although this can be estimated, the profile of the original installations, and therefore the numbers of systems that will come to end of life each year, are unknown. In addition, as explained further in section 5.4, the sales data we have is not fully comprehensive of all air-to-air heat pump sales and is likely to be an underestimate.

- *What is the international picture on A2A HPs? In which countries are they widely used, what are the reasons for this, and how much of this evidence (e.g. housing characteristics, existing heating system types, energy costs, social norms etc) is relevant to the UK (both now and for a future scenario with warmer summers)?*

Air-to-air heat pumps are much more prevalent in countries including Norway, Finland and Sweden, where they account for 35%, 21% and 11% of primary heating systems respectively. One reason for the high rates in these countries is that many properties did not already have wet central heating systems installed, making air-to-air heat pumps more attractive to install, compounded by open plan architecture reducing the number of indoor units required.

We have also seen high rates of air-to-air heat pump sales in France, due to high rates of existing electric heating making it a favoured replacement along with financial support for installation, and in Italy, where there is a greater need for cooling. Another factor common to these countries is that the ratio of the price per unit of electricity to gas is lower than in the UK, incentivising the uptake of heat pumps more generally.

As climate change causes temperatures in the UK to increase and get closer to those in other countries such as France and Italy, we can expect increasing consumer demand for air-to-air heat pumps to avoid overheating in homes. Financial incentives through grants and increased parity between electricity and gas prices would also drive higher sales.

- *What evidence exists on examples of domestic A2A HP installations in the UK (e.g. in off-gas grid locations)?*

There are many examples of air-to-air heat pumps installed in a plethora of domestic properties in the UK, largely through manufacturer-published case studies. They have been effectively deployed in cases such as park homes, where there is no gas grid connection, and new build properties where they can be used to combat the risk of overheating. There does however appear to be a lack of large-scale trials to verify performance across property types that would allow more data to be gathered on user behaviour and real-world Seasonal Coefficients of Performance (SCOPs). Examples of installations found often address poor

[1] Eunomia Research and & Consulting Ltd., “RHI Evidence Report:,” Department of Energy and Climate Change, London, 2014.

comfort in a limited area of a home, rather than providing a whole-home primary heating system.

- *What are the main barriers to air-to-air heat pump uptake in UK homes (e.g. consumer understanding and behaviour)?*

Barriers to uptake in the UK include the high proportion of existing wet central heating systems, making air-to-water heat pumps the favoured solution. Additionally, limited grants are available for installation, meaning that air-to-water systems are favoured due to their inclusion in schemes such as the Boiler Upgrade Scheme (BUS). Finally, the higher unit cost of electricity compared to gas in the UK impacts the uptake of electrified heating solutions in general, including air-to-air heat pumps, as they do not generally deliver significant running cost savings compared with gas boilers, despite their higher efficiency.

- *What is the installer capacity and capability to install air-to-air heat pump systems in homes, and potential to scale up (including key threats to scaling up)?*

There are far more installers qualified to install air-to-air heat pumps in the UK (50,000) than air-to-water (7,000), due to the widespread use of air-to-air in commercial buildings. This presents a real opportunity to utilise the existing pool of F-gas installers to fit air-to-air heat pumps at pace in domestic settings. However, this capacity is likely to be in high demand from the commercial market.

2 Introduction

In 2019 the UK Government committed to achieving Net Zero carbon emissions by 2050. In the UK, domestic heating accounts for 18% of average household emissions[2] [3], therefore highlighting the need for decarbonisation in this area, to enable us to reach these Net Zero goals. Most of the emissions from domestic heating are due to natural gas boilers[4]; alternative sources of domestic home heating that produce lower greenhouse gas emissions must be employed.

Air-to-air heat pumps are a cost-effective and energy-efficient heating solution for homes and commercial buildings, however this study focuses solely on air-to-air heat pumps in domestic applications. These systems work by extracting heat from the outside air, even in cold weather, and transferring it directly to air indoors; they do not use water circulating inside a central heating system. However, the share of the UK domestic heat pump market attributed to reversible air-to-air systems remains much lower[5] [6] compared with that of air-to-water systems. Air-to-air and air-to-water heat pumps are both classified under the general umbrella of air-source heat pumps. Air-to-water systems work differently, by transferring heat from outside air into water that is transported around a building in pipework, before transferring the heat into rooms via heat emitters such as radiators or underfloor heating, otherwise known as a wet system.

One of the main advantages of air-to-air heat pumps is their versatility and ease of installation. They can be easily retrofitted into existing buildings without the need for extensive plumbing or major modifications. They also have the benefit of providing cooling during the summer months, acting as both a heating and air conditioning system.

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[2] Department for Energy Security and Net Zero, “Final UK greenhouse gas emissions national statistics: 1990 to 2021 - dataset of emissions by end user,” Department for Energy Security and Net Zero, London, 2023.
[3] Department for Energy Security and Net Zero, “Energy consumption in the UK 2022,” Department for Energy Security and Net Zero, London, 2022.
[4] Institute for Government, “Decarbonising heating at home,” Institute for Government, London, 2021.
[5] Nesta, “How the UK compares to the rest of Europe on heat pump uptake,” Nesta, London, 2023.
[6] Eunomia Research & Consulting Ltd, “Heat Pump Manufacturing Supply Chain Research Project,” Department for Business, Energy and Industrial Strategy, London, 2020.

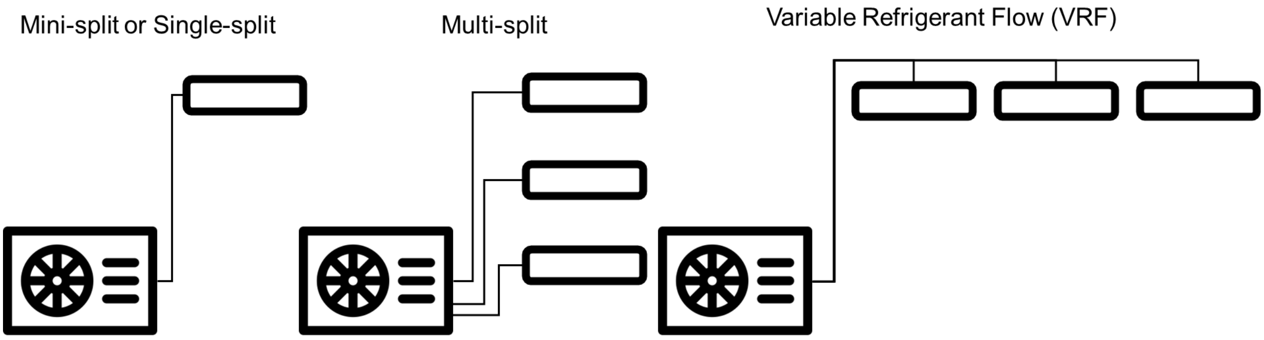
3 Technical overview of current UK market

Air-to-air heat pumps are commonly referred to in the UK as air conditioners, and they are a familiar technology in commercial premises; the “Cooling in the UK” report showed that around 95% of the reversible air-to-air heat pump market was attributed to non-domestic installations[7]. Reversible air-to-air heat pumps are the most common type, where ‘reversible’ refers to the fact they can be run in one direction to provide heating or reversed to provide cooling. As explained in the introduction, an air-to-air heat pump transfers heat from one air mass and expels it into another. It does this by utilising a Carnot refrigeration cycle, comprising an expansion valve, a condenser, an evaporator, a compressor, pipework connecting the components, and refrigerant travelling around the system. Both the condenser and evaporator act as heat exchangers.

3.1 Technology

There are three main types of air-to-air heat pump systems, not including systems that can also produce hot water:

- Mini-split, also known as single-split – An outdoor unit, connected to a single indoor unit, or cassette, connected by pipework transporting the refrigerant between the two.
- Multi-split – One outdoor unit is connected to two or more indoor units, or cassettes, connected by pipework that navigates to each indoor unit transporting the refrigerant.
- Variable Refrigerant Flow (VRF) – Numerous indoor units are connected to one outdoor unit, and they allow simultaneous cooling and heating with different indoor units. Generally, these systems are more suited to commercial settings such as offices[8].



Single-split, Multi-split and VRF System diagrams.

[7] AECOM, Delta-EE & University of Exeter, “Cooling in the UK,” Department for Energy Security and Net Zero, London, 2021.
[8] N. Enteria, O. Cuartero-Enteria and T. Sawachi, “Review of the advances of applications of variable refrigerant flow heating, ventilation, and air-conditioning systems for improving indoor thermal comfort and air quality,” International Journal of Energy and Environmental Engineering, vol. 11, pp. 459-483, 2020.

The outdoor unit houses the compressor, expansion valve, heat exchanger, fan, and associated electricals and components. The indoor unit, or cassette, contains a heat exchanger, fan and associated electrical controls and components[9].

The above types are known as 'ductless' systems. There is an additional type of system referred to as 'ducted' air-to-air heat pumps. These work in a similar way moving heat from one air mass to another, but the difference is that they use ducts to transport the heated, or cooled, air around the property, rather than having pipes transferring the refrigerant. Ducted systems are common in homes in North America, where centralised ducted systems account for 87% of heat pump systems installed in the US for space heating, followed by ground source and mini-split systems at 7% and 6% respectively[10]. This work focuses on whole property multi-split solutions, whereas a single split system would only provide heating or cooling to one room.

There are many manufacturers of air-to-air heat pumps that retail in the UK for the domestic market, but major players include: Mitsubishi, Samsung, Hitachi, Daikin, and Panasonic.[11]

Outdoor heat pump units are typically classified in terms of their heat output, stated in kilowatts (kW). The literature produced by the manufacturers shows that singular, multi split, outdoor units can range from as little as 3.3 up to 12 (kW) heating output, on a single-phase electricity supply. Larger outdoor units are available, but these would require a three-phase electrical supply, which is non-standard for typical domestic premises.

Table 1: Summary of data for outdoor air-to-air multi-split units by manufacturer

Manufacturer	Heating Min—max power (kW)*	Cooling Min—max power (kW)*	Max no. of indoor units
Mitsubishi[12]	3.3-11.6	3.2-12.1	6
Samsung[13]	4.2-12.0	4.0-10.0	5
Hitachi[14]	4.0-12	3.3-10	5
Daikin[15]	3.5-10	3.0-9.0	5
Panasonic[16]	4.4-6.8	4.1-5.2	3

*Nominal figures for power have been used

Vaillant manufactures multi-split systems, but they do not appear to retail on the UK market. Additionally, Panasonic has a smaller range available to the UK market than for the European market, likely due to demand.

[9] T. L. Collins and R. F. Petit, Sr, "Heat pumps - Operation, Installation, Service," Esco Press, Illinois, 2012.
[10] https://atlasbuildingshub.com/2023/08/18/2020-residential-u-s-heat-pump-market-update/
[11] Eunomia Research & Consulting Ltd, "Heat Pump Manufacturing Supply Chain Research Project," Department for Business, Energy and Industrial Strategy, London, 2020.
[12]https://les.mitsubishielectric.co.uk/products/air-conditioning/multi-splits/mxz-f-r32-inverter-heat-pump.
[13] https://samsung-climatesolutions.com/en-gb/b2c/products/fjm/outdoor.html
[14] https://www.hitachiaircon.com/uk/ranges/multi-splits/multizone-air-conditioning.
[15] https://www.daikin.co.uk/content/dam/document-library/catalogues/ac/split/Split%20installer%20catalogue_ECPEN20-000_Catalogues_English.pdf.
[16] https://www.aircon.panasonic.eu/_____/product/multi-wall-tz-r32/.

In terms of the range of efficacy of the outdoor units, a review of the literature found that the minimum operating temperature for all the units was -15°C and -10°C for heating and cooling respectively, while the maximum operating temperature across the range of manufacturers was +24°C and +46°C for heating and cooling respectively. In comparison, air-to-water heat pumps generally have a stated operating range for heating of between -20°C and +35°C, but literature could not be found comparing the performance of the two types of heat pump across the temperature ranges. According to data from the Met Office on UK temperatures, there have been many occasions when temperatures have dropped below -15°C[17], outside of the operating range of the models reviewed, although these events have decreased in frequency over the last ten years and are limited to typically colder regions in Scotland. The highest recorded temperature in the UK is 40.3°C[18], well within the operating maximum. Overall, the occurrence of temperatures in the UK deviating from the operating range of air-to-air heat pumps is likely to be minimal but must be considered by installers to ensure that appropriate back up heating is in place.

All the units summarised in Table 1 above use R32 refrigerant, which is classified as a hydrofluorocarbon (HFC) due to its chemical composition including hydrogen, fluorine and carbon[19]. HFCs sit under the general umbrella of 'F-gases', and in the atmosphere act as greenhouse gases with global warming potential (GWP) much higher than that of CO_2[20]. R410A is an HFC refrigerant that started to be used by manufacturers around 2006, chosen to replace other refrigerants such as R407C because it offered higher efficiencies[21]. R32 is used as a replacement to R410A, due to its lower GWP at 675 compared with 2088[22]. From 1st January 2025, UK F-Gas regulations will ban the use of refrigerants with a GWP of more than 750 in single split systems that contain less than 3kg of refrigerant, although R32 still able to be used, hence why manufacturers have transitioned away from R410A[23]. European Union rules differ, where they have announced that split air conditioning and heat pumps less than 12kW must use refrigerants with GWP less than 150 from 2027, while systems greater than 12kW can continue to use refrigerants with GWP greater than 150 until 2032. Split heat pumps and air conditioners containing F-gases will be banned from 2035[24].

An alternative refrigerant that is increasing in prevalence is Propane or R290, due to its lower GWP of 3[25]. F-Gas regulations in the EU are due to change again as it has been provisionally decided that the consumption of HFCs will be phased out by 2050, although it is not clear if this will be adopted into UK law, with a review being conducted by the Department for Environment, Food and Rural Affairs (DEFRA)[26]. Phase-out of HFCs would mean a ban on the use of R32, so other refrigerants, such as R290, would have to be employed. Currently, none

17 https://blog.metoffice.gov.uk/2021/02/11/record-low-temperature-for-the-uk-this-millennium/.
18 https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-extremes.
19 https://www.gov.uk/guidance/fluorinated-gases-f-gases#hfcs.
20 Climate Change Committee, "The Sixth Carbon Budget - F-Gases," Climate Change Committee, London, 2020.
21 https://les.mitsubishielectric.co.uk/the-hub/whychangetor32
22 https://www.gov.uk/guidance/fluorinated-gases-f-gases#hfcs.
23 Department for Environment, Food and Rural Affairs, "F gas regulation in Great Britain," Department for Environment, Food and Rural Affairs, London, 2022.
24 https://www.consilium.europa.eu/en/press/press-releases/2023/10/05/fluorinated-gases-and-ozone-depleting-substances-council-and-parliament-reach-agreement/
25 https://www.agas.com/au/products-services/refrigerants/r290/.
26 https://wave-refrigeration.com/unpacking-the-new-eu-f-gas-regulation/.

of the manufacturers explored in Table 1 offer air-to-air heat pumps with R290 for the UK market, which aligns with a report by DEFRA that found limited uptake in Great Britain[27], although air-to-water heat pumps using this refrigerant are available[28]. Air-to-water heat pumps installed in the UK are mainly monobloc in type, with the refrigerant sealed and contained in the outdoor unit, but split air-to-air heat pumps have indoor units that share the refrigerant with the outdoor unit. R290 is highly flammable and is heavier than air, meaning that a leak could go undetected, building up in unventilated voids which can result in the risk of explosion. The challenges of using R290 as a refrigerant are discussed further in section 3.1.3.

While the outdoor unit is important to extract heat from the external air, the indoor unit is equally important to the system in transferring that heat to the internal air. As summarised in Table 1, Mitsubishi offers an outdoor unit that can be connected to the greatest number (six) of indoor units. Manufacturers offer a range of indoor units that can be paired with their available multi-split outdoor units, and most offer units that can be floor-, wall- or ceiling-mounted. A mixture of different types of indoor units can be used in a system to enable flexibility according to needs and to match to aesthetic requirements. However, units do not just differ in how they are mounted or how they look; they range in heating output and in-built features such as multi directional outlets, smart controls, or movement sensors. Most indoor units also feature some form of air filtration, which can range from particulate filtration through to odour removal, depending on the technical specification of the model chosen.

3.1.1 Control, User Experience and Consumer Appeal

The integration of smart technology in air conditioning systems has increased in prevalence. Smart thermostats and control systems allow users to manage and monitor their home's temperature remotely, contributing to energy, and thus cost, savings.

A study into energy use in homes found that up to 39% of energy use in a home was wasted, with the majority attributed to heating or cooling unoccupied rooms, or overcooling or overheating to achieve comfort[29]. One common feature of several indoor units is motion detection to identify when rooms are unoccupied, which will shut off the indoor unit, saving energy. Similarly, many indoor units have inbuilt smart thermostat controls, allowing the user to operate the unit remotely from their mobile device, changing the target temperature and settings, and setting up programmes. All of the manufacturers studied for this research had their own mobile application that links the user's mobile device to their air-to-air heat pump via Wi-Fi. The inclusion of this smart technology in air-to-air pump systems is reported to provide energy savings of between 11-12%[30] [31].

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[27] Department for Environment, Food and Rural Affairs, "F gas regulation in Great Britain," Department for Environment, Food and Rural Affairs, London, 2022.
[28] https://les.mitsubishielectric.co.uk/products/residential-heating/outdoor/ecodan-r290
[29] R. J. Meyers, E. D. Williams and H. S. Matthews, "Scoping the potential of monitoring and control technologies to reduce energy use in homes," Energy and Buildings, vol. 42, pp. 563-569, 2010.
[30] Nest Labs Inc., "Energy savings from Nest: The impact of Nest learning thermostat," Nest Labs Inc., Palo Alto, 2014.
[31] A. Beizaee, D. Allinson, K. Lomas, E. Foda and D. Loveday, "Measuring the potential of zonal space heating controls to reduce energy use in UK homes: The case of un-furbished 1930s dwellings," Energy and Buildings, vol. 92, no. 1, pp. 29-44, 2015.

Studies conducted into the use of smart thermostats and controls – both wall mounted and handheld (usage differences between these types were not explored) – have shown that while most users engage with the devices, setting up schedules that closely match their occupancy patterns to save energy, there are occasions where users have issues preventing efficient use of the system[32]. Combe et al.[33] explains that numerous studies had found that older people tend to struggle with smart technology and therefore will be less able to use the technology. However, the indoor units do always come with a more traditional infrared remote control that they may prefer to use.

Little research was available looking specifically at user satisfaction with domestic air-to-air heat pump installations in the UK, but research was found relating to heat pumps more broadly, both air-source and ground-source. However, work by YES Energy installing air-to-air heat pumps in 30 park homes with elderly and vulnerable residents, found that users reported that properties heated up more quickly than with previous fossil fuel or electric systems, and that homes were warmer and more comfortable[34].

Noise is often a concern reported with respect to air-source heat pumps. Although a report by Eunomia[35] did not explicitly gather opinions on noise levels from air-to-air heat pumps, air-to-air and air-to-water heat pumps have common components in their outdoor units. Indeed manufacturer literature shows they have very similar levels of noise in terms of sound pressure level and sound power level. Therefore, they are comparable in terms of outdoor noise. Most heat pump users (85%[35]) were satisfied with noise levels from their heat pump, although it should be noted that this includes both ground-source and air-source installations, while satisfaction regarding noise with gas boilers was only marginally higher, at 90%. Additionally, the survey only looked at noise as a whole and did not attempt to make a distinction between noise that might be created by the indoor unit and that created by the outdoor unit. Further work is needed to understand satisfaction with noise from air-to-air indoor units specifically.

Unfortunately, no literature could be found looking specifically at noise from air-to-air heat pumps but a review and research by WSP[36] found that the majority of consumers were happy with noise levels from air-source heat pumps, levels of noise complaints regarding them were low, and that problems with noise were generally the result of quality of installation which could be easily resolved.

The ability to control individual indoor units, whether via smart phone app or remote control, means that users can easily heat or cool a single room in a property and could be of particular benefit to elderly residents. Nearly half of those over 65 live alone[37] and 57% of those over 65

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[32] L. Miu, C. Mazur and K. Dam, “Going smart, staying confused: Perceptions and use of smart thermostats in British homes,” Energy Research & Social Science, vol. 57, 2019.
[33] N. Combe, D. Harrison and H. Dong, “Designing Technology for older people - the role of technical self-confidence in usability of an inclusive heating control,” in Design, User Experience, and Usability: User Experience in Novel Technological Environments, Las Vegas, 2013.
[34] YES Energy Solutions, “Heat Pumps for Park Homes,” National Energy Action, Newcastle Upon Tyne, 2017.
[35] Eunomia Research and Consulting, “Heat pumps: a user survey,” Nesta, London, 2023.
[36] WSP, “Review of Air Source Heat Pump Noise Emissions, Permitted Development Guidance and Regulations,” Department for Energy Security and Net Zero, London, 2023.
[37] https://commonslibrary.parliament.uk/research-briefings/cbp-9239/

under-occupy their home[38], representing an opportunity for energy and cost savings if they had an air-to-air heat pump installed. While it is also possible to do this with a traditional wet system, connected with an air to water heat pump, ground source heat pump or gas boiler, each individual thermostatic radiator valve would need to be adjusted. Some experts advise against closing radiator valves in unused rooms because a reduction in system volume and higher heat loss, from heated to unheated rooms, means that performance and efficiency are reduced, increasing costs[39]. This limitation of not being able to close off valves to prevent heating or cooling unoccupied rooms does not apply to air-to-air heat pump systems. It should be noted that smart thermostatic valves are also available on the market with features such as motion sensing and remote operation, which could be retrofitted to existing wet systems to achieve some of these benefits.

3.1.2 Installation

Proper installation of a heat pump, according to the manufacturer's installation instructions, is imperative to ensuring its smooth and efficient operation. As with all heat pumps, the installation of an air-to-air system is likely to cause some disruption to occupiers and will require surveys and visits before installation takes place. Air-to-air heat pumps can be easily retrofitted into existing properties, and because of their lack of reliance on a wet central heating system, could be retrofitted into a property while a wet central heating system is still in situ. This could be particularly useful in circumstances where installation is taking place during colder periods and there are vulnerable customers who cannot go without heating.

As with the installation of an air-to-water system, there will be some disruption to occupiers where an installation is taking place to allow indoor units to be mounted, pipework installed, an external unit mounted and associated wiring. If installed in a dwelling where there is already a wet central heating system installed, then it is likely that occupiers would want this to be removed. This would cause some disruption to the resident with the potential for floorboards taken up to allow pipework to be removed, flooring such as carpets or wooden flooring replaced where pipework transited through, and redecoration following the removal of radiators. However, because the indoor units are generally mounted at higher level, occupiers may benefit from additional space where radiators are removed. Current energy saving advice is that a gap should be left between furniture and radiators[40], with some radiator manufacturers stating that this should be as much as 60cm to ensure circulation of heat[41].

The Cost-Optimal Domestic Electrification (CODE) project[42] noted that a significant advantage of air-to-air heat pumps was that radiators are not required in their installation, driving down capital costs, whereas with air-to-water installations these radiators would often need to be replaced and upgraded. However, Lowes[43] explains that pipework needs to be run to connect

[38] Department of Levelling Up, Housing and Communities, "English Housing Survey: Older people's housing 2022-21," Department of Levelling Up, Housing and Communities, London, 2022.
[39] https://www.heatgeek.com/stop-turning-off-radiators-in-unused-rooms-it-costs-more/
[40] https://energysavingtrust.org.uk/quick-tips-and-home-improvements-to-help-you-heat-your-home-for-less/
[41] https://www.theradiatorcentre.com/blog/article/26/3-steps-to-placing-your-radiator.
[42] Cambridge Architectural Research, "Cost-Optimal Domestic Electrification (CODE)," BEIS, London, 2021.
[43] R. Lowes, "Blowing hot and cold: Reflecting the potential value of air-to-air heat pumps in UK energy policy," REGULATORY ASSISTANCE PROJECT (RAP), Brussels, 2023.

the outdoor unit to the indoor unit and that this can still be disruptive, much like with a wet central heating system.

As explained in a report by Nesta[44], rates of air-to-air heat pump installations in most European countries are much higher than in the UK. One common reason for this is that most buildings in countries such as Finland, Norway and Sweden do not have wet or hydronic heat systems already installed. Lowes[45] notes that the UK has lots of wet systems already installed, so the more natural option is to go with air-to-water. However, as noted above, lots of hydronic systems must be upgraded, pipework replaced, and radiators increased. As explained by Rosenow[46], the open plan nature of the architecture in Nordic countries makes the installation of air-to-air heat pumps more attractive, reducing the number of individual indoor units required. Air-to-air heat pumps are often still used in conjunction with other heating sources, such as in Norway, where households continued to use wood fired stoves[47], and Finland where they are used alongside direct electric heating[48]. As explained by Rosenow, the majority of Finnish properties with heat pumps are singular installations, although there are a minority of cases where more than one heat pump is installed for a single building. Unfortunately, no information could be found about singular vs multiple heat pumps in other countries or how multiple heat pumps are used, for example to heat different floors.

The outdoor components of air-to-air heat pumps are very similar in appearance and installation requirements to those of air-to-water. This makes air-to-air equally well suited to properties where the installation of ground source heat pumps is impractical or cost prohibitive. As with air-to-water, clearance must be left around the outside unit to allow airflow; a review of the manufacturer literature has found that this could be up to $10m^2$ [49]. Air-to-air heat pumps therefore do not offer an advantage, in terms of space requirements, over air-to-water heat pumps in properties where there is limited external space. Additionally, the heaviest outdoor unit found in the literature was 87kg and appropriate structural calculations would need to be completed, particularly when mounting it to external walls. Challenges of wall mounting units are also faced when installing air conditioning units for cooling alone. Currently, little work has been done to investigate how such installations would be received by users and communities.

Permitted development only applies to heat pumps used solely for heating, therefore reversible air-to-air heat pumps require planning permission, unlike most air-to-water heat pumps that only provide heating and come under permitted development [50]. As explained by the Energy Networks Association[51], approval may be needed from the relevant Distribution Network Operator (DNO), particularly for higher power installations, and may require resulting works

[44] Nesta, "How the UK compares to the rest of Europe on heat pump uptake," Nesta, London, 2023.
[45] R. Lowes, "Blowing hot and cold: Reflecting the potential value of air-to-air heat pumps in UK energy policy," REGULATORY ASSISTANCE PROJECT (RAP), Brussels, 2023.
[46] https://www.carbonbrief.org/guest-post-how-heat-pumps-became-a-nordic-success-story/.
[47] T. Winther and H. Wilhite, "The use of heat pumps in Norwegian homes: Accounting for the comfort rebound effect," Centre for Development and the Environment (SUM) - University of Oslo, Oslo, 2014.
[48] https://stat.fi/uutinen/lampopumppujen-kaytto-lisaantynyt-oljy-painumassa-marginaaliin
[49] https://les.mitsubishielectric.co.uk/products/air-conditioning/multi-splits/mxz-f-r32-inverter-heat-pump.
[50] https://www.legislation.gov.uk/uksi/2015/596/schedule/2/part/14/crossheading/class-g-installation-or-alteration-etc-of-air-source-heat-pumps-on-domestic-premises/made.
[51] https://www.energynetworks.org/industry/connecting-to-the-networks/connecting-electric-vehicles-and-heat-pumps.

such as fuse upgrades or de-looping. This constraint of DNO approval, however, applies to all types of heat pumps and work on the Electrification of Heat Demonstration project found that there could be significant delays in decision making with some DNOs[52]. Therefore air-to-air heat pumps do not offer any significant advantages when it comes to connections to electrical networks.

Unlike air-to-water heat pumps, air-to-air heat pumps are not currently included under the government Boiler Upgrade Scheme (BUS)[53]. A requirement of the BUS is that units must be installed using a Microgeneration Certification Scheme (MCS) installer, but since air-to-air heat pumps are not included, this does not apply. The Microgeneration Certification Scheme (MCS) does have acceptance criteria for air-to-air heat pumps[54], however, no air-to-air heat pumps are currently listed under the product directory[55].

3.1.3 Challenges

There are several challenges around the deployment of air-to-air heat pumps. Firstly, as is well documented in the industry including a report by Nesta[56], and highlighted in a House of Commons report[57], there is a skills shortage in the sector that threatens government targets for heat pump installations of all types. To compound this general skills shortage, installers of air-to-air systems must be F-Gas registered to install the pipework containing the refrigerant that will be transported between the outdoor and indoor units, and not all installers have this qualification[58]. In contrast, the most common type of air-to-water heat pump installed in the UK is a monobloc unit; since the refrigerant is contained within the monobloc unit, F-Gas trained engineers are not required to install these systems.

As explained by Ian Bevan of Daikin UK, there is already a pool of F-Gas installers, many of these operating in the commercial air conditioning market[59], although estimates are that this needs to double to service the expanding commercial market alone[60]. Bevan goes on to explain that skills need to be developed that could allow more split systems, such as air-to-air heat pumps, to be installed. Additionally, there is a range of training courses available, delivered by different training providers to suit the range of activities installers could be involved in and the range in sizes of systems[61]. A category 1 certificate usually takes 5 days to complete and enables those with no prerequisite qualifications to become legally entitled to install F-gas equipment and carry out all activities[62]. Analysis by Nesta shows that in 2022

[52] https://es.catapult.org.uk/report/electrification-of-heat-home-surveys-and-install-report/
[53] https://www.ofgem.gov.uk/environmental-and-social-schemes/boiler-upgrade-scheme-bus/installers.
[54] https://mcscertified.com/wp-content/uploads/2021/10/MCS-007.pdf
[55] https://mcscertified.com/product-directory/
[56] Nesta, "How to scale a highly skilled heat pump industry," Nesta, London, 2022.
[57] Business, Energy and Industrial Strategy Committee, "Decarbonising heat in homes," House of Commons, London, 2022.
[58] Eunomia Research & Consulting Ltd, "Heat Pump Manufacturing Supply Chain Research Project," Department for Business, Energy and Industrial Strategy, London, 2020.
[59] https://www.racplus.com/news/refrigeration-contractor-skills-seen-as-crucial-for-uk-heat-pump-growth-12-12-2022/.
[60] https://www.cibsejournal.com/general/commercial-heat-pumps-the-default-solution/.
[61] https://www.gov.uk/guidance/qualifications-required-to-work-on-equipment-containing-f-gas.
[62] https://www.cityandguilds.com/qualifications-and-apprenticeships/building-services-industry/refrigeration-and-airconditioning/2079-f-gas-and-ods-regulations#tab=information&acc=general-info.

there were only around 4,000 hydronic heat pump installers, dwarfed by F-gas installers who number around 50,000[63]. Data from the Heat Pump Association shows that 8,000 hydronic heat pump installers became qualified in 2023, indicating a dramatic increase since the Nesta analysis, although there is uncertainty around how many of those who have completed training are now practicing in the trade[64]. It appears that there is real opportunity to utilise the existing pool of F-gas installers to fit air-to-air heat pumps at pace in domestic settings, although there may be increased demand from the commercial sector which could prevent this.

If the UK were to do the same as the EU in banning F-Gases, or reducing GWP limits further, then alternative refrigerants would be needed. As discussed in section 3.1, R290 (propane) is a promising alternative to R32 with a low GWP, however, high flammability of this refrigerant is a concern. BS EN IEC 60335-2-40:2023+A11:2023 is the product safety standard governing maximum refrigerant charge, which was recently updated and the maximum limit for R290 charge increased to 988g, allowing ~13kW of heating or cooling [65]. Additional safety steps including design measures to ensure resistance of components to heat, limiting the potential size of leaks, the use of safety valves, and ensuring adequate airflow have all been introduced[66]. Monobloc air-to-water systems using R290 have an advantage over air-to-air units in this regard because the refrigerant stays outside the property, thus reducing the level of risk which needs to be mitigated through safety measures mentioned above. In an article by Bob Cowlard, Managing Director for Haier – a manufacturer of heat pumps – he explains why R290 needs to be brought under the F-Gas regulations, stating: “I am perfectly in tune with the decision to develop products that use R290 as a low GWP alternative but as it is not covered by any legislation for those working with it, the consequences could be dire”[67].

3.1.4 Novel Technologies

There has been continued innovation in air-to-air heat pump technology including improvements in energy efficiency, through changes in refrigerant and changes to physical components, and the inclusion of smart technology as discussed above. This innovation continues and there are several novel technologies that are currently emerging, although they may be some way from being commercially available.

One focus of development for air-to-air heat pumps is around separating cooling and dehumidifying operations, standard air-conditioning systems do both simultaneously causing inefficiency. Desiccant is used in some newer air-to-air heat pumps to perform dehumidification before cooling and Transaera has developed technology to recharge the desiccant using recycled heat, achieving energy savings of up to 35% compared with standard air-to-air heat pumps[68]. Research and development has also been undertaken around using evaporative cooling in air-to-air heat pumps as an alternative to vapour compression. Harvard University’s cold Superhydrophobic Nano-Architectured Process (cSNAP) team has developed a technology using evaporative cooling, which does not require refrigerants and claims to be

63 https://www.nesta.org.uk/blog/how-air-conditioning-could-help-us-tackle-climate-change/.
64 https://www.heatpumps.org.uk/166-increase-in-qualified-heat-pump-installers/
65 https://www.cibsejournal.com/cpd/modules/2023-12-prhpac/
66 https://etech.iec.ch/issue/2022-03/much-awaited-new-iec-standard-on-refrigerants
67 https://www.acrjournal.uk/heat-pumps/time-to-act-on-r290/ .
68 https://www.technologyreview.com/2023/07/26/1076731/materials-air-conditioning/

75% more efficient than traditional air-to-air heat pumps[69]. However, neither the Transaera nor cSNAP solutions are yet commercially available, but could provide significant cost and energy savings if deployed at scale.

Advancements are also being made in the use of heat pumps using semiconductor cooling. Numerous studies have been undertaken testing the deployment of this technology as summarised by Greco et al.[70] Most notably Johra et al.[71] employed the technology in a residential setting achieving a COP of between 2.9 and 3.51, although the system was employed with a ground source heat exchanger and underfloor heating. Therefore more investigation is required in an air-to-air configuration in residential settings.

The ActiveWall air-to-air heat pump[72] is vastly different to the traditional air-to-air heat pumps described above, as it does not contain refrigerant and is solid state, meaning that there are no moving parts. The system is a wall integrated heat pump, therefore there is no pipework, indoor or outdoor unit. According to the manufacturers of the system, the performance of the system is comparable to that of other heat pump systems, with COP of 5.0, and comparable capital cost at ~€7-10k, although savings may be made in other building costs. The system does not, however, lend itself to retrofit, which would require the costly and impractical replacement of walls to enable installation. The technology is not yet commercially available and still in an experimental phase.

3.2 Energy efficiency and measuring system performance

Energy efficiency and environmental considerations are important factors in the selection of heat pumps and consumers are increasingly looking for systems that are energy-efficient and environmentally friendly. Air-to-air heat pumps are highly energy efficient and they work by using a small amount of electricity to operate the compressor, with most of the heating or cooling provided by the extracted heat from the outside air, making them a greener alternative to traditional heating systems that rely on burning fossil fuels.

Heat pump efficiency is measured and expressed in terms of the Coefficient of Performance (COP) and is a ratio of heat output over electrical power input, with a higher COP indicating higher efficiency. COP is affected by several factors such as the temperature of the heat source and therefore can vary throughout the year[73]. COP refers to use of the unit for heating while the Energy Efficiency Ratio (EER), calculated in the same way, refers to use for cooling.

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[69] https://wyss.harvard.edu/technology/eco-friendly-air-conditioning/
[70] A. Greco, C. Aprea, A. Maiorino and C. Masseli, "A review of the state of the art of solid-state caloric cooling processes at room-temperature before 2019," International Journal of Refrigeration, vol. 106, pp. 66-88, 2019.
[71] H. Johra, K. Filoneko, P. Heiselberg and C. Veje, "Integration of a magnetocaloric heat pump in an energy flexible residential building," *Renewable Energy,* vol. 136, pp. 115-126, 2019.
[72] https://www.sainttrofee.nl/topics/heat-pumps/activewall-heat-pump/development/activewall-heat-pump-technology/
[73] Joint Research Centre, "The Heat Pump Wave: Opportunities and challenges," European Commission, Luxembourg, 2023.

3.2.1 Seasonal Coefficient of Performance

Because ambient temperatures vary throughout the year, affecting the COP, the Seasonal Coefficient of Performance (SCOP) is often used instead as a measure to compare heat pumps, indicating their performance over time. It is calculated over an entire heating season and considers variations in external temperatures. The SCOP is expressed as a ratio of the heat output to the electricity input, and across air-to-air heat pumps can vary based on the specific model, technology, and manufacturer. Within the European Union and UK, minimum efficiency requirements must be met under the Ecodesign directive, meaning that the SCOP of units must be at least 3.4[74].

How SCOP is measured is extremely important and this is set out under EN14825. As explained by Rasmussen[75], the heating season is divided in terms of time between different temperatures to reflect temperatures across the season, and a heating demand curve is created. This is done based on three climate zones, although only the average climate zone is required under the standard. Testing under EN14825 is completed by manufacturers and declared in equipment documentation; a summary of SCOP values across manufacturers is presented in Table 2, alongside SCOP values for air-to-water units of the same manufacturers.

As explained by Lowes[76], the SCOP for air-to-air systems cannot be directly compared with that of air-to-water systems because the SCOP figure for air-to-water systems includes hot water production, which generally achieves lower efficiency than space heating. Work by Garcia-Cespedes et al.[77] explains that ground source heat pump installations can perform up to 50% more efficiently than air source heat pumps, both air-to-water and air-to-air. However, an evidence review by the Climate Xchange across heat pumps installed in Scotland found a range of in situ SCOPs, with both ground source and air source heat pumps spanning SCOP values from 1.2-4.5, with no clear front runner. No information could be found on field trials looking specifically at comparing in situ performance of air-to-air and air-to-water heat pumps directly. Field trials in the UK with air-to-air heat pumps have been limited, although they have been conducted, such as the trial conducted by YES Energy installing air-to-air heat pumps in 30 park homes[78], although SCOP values were not presented. A review by Stignor et al[79], of studies which installed air-to-air heat pumps in Sweden, found that real world SCOP values ranged from 2.0-5.0. No other in-situ data could be found, a problem also noted by RAP[80].

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[74] The European Commission, COMMISSION REGULATION (EU) No 206/2012: ecodesign requirements for air conditioners and comfort fans, Brussels: Official Journal of the European Union, 2012.
[75] P. Rasmussen, “Calculation of SCOP for heat pumps according to EN 14825,” Danish Technological Institute, Taastrup, 2011.
[76] R. Lowes, “Blowing hot and cold: Reflecting the potential value of air-to-air heat pumps in UK energy policy,” REGULATORY ASSISTANCE PROJECT (RAP), Brussels, 2023.
[77] J. Garcia-Cespedes, G. Arno, I. Herms and J. Felipe, “Characterisation of efficiency losses in ground source heat pump systems equipped with a double parallel stage: A case study,” Renewable Energy, vol. 147, no. 2, pp. 2761-2773, 2020.
[78] YES Energy Solutions, “Heat Pumps for Park Homes,” National Energy Action, Newcastle Upon Tyne, 2017.
[79] C. H. Stignor and T. Walfridson, “Nordsyn study on air-to-air heat pumps in humic Nordic climate,” Nordic Council of Ministers, Copenhagen, 2019.
[80] R. Lowes, “Good COP/Bad COP: Balancing fabric efficiency, flow temperatures and heat pumps,” REGULATORY ASSISTANCE PROJECT, Brussels, 2022.

3.2.2 Seasonal Energy Efficiency Ratio

As with COP, the EER describes the performance of the unit at a snapshot in time, so instead the Seasonal Energy Efficiency Ratio (SEER) is often used to compare products. This SEER is a measure of the total cooling output of a heat pump over a cooling season divided by the total electrical energy input during the same period. It should be noted that in the UK and Europe both SEER and EER are calculated, according to legislation[81], using kilowatt-hours (kWh), while in the US the calculation uses British Thermal Units (BTU) divided by watt-hours (Wh), thus producing slightly different results.

As with SCOP, the Ecodesign regulation also applies, which stipulates that the SEER of a unit must be at least 3.6[82]. SEER ratings declared by several manufacturers are presented in Table 2.

3.2.3 Energy labelling

In the UK and Europe, there are energy labelling requirements for air conditioners, and products are classified based on their energy efficiency using a scale from A+++ to G, with A+++ being the most efficient. The requirements for this and a table showing the relationship of SEER and SCOP to seasonal energy labelling are in legislation[83]. The energy label also contains information about noise, both internal and external, and the power rating of the unit in kilowatts. A study by the CentERdata consortium, looking at consumer understanding of energy labelling of heat pumps, found that while most respondents understood the labelling, they struggled to compare units that had the same energy labelling but different SCOP or SEER[84]. This highlights the need for advice and guidance from installers when consumers are selecting the appropriate system.

Table 2: Summary of the range of SCOP and SEER values for outdoor multi-split units found in manufacturer literature

SCOP	SEER	Seasonal Energy Labelling – Heating	Seasonal Energy Labelling – Cooling
3.8-4.8	4.9-8.7	A – A++	B— A+++

3.2.4 Total energy use

Along with seasonal energy labelling, on the scale from A+++ to G, manufacturers must also indicate the anticipated energy use across the year, displayed in kilowatt hours per annum (kWh/a), and is calculated using the EN14825 standard method. A review of manufacturer data found that total energy consumption per annum ranged from 944-2438 and 189-559 (kWh/a), for heating and cooling respectively. The range in numbers reflects the range in size of

[81] https://www.legislation.gov.uk/eur/2011/626/2017-03-07?view=plain.
[82] The European Commission, COMMISSION REGULATION (EU) No 206/2012: ecodesign requirements for air conditioners and comfort fans, Brussels: Official Journal of the European Union, 2012.
[83] https://www.legislation.gov.uk/eur/2011/626/2017-03-07?view=plain.
[84] CentERdata consortium, “Study on consumer understanding of the energy label for air conditioners and heat pumps ≤ 12 kW,” European Commission, Brussels, 2018.

systems and number of units connected, while the cooling period is shorter producing lower figures. Although there is some literature around air-to-air heat pump use in the UK, no figures for total annual energy use based on in situ units could be found.

A report by Kirsten et al.[85] that looked at energy savings from the replacement of heating systems with air-to-air heat pumps in Denmark found that energy savings were not as high as expected due to changes in user behaviour, and some of the reduction in electricity consumption converted into an increase in comfort. However, the work did overrepresent older people (which could have skewed usage behaviour data) and looked at electricity consumption of the whole house without considering hot water or changes to hot water production. The work did still find a reduction in energy consumption of 26%, compared with the expected 32%, for permanently occupied dwellings that moved from direct electric heating to air-to-air heat pumps. It is also not clear if the air-to-air heat pumps in the study had any of the smart control functions mentioned in section 3.1.1. The study goes on to recommend that this ‘rebound effect’ should be factored into future energy planning.

3.2.5 Alternative methods and challenges

As explained by Eguiarte et al.[86], the conditions of EN14825 cannot be replicated in installations in the field, therefore lower SCOP and SEER values are often realised by users. This could be due to a longer pipework run than that used by the manufacturer for testing and of course, ambient conditions will also affect the performance of the system. Estimates for real world performance of air-to-air heat pumps placed SCOP at 2.8[87] and SEER at 3.0[88], in reports by Delta EE and Arup respectively, vastly below the minimum standards set out under the Ecodesign directive. However, it should be noted that there have been significant improvements in performance in recent years. As an example the real-world SCOP of air-to-water heat pumps was found to be ~2.65 in 2017, but in more recent work published in 2023 SCOP was found to be ~2.94[89], indicating the sort of increase in air-to-air heat pump SCOP that could have taken place.

Several pieces of work including Tran et al.[90] and Gustafsson et al.[91] suggest alternative in-situ test methods that produce more reliable results than those of EN14825. Work by Tran et al uses an energy balance method, verified through intrusive refrigerant measurements, while work by Gustafsson et al. uses a compensation method and factors in the control of the heat

[85] G.-H. Kirsten, T. H. Christensen and P. E. Petersen, “Air-to-air heat pumps in real-life use: Are potential savings achieved or are they transformed into increased comfort?,” Energy and Buildings, vol. 53, pp. 64-73, 2012.
[86] O. Eguiarte, A. Garrido-Marijuan and P. d. Augustin-Camacho, “Energy, Environmental and Economic Analysis of air to air heat pumps as an alternative to heating electrification Europe,” Energies, vol. 13, no. 15, 2020.
[87] Delta-ee, “The Contribution of Reversible Air-to-air heat pumps to the UK's Obligation under the Renewable Energy Directive,” Department for Business Energy and Industrial Strategy, London, 2017.
[88] Arup, “Addressing overheating risk in existing UK homes,” Climate Change Committee, London, 2022.
[89] Energy Systems Catapult, “Electrification of Heat Demonstration Project - Interim Insights from Heat Pump Performance Data,” Energy Systems Catapult Limited, Birmingham, 2023.
[90] C. Tran, D. Noel, P. Riviere, C. Arzano and D. Marchio, “In-situ method for air-to-air heat pump seasonal performance determination including steady-state and dynamic operations,” International Journal of Refrigeration, vol. 127, pp. 239-249, 2021.
[91] O. Gustafsson, E. Lindeblom, T. Walfridson, A. Folk and C. Stignor, “Alternative test methods, declaration of capacity and test of heat pumps in multiple climate zones,” Nordic Council of Ministers, Copenhagen, 2020.

pump, unlike EN14825 that uses locked frequencies. Work by Palkowski et al.[92] does not aim to increase the reliability of results but did find that EN14825 could be modified to include only 2 test points, achieving comparable results, and reducing testing time and thus cost. The findings of these pieces of work should be considered in any review of the standard but until that takes place, this gap between stated and real-world performance should be considered by installers, with contingency built into calculations, and factored into planning by DNOs.

3.3 OPEX Costs

Analysis by the International Energy Agency shows that air-to-air and air-to-water systems have very similar operating costs (OPEX) at 95 and 93 USD/MWh[93], based on similar values for SCOP. A report by Draper et al.[94] modelling and comparing decentralised and centralised heating systems in Milton Keynes, utilised a figure for air-to-air heat pump OPEX of 380 EUR/Year. Unfortunately, neither piece of analysis accounts for the cooling potentially supplied by reversible heat pumps. As noted by Bush et al.[95] in a Climate Xchange report, there is a lack of literature around OPEX costs for air-to-air heat pumps, therefore further work and trials are required to provide this data.

Other figures could be found for Levelised Cost of Energy (LCOE); however, this considers the investment costs (CAPEX) and operating costs (OPEX) over the lifetime of the technology. A report by Frontier Economics[96] found that the LCOE ranged between ~85-115 (£/MWh) for air-to-air systems installed in UK domestic settings, compared with ~70-82 and ~90-105 (£/MWh) for air-to-water and ground source heat pump systems, respectively. The work by Frontier assumed a 15-year lifespan for all types of heat pump and SCOPs of 2.5-2.75 and 3.2-3.8 for air-source and ground-source heat pumps, respectively. A similar pattern of figures is presented in a report by the International Energy Agency[97], with UK-installed air-to-air having the highest LCOE values at 117-183 USD/MWh, followed by 97-147 and 64-104 (USD/MWh) for air-to-water and ground source systems respectively. The main difference is that the equipment lifetime is expected to be 12, 18, and 18 years for air-to-air and air-to-water and ground source heat pumps respectively, although it is unclear what the evidence basis is for these assumptions.

Findings of the Cost-Optimal Domestic Electrification (CODE) project somewhat contradict that of the reports by Frontier and the International Energy Agency. The work found only '*small*

[92] C. Palkowski and A. Simo, "Quick seasonal performance testing for heat pumps," in ECEEE Summer Study 2019, Stockholm, 2019.
[93] International Energy Agency, "Is the energy crisis really making the business case for heat pumps?," International Energy Agency, Paris, 2022.
[94] J. Draper, C. Ballard, M. Kowalska and A. Odgaard, "D6.3 Heating and cooling strategies for pilot areas - Milton Keynes," Hotmaps, Vienna, 2020.
[95] R. Bush, O. Angelidis, A. Bates, I. Van Duivenbode, W. MacRae and G. Milligan, "Costs of zero emissions heating in new build," Climate Xchange, Edinburgh, 2021.
[96] Frontier Economics, "Pathways to high penetration of heat pumps," Frontier Economics, London, 2013.
[97] International Energy Agency, "Renewables 2021," International Energy Agency, Paris, 2021.

differences in costs over 15 years between low- or high-temperature (air-to-water) heat pumps, or air-to-air heat pumps, or storage radiators.' and states a maximum of 10% difference[98].

The literature found by this work mainly focused on costs for air-to-air heat pumps delivering heating, but little could be found related to cooling. A report by Arup, focussing on a range of property types including flats, terraced houses and detached houses, found that annual energy costs for a mid-terraced property in London, analysed in their study, could increase by 20-90 £/annum when utilising cooling, assuming 2022 electricity costs and 2°C global warming scenario[99].

3.3.1 Maintenance

Information from manufacturers[100] shows that yearly servicing of air source heat pumps is recommended, to ensure efficient operation, where technicians will top up refrigerant and ensure the system is working correctly. Similarly, annual servicing of gas boilers is recommended for individual users and a legal requirement for landlords[101]. Additionally, users of air-to-air heat pump systems are required to clean air filters within the indoor unit between servicing, with recommendations ranging between two weeks and two months[102] [103]. Cleaning filters regularly is essential to ensure efficient operation of the unit; one estimate states that clogged filters can increase energy consumption by up to 15%[104]. There is a risk that if lots of users fail to perform regular maintenance by cleaning filters, then energy use could increase. However, users of gas boilers and air-to-water heat pumps must bleed radiators and top up their system regularly[105] and although different, regular user maintenance would not be a new requirement for anyone changing from a gas boiler.

As explained by Flower[106], smart controls and connectivity of the units via Wi-Fi also allows the ability to diagnose issues remotely, meaning that maintenance visits may not be required, saving the user time and money. Sadeghi et al.[107] reviewed the use of a range of different types of heat pumps in Norway, drawing on a plethora of literature, and found that the maintenance costs of air-to-air heat pumps could be as much as 30% less than for air-to-water or ground source heat pump installations. A study was conducted by Heimdal[108] into the reliability of air-to-air heat pumps installed in Norway, gathering feedback from 2361 users over 7 years. The study found that across the period, 78% of respondents required one or no repairs to their system. While this still leaves a percentage of systems having multiple issues, it

[98] Cambridge Architectural Research, "Cost-Optimal Domestic Electrification (CODE)," BEIS, London, 2021.
[99] Arup, "Addressing overheating risk in existing UK homes," Climate Change Committee, London, 2022.
[100] https://www.daikin.co.uk/en_gb/residential/inspiration/articles/how-often-should-you-maintain-an-air-source-heat-pump-system.html.
[101] https://heatable.co.uk/boiler-advice/how-often-should-a-boiler-be-serviced.
[102] https://www.daikin.com.au/faq/how-often-should-i-clean-filters-my-air-conditioner.
[103] https://www.praairconditioning.co.uk/air-conditioner-servicing/.
[104] https://www.energy.gov/energysaver/maintaining-your-air-conditioner.
[105] https://www.gassaferegister.co.uk/gas-safety/gas-appliances/boiler-appliance-guide/.
[106] https://les.mitsubishielectric.co.uk/the-hub/the-changing-face-of-maintenance-protocols.
[107] "Current status of heat pumps in Norway and analysis of their performance and payback time," Sustainable Energy Technologies and Assessments, vol. 54, p. 102829, 2022.
[108] S. I. Heimdal, "Reliability of air to air heat pumps and their contribution to energy savings in Norway," in ECEEE 2011 SUMMER STUDY • Energy efficiency first: The foundation of a low-carbon society, Stockholm, 2011.

should be noted that these systems were installed in 2003 and the likelihood of them having remote diagnostics is very low.

3.4 Carbon Emissions

In this section we will look at the carbon emissions associated with operation of air-to-air heat pumps, but not embodied carbon emissions or refrigerant leakage, as no literature comparing them could be found. While air-to-air heat pumps produce no direct greenhouse emissions from combustion in their operation[109], refrigerants used often have much higher global warming potentials than CO_2 and therefore leakage contributes to global warming and emissions are produced in generating the electricity that powers them.

Work by Eguiarte et al.[110] looking at air-to-air heat pumps as a replacement for other heating technologies, specifically gas boilers in the UK, found that CO_2 emissions were almost 3 times lower using a heat pump than a gas boiler, although the figure depends on the carbon intensity of electricity versus gas and changes with time.

The International Energy Agency has produced analysis of the carbon emissions from a range of heating sources including air-to-air heat pumps, air-to-water heat pumps, and gas boilers with figures presented depending on the country or region. The analysis shows that over the 12-year expected lifespan of an air-to-air heat pump, 8.8 tonnes of CO_2 will be produced in its operation, compared with 36.5, 10.4 and 8 tonnes of CO_2 for a gas boiler, air-to-water heat pump and ground source heat pump respectively[111]. The analysis is only energy related and does not include refrigerant leakage or embodied carbon. It also does not consider carbon emissions from cooling and only considers use of the units in heating operation.

[109] Department for Business, Energy and Industrial Strategy, "Clean Growth - Transforming Heat," Department for Business, Energy and Industrial Strategy, London, 2018.
[110] O. Eguiarte, A. Garrido-Marijuan and P. d. Augustin-Camacho, "Energy, Environmental and Economic Analysis of air to air heat pumps as an alternative to heating electrification Europe," Energies, vol. 13, no. 15, 2020.
[111] https://www.iea.org/articles/are-renewable-heating-options-cost-competitive-with-fossil-fuels-in-the-residential-sector.

4 Integration overview and suitability including hot water provision

4.1 Archetype suitability

It is important to understand which types of property are best suited for air-to-air heat pumps and where they may be better suited than other solutions. A Parliament POST note[112] compiling evidence from across the sector on heat pump deployment explains that air-to-air heat pumps would be more suitable than other types of heat pumps for buildings where there is high heat loss, such as park homes or properties with poor insulation. This is because air-to-air heat pumps heat the air directly, where radiators emit heat, some of which is lost to the building fabric. This is concordant with evidence from the CODE project, where fabric improvement measures and low carbon technologies including air-to-air and air-to-water heat pumps were modelled in a range of property types, which found that found that on the balance of total cost across lifespan, air-to-air heat pumps were particularly suited to the two property types: a medium and sprawling sized house, with solid walls[113]. However, wall type had a part to play in making air-to-air heat pumps the cost optimal solution, cavity walls would have been cheaper to insulate and may have resulted in a different outcome. Additionally, the work found that air-to-air heat pumps were the cost optimal solution for all the flats analysed by the study. Limitations of the work under the CODE project are that systems were modelled in a variety of property types but were not physically installed, and that the effect of cooling was not explored.

As explained in section 3.1.2, air-to-air heat pumps are a natural fit for properties where there is not already a wet central heating system that would need to be removed. Such properties include those with electric storage heaters, and a report by MCS explains that air-to-air systems are the most suitable replacement where there are existing electric heaters[114]. The English Housing Survey[115] found that over 90% of dwellings in England had central heating as the main heating source, with the majority being gas fired boilers with radiators. This limits the scope for installations, where these properties could be better suited to having an air-to-water system installed. However, the survey found that 5% of dwellings had storage heaters, which presents an opportunity.

As in Table 1, the maximum number of indoor units that can be connected to a single outdoor unit is 6, thereby limiting the number of rooms that can be heated or cooled by the system, unless multiple outdoor units are used. In a review by the Joint Research Centre[116] into the challenges and opportunities with heat pumps across Europe, they explain that air-to-air heat

[112] UK Parliament POST, “Heat Pumps POSTnote 699,” UK Parliament POST, London, 2023.
[113] Cambridge Architectural Research, “Cost-Optimal Domestic Electrification (CODE),” BEIS, London, 2021.
[114] MCS Charitable Foundation, “Heat pump rollout in France and the UK,” MCS Charitable Foundation, Daresbury, 2023.
[115] Department for Levelling Up, Housing and Communities, “English Housing Survey 2021 to 2022: headline report,” Department for Levelling Up, Housing and Communities, London, 2022.
[116] Joint Research Centre, “The Heat Pump Wave: Opportunities and challenges,” European Commission, Luxembourg, 2023.

pumps are typically used in combination with other types of heating, but by this combination cost savings can be achieved. Complementary heating could include electric resistive panel heaters, infrared panels or even storage heaters (although as found in the CODE project, storage heaters would not provide adequate comfort). Although these complementary heating systems do not have the same levels of efficiency as air-to-air heat pump systems, with an equivalent COP of only 1, they could be used in areas of properties that are occupied less frequently, using the heat pump in rooms occupied more frequently. Complementary heating systems could provide redundancy in the event of heat pump failure, meaning that vulnerable customers would not be left without any heating.

4.2 Technology with hot water provision

Hot water production accounts for 19% of the overall demand for domestic heat, both space heating and hot water[117]. With an air-to-air system, hot water production is not integral to the function because its primary design is to transfer energy to air, while air-to-water systems heat water as part of the inherent design. However, a review of the market shows there are several manufacturers that produce air-to-air heat pumps that can also produce hot water, using a single system. These include Mitsubishi – PXZ[118], Samsung – EHS TDM Plus Climatehub[119] and Daikin – Multiplus[120]. These units offer a significant advantage over more traditional air-to-air systems where a separate hot water production solution would need to be installed. However, it appears at present that there are few available on the UK market, with Samsung retailing on UK websites and Daikin officially stating that their unit will be sold on the UK market[121], but with no release date.

Looking specifically at the technology currently or soon to be available on the UK market, the Daikin Multiplus system[122] can be connected with a 90 or 120 litre tank for hot water production, but one drawback is that a maximum of 3 indoor units can be connected to the system, while the Samsung TDM Plus Climate Hub has a slightly larger capacity with either 200 or 260L hot water tank capacity and up to 7 indoor units. It should be noted that technology with hot water provision has not been included in the summary presented in Table 1. Other units are available, such as the LG Multi-V with Hydrokit[123] but these are variable refrigerant (VRF) systems, typically used for commercial applications, with average systems installed in the UK five times the heating and cooling capacity of multi split systems[124]. They require additional components such as a heat recovery unit, Hydrokit and separate tank,

[117] Department for Energy Security and Net Zero, “Domestic hot-water use: observations on hot-water use from connected devices,” DESNZ, London, 2024.
[118] Mitsubishi Electric, “Mitsubishi Electric hybrid multi-split PXZ,” Building Services Engineering, p. 46, October 2023.
[119] https://samsung-climatesolutions.com/en-gb/b2c/our-solutions/home/heat-pump-solutions/heating-cooling/tdm-plus.html.
[120] https://www.daikin.ie/en_gb/product-group/air-to-air-heat-pumps/multiplus.html.
[121] https://www.daikin.co.uk/en_gb/press-releases/enjoy-greater-comfort-and-save-energy-with-the-new-multi--all-in.html.
[122] https://www.daikin.ie/en_gb/product-group/air-to-air-heat-pumps/multiplus.html.
[123] https://www.lg.com/uk/business/hvac/vrf/hydrokit/.
[124] Delta-ee, “The Contribution of Reversible Air-to-air heat pumps to the UK's Obligation under the Renewable Energy Directive,” Department for Business Energy and Industrial Strategy, London, 2017.

driving up capital cost. The two systems compared above would be able to provide surplus to the 80 litres the average UK household uses in a day[125]. Overall, there are solutions to suit different applications, although choice is limited when compared to systems available in Europe.

In terms of the impact on CAPEX, when comparing the price of similar heat output air-to-air heat pumps, with and without hot water functionality, prices of the outdoor unit are both around ~£1600. This is based on a comparison of two Samsung air-to-air heat pumps since they are the only manufacturer currently offering systems in the UK with hot water provision, the EHS TDM+ 6.6kW[126] and FJM 6.8kW[127], with and without hot water provision respectively. However, the Hydro Tank that is required to produce hot water retails at ~£4300[128], considerably more expensive than a standard electrically heated hot water cylinder. On comparison of the indoor units, no significant differences in price could be found.

There are other options for hot water production available, but these would be standalone units and not as part of an 'all-in-one' system as described above. Standalone options include resistive electrically heated hot water cylinders, and instantaneous resistive electrical water heaters, such as showers and 'instant' taps. There are however stand-alone hot water cylinders with integrated air source heat pumps, with examples including the Dimplex Edel[129], Mixergy iHP[130] or Vaillant aroSTOR[131]. These units offer the benefit of leveraging electricity to move heat, reducing energy consumption in comparison to direct resistive alternatives where the stated maximum efficiency across the three units is ~300%, vastly above the 100% maximum for direct resistive alternatives, but have the downside that they require ductwork to provide air. Heat pump cylinders were also found to be more expensive in terms of purchase price at between £2100 and £2500, compared with £600-£1500 for an unvented direct resistive alternative, compared based on a 200L capacity. This work found little research or evidence presented in relation to the use of air-source cylinders.

4.2.1 Energy and control strategy

As in section 3.2, energy efficiency is extremely important and can vary between models and manufacturers. As explained in a report by the Sustainable Energy Authority of Ireland[132], heat pump cylinders are tested under EN16147, the standard for water heating only. The standard uses a scale from A+ to F, different to that of EN14825, and direct comparison should not be made. EN16147 testing comprises heating water at different reference temperatures to determine COP values. The three air-source cylinders above achieved a rating of A+, while the Samsung TDM Plus Climate Hub and Daikin Multi+ system achieve an A and B, respectively, when producing hot water. In terms of space heating and cooling, both the Samsung and

[125] https://tools.bregroup.com/heatpumpefficiency/hot-water-consumption.
[126] https://www.alphawholesale.co.uk/samsung-ehs-tdm-r410a-inverter-heat-pumps
[127] https://cooleasy.co.uk/products/samsung-fjm-3-head-multi-split-outdoor-unit?variant=47775231705372
[128] https://www.alphawholesale.co.uk/samsung-ehs-tdm-with-integrated-hydro-tank
[129] https://www.dimplex.co.uk/professional/heat-pumps/hot-water-heat-pumps.
[130] https://mixergy.co.uk/mixergy-ihp/.
[131] https://professional.vaillant.co.uk/for-installers/products/arostor-domestic-hot-water-heat-pump-58880.html.
[132] Sustainable Energy Authority of Ireland, "DEAP Heat Pump Methodology," Sustainable Energy Authority of Ireland, Dublin, 2016.

Daikin 'all-in-one' solutions have SCOP and SEER values in line with that presented in Table 2; the addition of a hot water solution does not appear to negatively affect these values.

Although the air-source cylinders above achieve a slightly higher energy rating than the all-in-one air-to-air heat pump systems, they do have a drawback as they lack inherent centralised control requiring third party solutions, which applies to standalone hot water solutions more generally. As explained in the manufacturer literature, a single control system can prioritise heating, cooling, and hot water generation based on ambient conditions and user requirements[133]. Using standalone hot water generation devices means that dwellings will require two power drawing devices - a cylinder or instantaneous heater and an air-to-air heat pump system. There are ongoing questions around the wide scale deployment of heat pumps and the impact of this on the electricity distribution grid. As presented in work by Akmal et al.[134] and Energy Systems Catapult[135], high heat pump uptake and events such as power cuts could lead to parts of the grid becoming overloaded. The use of air-to-air heat pumps and standalone hot water solutions could exacerbate this issue with both devices demanding power, whereas this demand would be managed by the control system of an all 'all-in-one' system.

4.2.2 Simultaneous cooling and hot water production

As explained in work by Byrne et al.[136] and Chaiwongsa et al.[137] the use of air-to-air heat pumps for simultaneous air cooling and transfer of energy to hot water can lead to energy savings, with increased COP. Unfortunately, according to the manufacturer literature neither the Daikin nor Samsung air-to-air heat pumps with hot water solution, currently or planned to be available in the UK, can perform this function. However, internationally, units are available including the Argo ISERIES[138] and Panasonic Aquarea EcoFleX[139] enabling simultaneous cooling using indoor units and production of hot water using the recovered heat. With standalone heating, whether heat pump or resistive in type, this is not possible. However, the LG Multi-V with Hydrokit and other variable refrigerant flow systems can achieve this by using a heat recovery unit.

[133] https://www.daikin.ie/en_gb/product-group/air-to-air-heat-pumps/multiplus.html.
[134] M. Akmal, B. Fox, J. Morrow and T. Littler, "Impact of heat pump load on distribution networks," IET Generation, Transmission & Distribution, vol. 8, no. 12, pp. 2065-2073, 2014.
[135] https://es.catapult.org.uk/case-study/uk-power-networks-cold-start/.
[136] P. Byrne, R. Ghoubali and A. Diaby, "Heat pumps for simultaneous heating and cooling," Heat Pumps: Performance and Applications, 2018.
[137] P. Chaiwongsa and W. Duangthongsuk, "Hot Water Making Potential Using of a Conventional Air-Conditioner as an Air-Water Heat Pump," Procedia Engineering, vol. 8, pp. 165-170, 2011.
[138] https://www.argoclima.com/en/discover-iseries-system/
[139] https://www.aircon.panasonic.eu/IE_en/happening/aquarea-ecoflex/

4.3 Added value potential

4.3.1 Impact of cooling

As noted by Lowes[140], air-to-air heat pumps offer an advantage over air-to-water heat pumps because cooling can easily be achieved. Cooling is more difficult and costly to achieve with an air-to-water heat pump and wet system, where there are issues around condensation, pooling water and large surface areas for heat transfer required. Cooling can be achieved with the installation of fan coils but would require a power supply, adding complexity and driving up capital cost.

The ability to cool as well as heat provides an additional benefit, perhaps making consumers more likely to move away from fossil fuel heating, in comparison to air-to-water systems which would only able to heat the property, the same as before the capital expenditure on a new system. No recent consumer research could be found to understand whether the additional functionality of cooling makes air-to-air heat pumps more appealing than other systems, without cooling functionality. However, a report by the Energy Technologies Institute in 2014[141] found evidence of a demand from consumers for domestic active cooling and that this demand would increase if periods of hot weather increase, as has happened since the research was published. Cooling can be used to avoid overheating and according to a report by Arup[142], 75% of housing stock in the UK would fail the Chartered Institution of Building Services Engineers (CIBSE) criterion B, part of TM59, for overheating in bedrooms if a 2°C global warming increase was realised. There are reports that we have already exceeded 1.5°C[143]. Further to this, the Energy Follow Up Survey[144] discovered that overheating risk was significantly higher in flats, disproportionately affecting vulnerable and poor members of society. As discussed in section 4.1, air-to-air heat pumps are particularly suited to flats, where we see this higher potential for overheating. This potential could be mitigated by the installation and use of reversible air-to-air heat pumps, which would be the only solution to remove the overheating risk in some London flats[145].

A report by the UK Energy Research Centre (UKERC) modelled the impact on electricity demand created by increased installation of air conditioning units into UK homes by 2050. It found that '*If air conditioning is used as we assume in our scenarios, summer peak will increase and demand will not coincide with optimum renewable generation.*'[146] The report also found that there were gaps in evidence around motivations for installation of cooling, when cooling is used, and how coincident demand is across households. A review by the Tyndall

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[140] R. Lowes, "Blowing hot and cold: Reflecting the potential value of air-to-air heat pumps in UK energy policy," REGULATORY ASSISTANCE PROJECT (RAP), Brussels, 2023.
[141] Energy Technologies Institute, "Smart Energy Solutions – the Consumer Perceptive," Energy Technologies Institute - ENERGY ENDEAVOURS CONSORTIUM, Birmingham, 2014.
[142] Arup, "Addressing overheating risk in existing UK homes," Climate Change Committee, London, 2022.
[143] https://www.bbc.co.uk/news/science-environment-68110310.
[144] Department for Business, Energy & Industrial Strategy, "Energy Follow Up Survey (EFUS)," Department for Business, Energy & Industrial Strategy, London, 2021.
[145] Arup, "Addressing overheating risk in existing UK homes," Climate Change Committee, London, 2022.
[146] UK Energy Research Centre, "Domestic Air Conditioning in 2050," UK Energy Research Centre, London, 2020.

Centre[147] found that there was little research into how cooling was used in domestic settings in the UK, with one piece of research showing that users switched it on at around 24°C, with time of use varying. In a response by the Electricity System Operator to the Heat Resilience & Sustainable Cooling inquiry, they state that while cooling demand grows, so too will solar generation capacity, which will likely correlate with cooling demand enabling this peak to be managed[148].

Studies by Aneli et al.[149], Bee et al.[150] and Baraskar at al.[151] into the deployment of heat pumps alongside battery storage and Solar PV systems found positive results, with reduced reliance on the grid, which could be used to counteract the increased demand from cooling. The studies, however, largely focused on air-to-water heat pumps in heating applications and were not centred around the UK. In addition, modelling presented in the UKERC[146] report found that air conditioning peak demand does not coincide with peak solar PV generation and is in fact offset by several hours, with peak demand including cooling around 18:00 and peak solar generation around 12:00. Alternatively, time of use tariffs could be used to mitigate the impact of increased cooling demand, with a review by the Tyndall Centre[152] explaining that positive results, in terms of managing the demand from air-to-air systems, had been found in Australia when dynamic pricing was adopted, although were not as successful in extreme heat conditions.

4.3.2 Air quality and health implications

Manufacturers across the board promote the benefits of air-to-air heat pumps with removal of dust and particulates, such as pollen and smoke, from the air, which can improve air quality benefitting those with asthma and hay fever[153] [154]. A review by Vijayan et al.[155] found that across a number of studies the findings suggested a prevention of progression of chronic respiratory diseases when filters, such as those used in the indoor unit of air-to-air heat pumps, were used to remove particulate matter and allergens.

Most air-to-air heat pumps can also be used as dehumidifiers. As explained in advice by the NHS, damp and mould caused by high levels of humidity can lead to adverse health effects and asthma attacks, with elderly and vulnerable people particularly sensitive[156]. World Health Organisation guidance explains that air-to-air heat pumps, or air conditioning systems, can be

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[147] Tyndall Centre, “Air conditioning demand assessment,” Tyndall Centre, Manchester, 2016.
[148] Electricity System Operator, “The Electricity System Operators Response to Heat Resilience & Sustainable,” The Environmental Audit Committee, London, 2023.
[149] S. Aneli, R. Arena and G. Tina, “Improvement of energy self-sufficiency in residential buildings by using solar-assisted heat pumps and thermal and electrical storage,” Sustainable Energy Technologies and Assessments, vol. 60, p. 103446, 2023.
[150] E. Bee, A. Prada and P. Baggio, “Demand-Side Management of Air-Source Heat Pump and Photovoltaic Systems for Heating Applications in the Italian Context,” Environments, vol. 5, no. 12, p. 132, 2018.
[151] S. Baraskar, D. Gunther, J. Wapler and M. Lammle, “Analysis of the performance and operation of a photovoltaic-battery heat pump system based on field measurement data,” Solar Energy Advances, vol. 4, p. 100047, 2024.
[152] Tyndall Centre, “Air conditioning demand assessment,” Tyndall Centre, Manchester, 2016.
[153] https://www.worcester-bosch.co.uk/bosch-air-conditioning-units/benefits-of-air-conditioning.
[154] https://les.mitsubishielectric.co.uk/homeowners/our-air-conditioning.
[155] V. Vijayan, H. Paramesh and S. Salvi, “Enhancing indoor air quality –The air filter advantage,” Lung India, vol. 32, no. 5, pp. 473-479, 2015.
[156] https://www.nhs.uk/common-health-questions/lifestyle/can-damp-and-mould-affect-my-health/.

used to control levels of moisture, reducing the potential for health problems and protecting the condition of the building. Poorly maintained systems can, however, have the opposite effect[157].

Air-to-air heat pumps are often considered to dry out the skin, making users feel uncomfortable. Stick et al.[158] explains that this is partially due to the movement of air by the fan. To combat this, Samsung has brought out the WindFree™ range[159], which disperses air uniformly through small holes, while others including Mitsubishi[160] and Daikin[161] use direction of airflow, all with the aim of reducing uncomfortable drafts.

4.3.3 Smart tariffs

With the increased prevalence of heat pumps, heat pump energy tariffs are now available to users, allowing them to make savings. This literature review found that in the UK there was only one dedicated heat pump tariff available and compatible with air-to-air heat pumps— Cosy Octopus by Octopus Energy, which provides a discount on all energy used in the home during discounted periods[162]. Heat Pump Plus by Ovo is the alternative, but it can only be used with Vaillant heat pumps, and Vaillant does not currently manufacture air-to-air heat pumps[163]. In Germany, as of 2023, there were over 200 heat pump energy tariffs allowing households to save a third in comparison to gas heating[164]. Evidence could not be found for the number of heat pump energy tariffs in other European countries.

Alternatively, time of use tariffs, where prices fluctuate across the day, could be used with heat pumps to provide savings. Smart thermostats built into air-to-air heat pumps allow users to set up programmes and make the most of energy when it is cheapest. The CODE project found that employing time of use tariffs resulted in air-to-air heat pumps remaining the most cost-effective technology for three of the flat types, in comparison to other technologies including air-to-water and ground source heat pumps, while low temperature air-to-water heat pumps became the optimal selection for all the house types[165]. However, time of use tariffs aside, the CODE project found that: “Other things being equal, running costs for an air-to-air system would be higher than an equivalent air-or ground-source heat pump with low temperature radiators or underfloor heating.” As explained in literature[166], utilising thermal mass of a property allows savings to be made when employing a flexible or time of use tariff. There is, though, a potential limitation to the savings with air-to-air heat pumps because air is being heated, which in comparison to water and metal pipework, has a lower thermal mass and lower

[157] World Health Organisation, WHO Guidelines for Indoor Air Quality: Dampness and Mould. Geneva: World Health Organization, Geneva: World Health Organisation, 2009.
[158] C. Stick and E. Proksch, “The influence of Climate on the Treatment of Dry Skin with moisturizer,” in Treatment of Dry Skin Syndrome, New York, Springer, 2012, pp. 503-513.
[159] https://samsung-climatesolutions.com/en-gb/b2c/products/hero-products/windfree.html.
[160] https://les.mitsubishielectric.co.uk/latest-news/new-3d-i-see-sensor-matches-air-conditioning-to-room-occupancy.
[161] https://www.daikin.eu/en_us/daikin-blog/how-to-find-the-air-conditioner-that-is-right-for-you.html.
[162] https://octopus.energy/smart/cosy-octopus/.
[163] https://www.ovoenergy.com/heat-pump-plus.
[164] https://www.cleanenergywire.org/news/heat-pump-owners-benefit-rising-number-power-price-rebates-germany
[165] Cambridge Architectural Research, “Cost-Optimal Domestic Electrification (CODE),” BEIS, London, 2021.
[166] Element Energy, “Low Carbon Heat Study – Phase 1,” ERM Group, London, 2023.

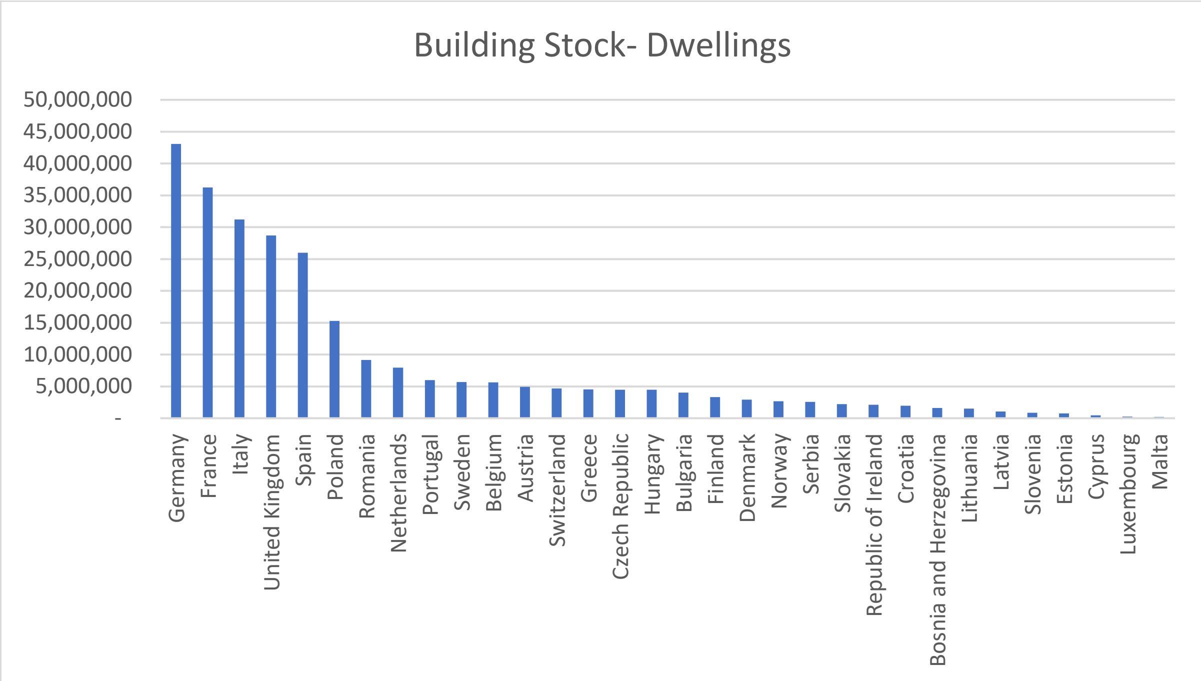
heat capacity. An article by Which?[167], reviewing potential savings of heat pumps in comparison to gas boilers, shows that significant savings can be made by using Octopus Agile, a time of use tariff. However, savings from time of use tariffs are harder to calculate because costs fluctuate from day to day and there is no way of predicting more than a few days in advance what tariffs will be. Time of occupancy is also a factor, and users must alter their behaviour to make the most savings.

[167] https://www.which.co.uk/news/article/a-heat-pump-might-be-a-lot-cheaper-than-you-think-heres-how-aSx7P0B2hOHW.

5 Market view

5.1 Building Stocks in European countries[168]

Figure 1: Building Stock in European Countries

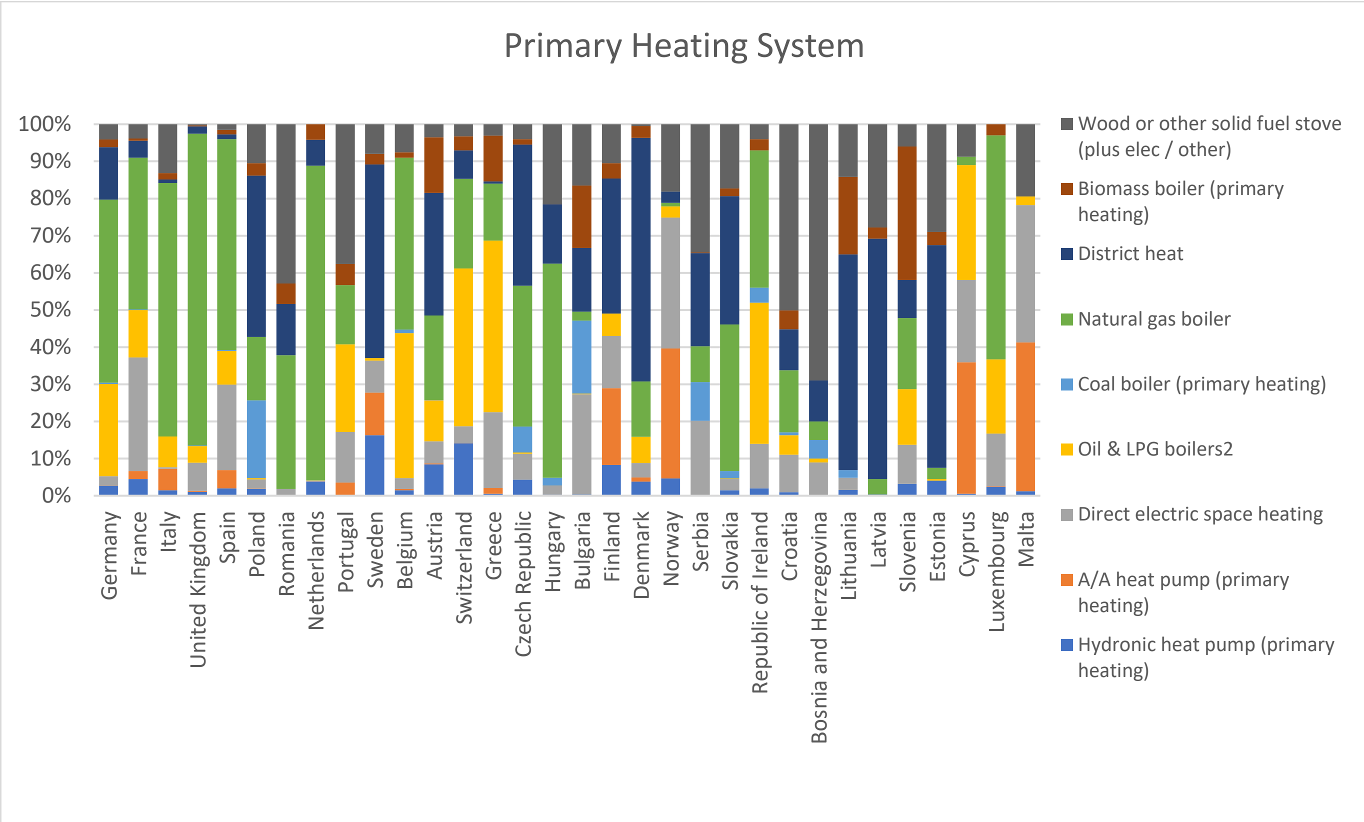


The UK, with 28,700,000 dwellings, has one of the highest numbers of dwellings among the European countries. It surpasses many countries such as the Netherlands, Norway, and Republic of Ireland by a significant margin. Only four other countries, France, Germany, Italy, and Spain, have more than 20 million dwellings like the UK. However, the majority of the countries listed have below 10 million dwellings, significantly fewer than the UK.

[168] Data for the European building stocks has been extracted from LCP Delta using a subscription account. Data Collection: European Electrification Heat Map https://research.lcpdelta.com/reportaction/LCPDelta_EHS_E-HeatMap_Database/Marketing?SearchTerms=electrification%20of%20heat

5.2 Primary Heating Systems in the UK and European Countries[169]

Figure 2: Primary heating system in European Countries



According to data the primary heating systems for various countries, as of 2021, are as follows:

- In France, the most common primary heating system is natural gas boilers in 40% of households, followed by direct electric space heating at 30%.
- In Germany the most common heating system is natural gas boilers (49%), followed by oil & LPG boilers at 25%.
- Italy's predominant primary heating system is natural gas boilers, making up 68% of systems. The rest is primarily made up of wood or other solid fuel stoves, and hydronic heat pumps.
- In the Netherlands, the vast majority of primary heating systems are natural gas boilers at 85%, with district heat and biomass boilers taking up 7% and 4% respectively.
- Norway has a more balanced mix of primary heating systems, with air-to-air heat pumps and direct electric space heating both accounting for 35%, while wood or other solid fuel stoves make up 18%.

[169] Data for unit sales of heat pumps has been extracted from LCP Delta using a subscription account. Electrification of Heat Service- Data collection: European Electrification Heat Map- June 2021- https://research.lcpdelta.com/reportaction/Delta-EE_E-Heat_Map_Database_June_2021.xlsx/Toc

- Spain primarily uses natural gas boilers for heating, accounting for 37% of systems, followed by direct electric space heating at 15%.
- Sweden's leading primary heating system is district heat at 52%, followed by hydronic heat pumps and air-to-air heat pumps at 16% and 11% respectively.
- Switzerland's primary heating systems are dominated by oil & LPG boilers at 42%, followed by natural gas boilers at 24%.

A comparison of the UK's primary heating systems, which comprise 84% natural gas boilers, with other European countries reveals a similarity to the Netherlands, where natural gas boilers constitute 85% of the primary heating systems. On the other hand, both Norway and Sweden have more diversified primary heating systems, relying less on natural gas boilers and more on a variety of other heat sources. Installing an air-to-air heat pump usually costs about the same as a gas boiler in most major heating markets. However, air-to-water heat pumps can be up to four times more expensive. More than 30 countries offer financial help. Some countries give more help to people with less money or who choose very efficient models. If countries change their energy taxes and apply CO_2 penalties to all home heating fuels, it could lower relative operating costs and make heat pumps a more attractive option economically.[170]

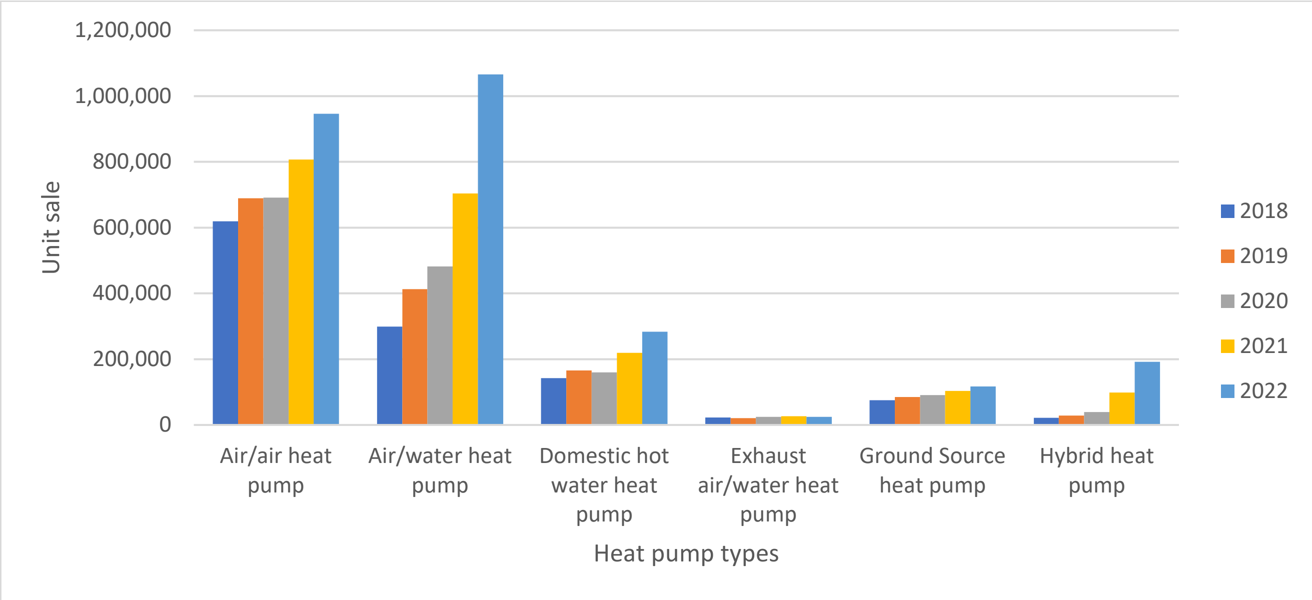
5.3 Heat Pump Sales by Type[171]

Based on the LCP Delta dataset, air-to-air was the type of heat pump to record the highest total unit sales in domestic settings, with over 3m units sold between 2018 and 2022 in Europe. This suggests that they were the most favoured type of heat pump among consumers. Their popularity is attributed to lower investment costs and easy installation, both at the unit and system level.[172] All figures for air-to-air heat pump sales volumes are for those believed to be used as the primary space heating system. In some countries, this can be a small fraction of the total volume of sales, with the majority used primarily for cooling.

- Air-to-water heat pumps had the second-highest total unit sales, with 2.9m units sold
- Domestic hot water heat pumps had total unit sales of 970k
- Exhaust air-to-water heat pumps had a relatively lower total unit sales of 119k
- Ground source heat pumps had total unit sales of 472k
- Hybrid heat pumps had total unit sales of 381k

[170] International Energy Agency (IEA), The future of heat pumps, Revised version 2022, P. 63 The Future of Heat Pumps (windows.net)
[171] Data for unit sales of heat pumps has been extracted from LCP Delta using a subscription account. Heat Pump Forecasts Dashboard https://research.lcpdelta.com/reportaction/EHS_HPforecasts_PowerBI/Toc
[172] Heat Pumps in Europe Key Facts & Figures https://www.ehpa.org/wp-content/uploads/2023/06/Heat-Pump-Key-Facts-May-2023_compressed.pdf

Figure 3: Total Heat Pump unit sales from 2018 to 2022 in Finland, France, Germany, Italy, Netherlands, Norway, Poland, Spain, Sweden, United Kingdom, and Belgium



Overall, air-to-air heat pumps and air-to-water heat pumps were the most prevalent types of heat pumps in the 11 countries analysed (named above).

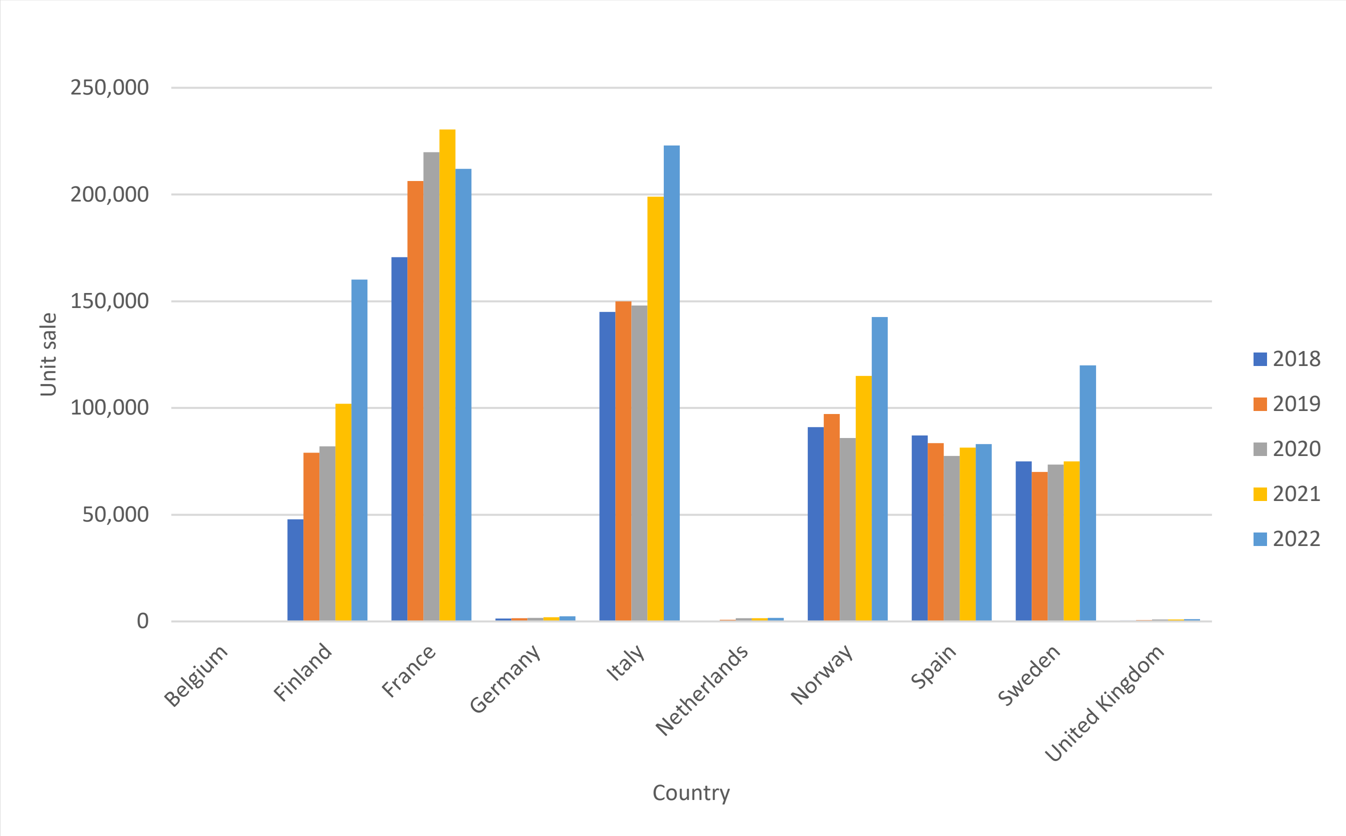
5.4 Air-to-air Heat Pump Sales by Country[173]

Based on the annual unit sales of air-to-air heat pumps in different countries from 2018 to 2022 provided by LCP Delta, the UK's sales figures are relatively low compared to some other European countries. While the UK's sales ranged from 470 in 2018 to 1,000 in 2022, countries like Finland, France, and Italy consistently had higher unit sales figures. As there are limited grants for air-to-air heat pumps and the UK Government is not targeting and actively monitoring sales of air-to-air heat pumps, data is a best estimate based on manufacturer or distributor sales data, which may not capture all sales from every route to market.

Germany, the UK, Belgium, and the Netherlands had much lower unit sales than the countries mentioned above. Germany's sales figures ranged from 1.3k in 2018 to 2.4k in 2022. Belgium had no sales over these years, and the Netherlands had unit sales ranging from 350 in 2018 to 1.6k in 2022.

[173] Data for unit sales of heat pumps has been extracted from LCP Delta using a subscription account. Heat Pump Forecasts Dashboard https://research.lcpdelta.com/reportaction/EHS_HPforecasts_PowerBI/Toc

Figure 4: Annual unit sales of Air-to-Air Heat Pump by country



5.5 Heat Pump Sales by Type in the UK[174]

The annual unit sales of different types of heat pumps in domestic settings in the UK from 2018 to 2022 are as follows:

- Air-to-water heat pump: Experienced significant growth, with sales increasing from 22.4k units in 2018 to 53k units in 2022.
- Ground source heat pump: Varying sales figures in the UK. Sales started at 2k units in 2018, peaked at 4.7k units in 2021, and then decreased to 2.2k units in 2022.
- Hybrid heat pump: Hybrid heat pumps also showed a consistent increase in sales figures, starting at 1.6k units in 2018 and reaching 3.3k units in 2022.
- Air-to-air heat pump: The sales figures for air-to-air heat pumps in the UK increased from 470 units in 2018 to 1k units in 2022. This indicates a steady growth in the popularity of air-to-air heat pumps, although no other literature for current UK sales could be found as a comparison.
- Domestic hot water heat pump: There were no recorded sales of domestic hot water heat pumps in the UK throughout the years 2018 to 2022.

[174] Heat Pump Forecasts Dashboard https://research.lcpdelta.com/reportaction/EHS_HPforecasts_PowerBI/Toc

- Exhaust air-to-water heat pump: Similarly, no sales of exhaust air-to-water heat pumps were reported in the UK during the same period.

Figure 5: Annual unit sale of different types of heat pump in the UK

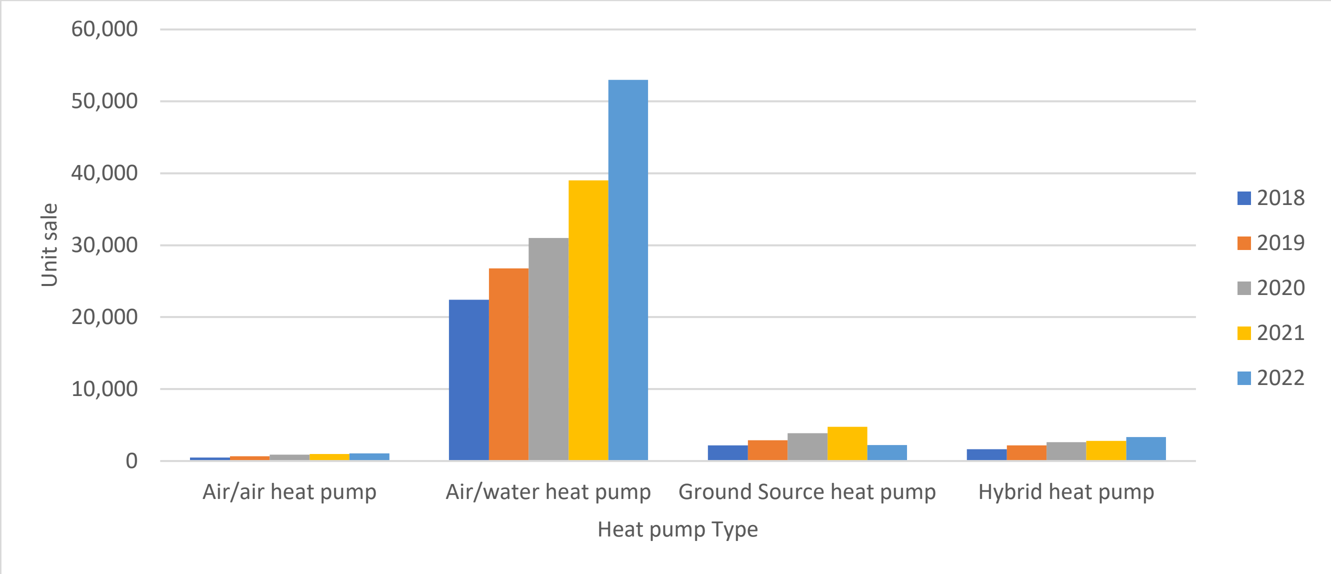
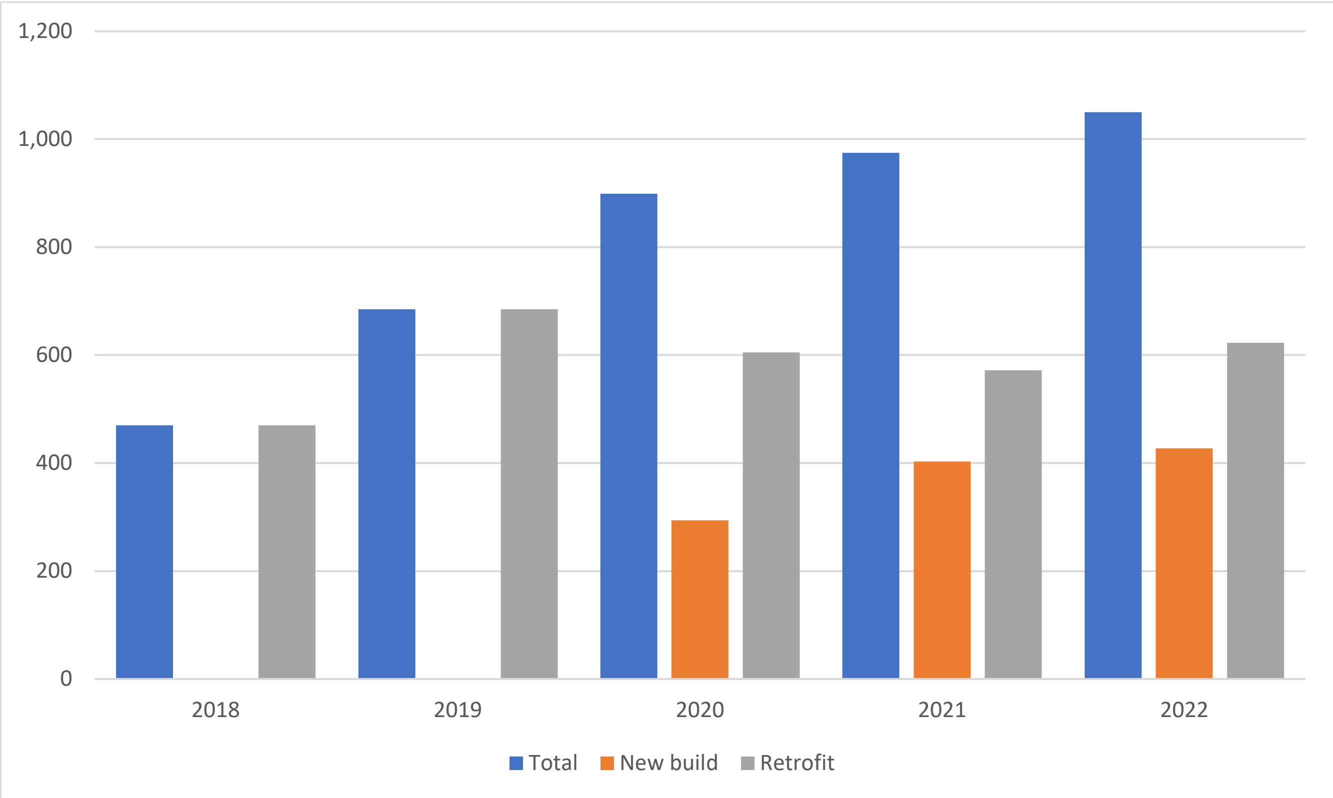


Figure 6: Annual unit sale of air/air heat pumps in the UK



Overall, according to the LCP Delta dataset, the data suggests a growing demand for air-to-water, air-to-air and hybrid heat pumps in the UK, albeit from a low base. These types of heat pumps are becoming increasingly popular for both residential and commercial use. On the other hand, there were no sales recorded for domestic hot water heat pumps and exhaust air-to-water heat pumps.

5.6 Air-to-air Heat Pumps by Property Segments

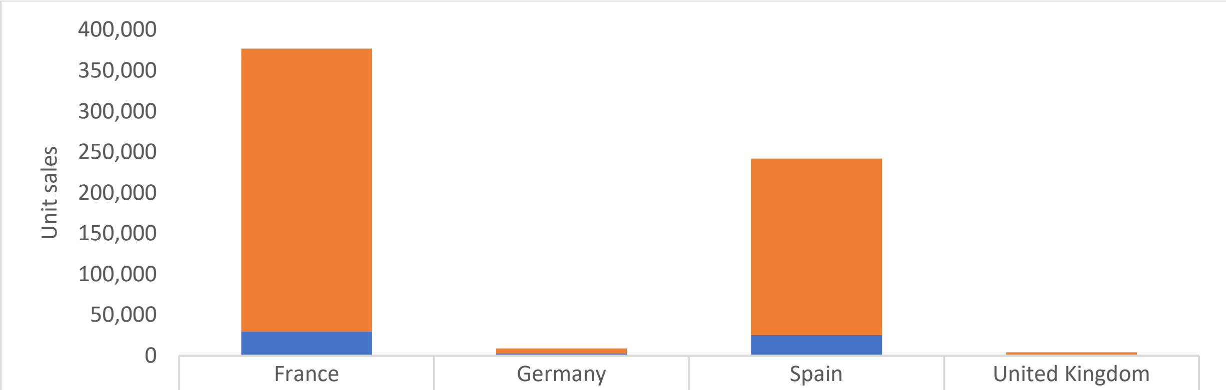
France had the highest number of air-to-air unit sales in both the new build and retrofit segments, at 29.7k and 347.2k respectively over the period 2018-2022.

Spain had a significant number of air-to-air sales as well; with 25.5k in the new build segment, and 216.6k in the retrofit segment.

Germany had lower air-to-air unit sales compared to France and Spain; 3k in the new build segment and 5.9k in the retrofit segment.

As previously mentioned, the UK had the lowest air-to-air unit sales among the listed countries; with 1.1k in the new build segment and 2.9k in the retrofit segment over the period 2018-2022.

Figure 7: Total air-to-air unit sales from 2018 to 2022 by property segments

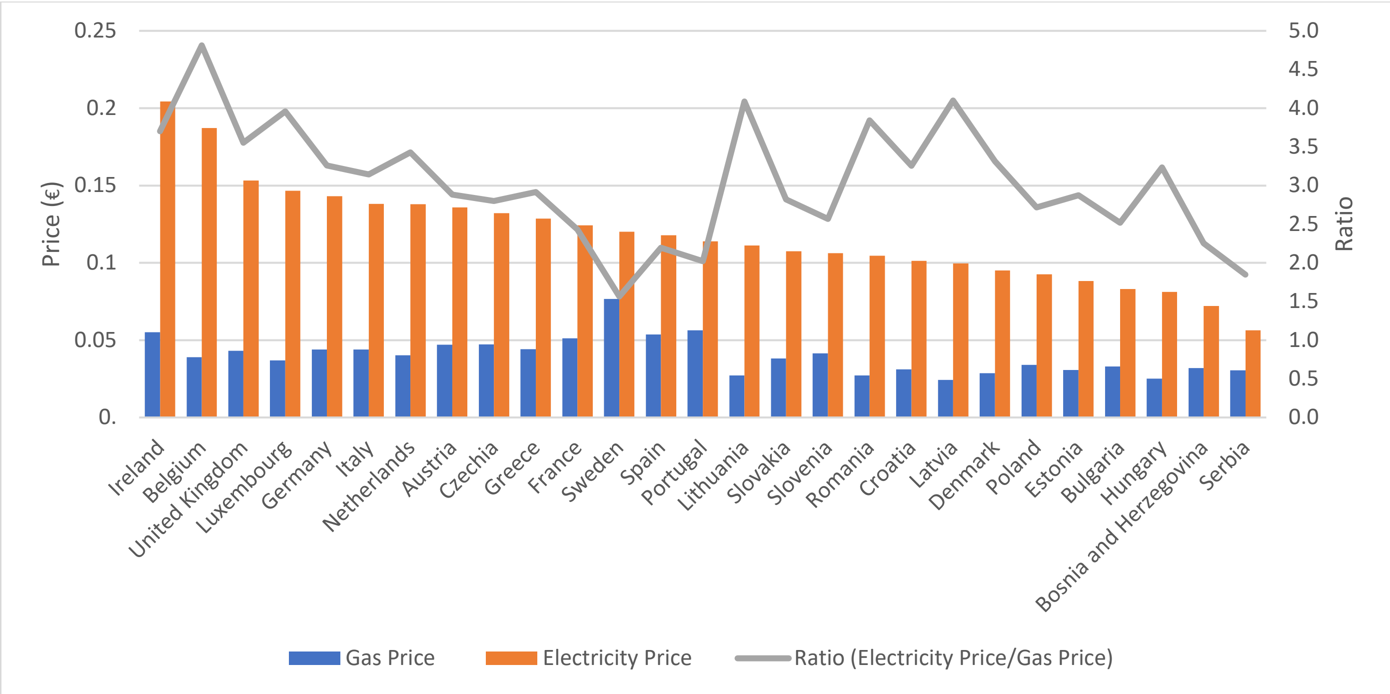


	France	Germany	Spain	United Kingdom
Retrofit	347,280	5,904	216,676	2,955
New build	29,720	3,001	25,513	1,124

Air-to-air unit sales in the retrofit property segment in France and Spain are vastly greater than the new build segment, as the number of existing buildings being upgraded or renovated is much higher than those being newly built.

5.7 Energy Price in European Countries[175]

Figure 8: Gas and electricity prices for household consumers in the first half of 2020 in European countries



The data shows that electricity prices for household consumers varied across different countries in Europe in the first half of 2020. The highest price was observed in Ireland, at € 0.2043, while the lowest was in Serbia, at € 0.0564.

On the other hand, gas prices showed a different trend. Sweden had the highest gas price at € 0.0767, whereas Latvia had the lowest at € 0.0243.

Countries with high electricity prices did not necessarily have high gas prices. For instance, while Ireland had the highest electricity price, its gas price was relatively moderate at € 0.0552. Similarly, Sweden had the highest gas price, yet its electricity price was comparatively low at € 0.1200.

There does not appear to be a direct correlation between the prices of gas and electricity across these countries in the first half of 2020.

175 Electricity prices for household consumers - bi-annual data (from 2007 onwards) https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_204__custom_11340302/default/table?lang=en
Gas prices for household consumers - bi-annual data (from 2007 onwards) https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_202/default/table?lang=en&category=nrg.nrg_price.nrg_pc
Note: The latest available data for the UK in Eurostat's dataset is for H1 2020.

5.8 Selected European Country Profiles

Germany, France, Italy, and the Netherlands have been selected for review as they are part of Western Europe, with building counts comparable to that of the UK.

5.8.1 Germany- Heat pump market growth, 2018-2022[176]

Figure 9: Annual unit sales of heat pumps in Germany

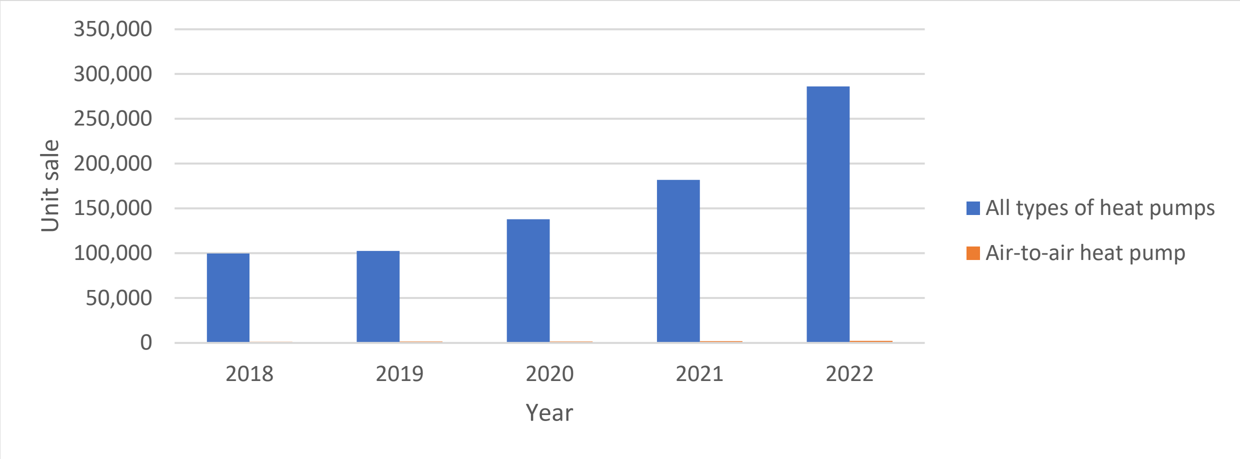
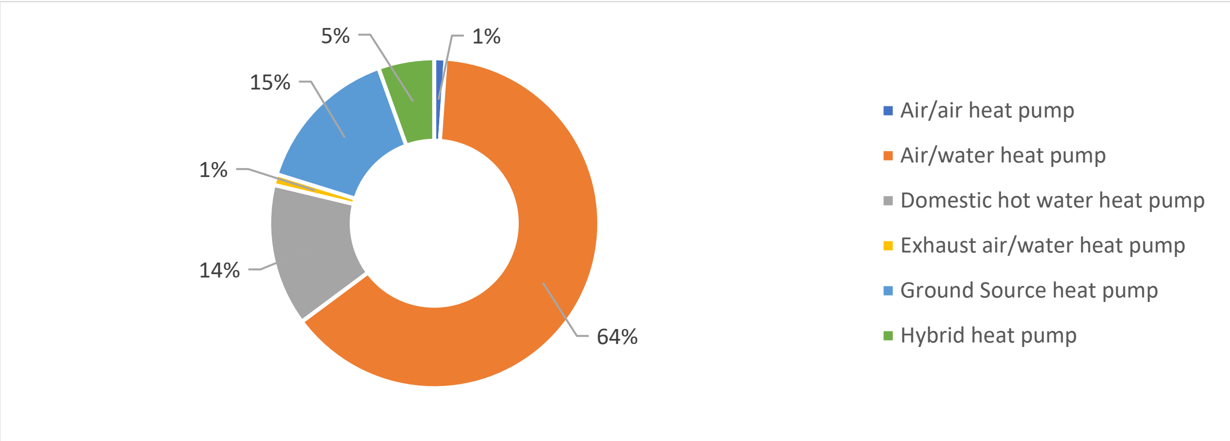
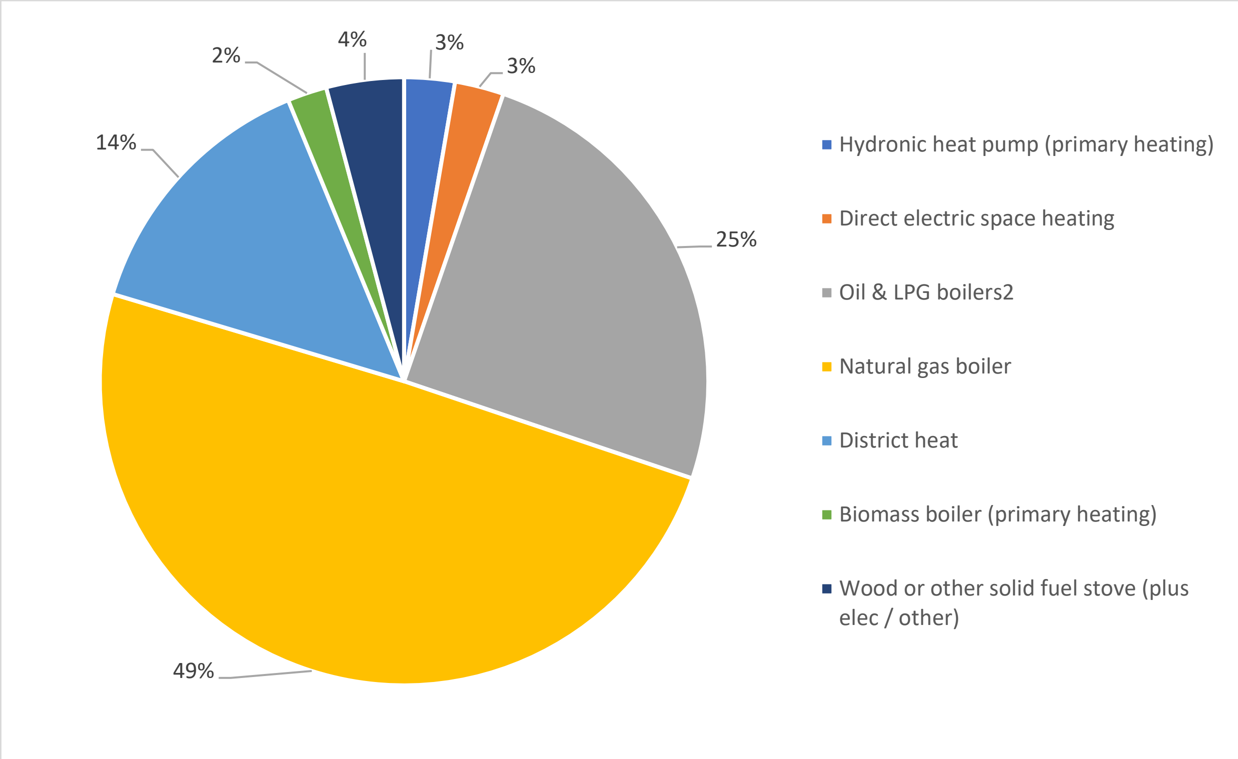


Figure 10: Total heat pump technology unit sales by type from 2018 to 2022 in Germany



[176] Opportunities for the Electrification of Heat: Germany https://research.lcpdelta.com/reportaction/EHS_Germany/Marketing?SearchTerms=Germany

Figure 11: Germany- Existing primary heating systems



In Germany, the least common primary heating systems are air-to-water heat pumps and biomass boilers, with usage rates of 3% and 2% respectively.

From 2018 to 2022, air-to-air heat pumps accounted for 1% of total heat pump technology unit sales. This is low compared to other types of heat pump. In terms of the type of building where heat pumps have been installed, 68% of installations were in retrofitted buildings and 32% were in new builds. The total heat pump unit sales in Germany grew by 187%. The air-to-air heat pump unit sales experienced a growth of 83% in the same period.

5.8.1.1 Opportunities and Challenges

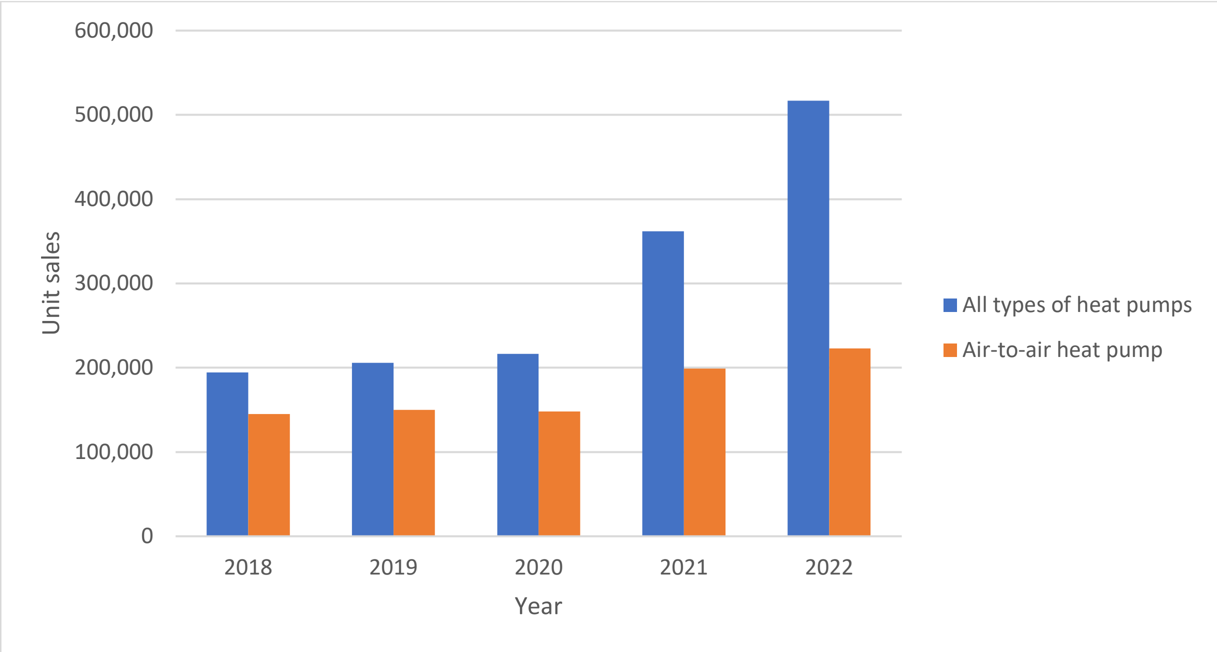
The process of electrifying homes in Germany is supported by several factors. There is strong political and public backing for reducing carbon emissions from heating. Both new builds and renovated properties are subject to strict rules that encourage the use of low-carbon heating appliances and offer substantial incentives. Heat pumps are becoming increasingly favoured in newly constructed homes. Plus, there is significant pressure on existing homes not connected to the gas grid and still reliant on oil boilers to transition to other fuel sources, with government banning fossil fuel heating systems entirely from 2045.

Challenges in Germany for the electrification of homes include current energy prices making it difficult to compete with natural gas, based on end-user economics alone. There are growing concerns over how the electricity networks can best manage the impacts of electrifying residential heating and transport. Additionally, there is a shortage of skilled heat pump installers and heating engineers more broadly.[177]

The government will cover up to 70% of the costs of new sustainable heating systems from 2024. The new system caps support for a whole house retrofit at €21,000, which is €3,000 less than the previous scheme. The government aims to install up to 500k new units per year by 2024 to decarbonise Germany's heating sector.[178]

5.8.2 Italy- Heat pump market growth, 2018-2022[179]

Figure 12: Annual unit sales of heat pumps in Italy



[177] Opportunities for electric heating in Germany. https://research.lcpdelta.com/reportaction/OpportunitiesforelectricheatinginGermany/Marketing?SearchTerms=OPPORTUNITIES%20FOR%20ELECTRIC%20%20HEATING%20IN%20GERMANY
[178] Heat pump installations tumble in Germany following subsidy cut. https://www.cleanenergywire.org/news/heat-pump-installations-tumble-germany-following-subsidy-cut
[179] Opportunities for Electrification of Heat in Italy (Interim update) https://research.lcpdelta.com/reportaction/Opportunities_for_Italy/Toc?SearchTerms=italy

Figure 13: Total heat pump technology unit sales by type from 2018 to 2022.

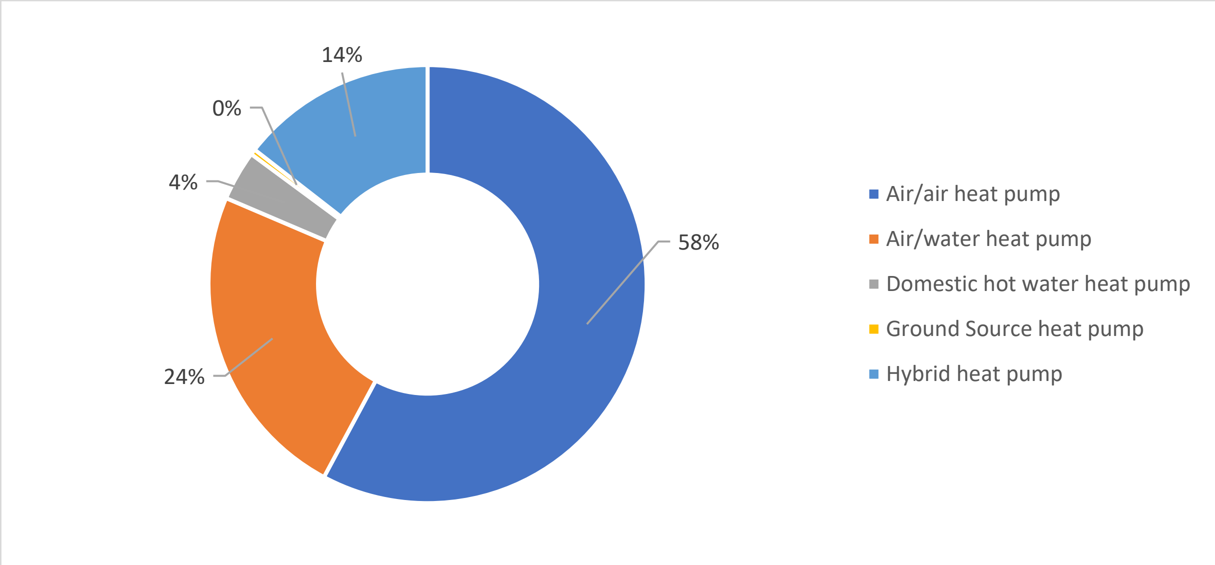
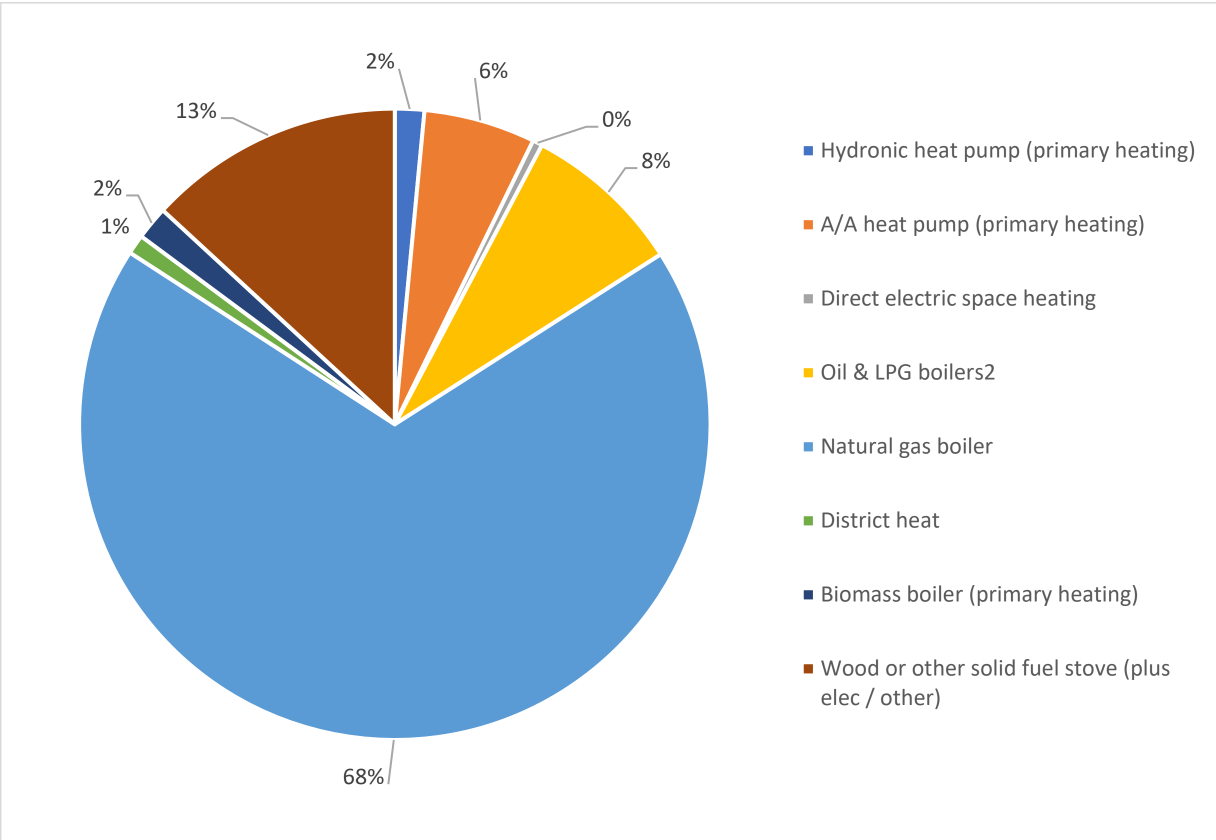


Figure 14: Italy- Existing primary heating systems



In Italy, from 2018 to 2022, air-to-air heat pumps had the highest sales among all heat pump types, selling a total of 865k units. The next most sold were air-to-water heat pumps, with 352k units sold. The sales of domestic hot water heat pumps and hybrid heat pumps were considerably lower, with 55k and 216k units sold, respectively. The least sold were ground source heat pumps, with only 6k units sold over this period.

The installation of air-to-air heat pumps in Italy has seen a consistent increase from 2018 to 2022. In 2018, approximately 145k units were sold. This number slightly increased to 150k in

2019 and mildly dropped to 148k in 2020. However, there was a significant jump in 2021 with 199k units sold. The trend continued in 2022 with 223k units sold. This continuous increase indicates a growing preference and demand for air-to-air heat pumps in Italy over these years.

In Italy, the primary heating source for most households is natural gas boilers, at 68.0%. The second most common heating source is wood or other solid fuel stove at 13.1%. Oil & LPG boilers make up 8.2% of heating, and air-to-air heat pumps are used by 5.7% of households. Hydronic heat pumps, direct electric space heating, district heat, and biomass boilers (primary heating) make up the rest, each accounting for less than 2% of the primary heating sources.

5.8.2.1 Opportunities and Challenges

In Italy, as with many other countries, the electrification of homes faces challenges such as fluctuating energy prices, policy measures, incentives, and developments in the building sector. The cost-effectiveness of heat pump systems is also influenced by the electricity-gas price ratio, which was 2.3 in the second half of 2022 and 2.2 in the second half of 2023. Moreover, a lack of awareness in the supply chain and the initial investment cost of heat pump technology poses additional hurdles.[180]

The challenges for heat pump implementation in Italy include the availability of incentives for fossil fuel boilers until 2024, along with plans to expand the existing natural gas network. Current energy prices make heat pumps less competitive with natural gas. There is also a shortage of skilled heat pump installers, and the potential role of 'green gases' and district heating growth could further influence the market.[181]

In terms of drivers for rates of installations, there were generous incentives in place that encouraged historic install of heat pumps, including funding for 110% of installation costs[182]. In addition, demand for air-to-air heat pumps is high because the summer cooling demand is greater than the winter heating demand, making the selection of air-to-air heat pumps attractive because they can provide heating and cooling.[183]

[180] The heat-pump market in Italy: an in-depth economic study about the reasons for a still unexpressed potential https://academic.oup.com/ce/article/3/2/126/5393281

[181] Opportunities for High Efficiency Gas Heating in Italy (Interim update) https://research.lcpdelta.com/reportaction/High_Efficiency_Italy/Marketing?SearchTerms=opportunity%20for%20electriv%20heating%20in%20italy

[182] https://www.theecoexperts.co.uk/heat-pumps/top-countries#seven

[183] M. Pieve and R. Trinchieri, “Heat pump market report for Italy,” IEA, 2018.

5.8.3 Netherlands - Heat pump market growth, 2018-2022[184]

Figure 15: Annual unit sales of heat pumps in the Netherlands

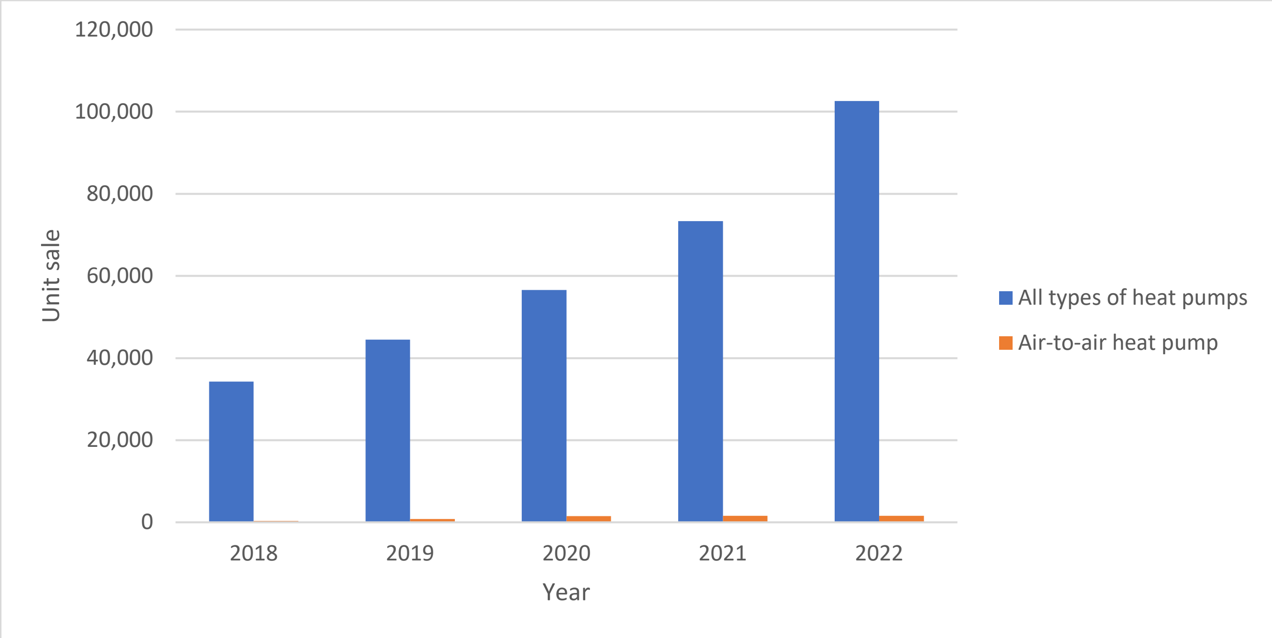
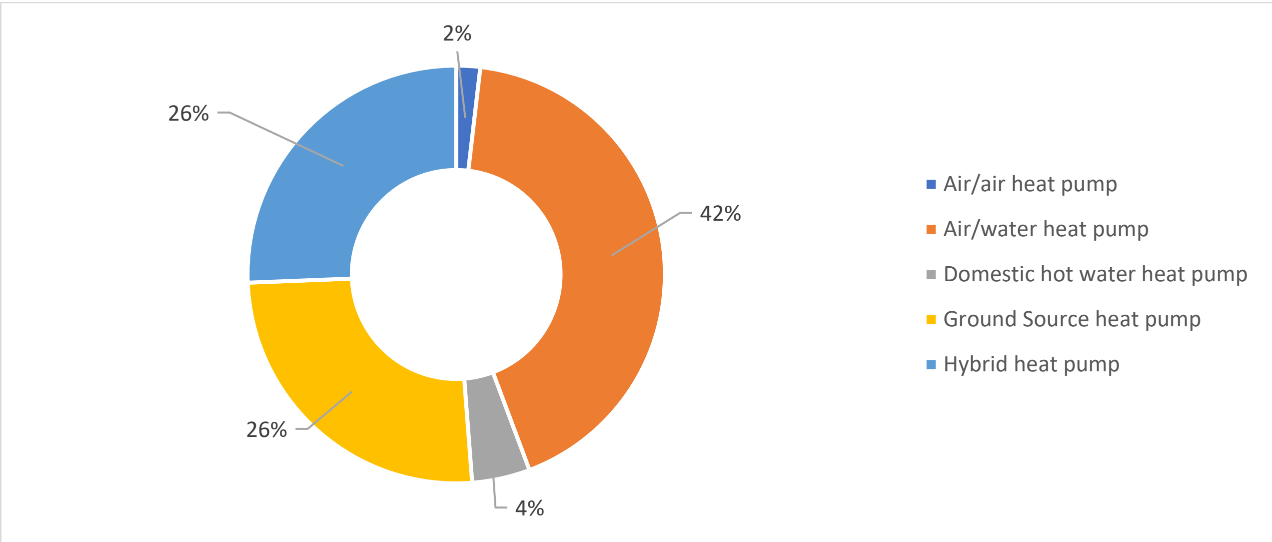


Figure 16: Total heat pump technology unit sales from 2018 to 2022 in the Netherlands



Heat pump sales in the Netherlands have significantly increased from 2018 to 2022. The figures rose from 34k units in 2018 to 103k units in 2022.

However, despite the substantial growth in heat pump sales in general, air-to-air still constitute a minor fraction of the total. While their sales increased four times from 2018 to 2022, they only

[184] Opportunities for Electrification of Heat in the Netherlands (Interim update) https://research.lcpdelta.com/reportaction/EHS_NL_Update_2023/Marketing?SearchTerms=Opportunities%20for%20High%20Efficiency%20Gas%20Heating%20netherland

made up 2% of total heat pump sales in 2022. Air-to-water heat pumps and hybrid heat pumps each accounted for 26% of total sales, and ground source heat pumps represented 42%.

5.8.3.1 Opportunities and challenges

In the Netherlands, air-to-water heat pumps are expected to dominate the new build market this decade, with strong policy support for retrofits and subsidies covering up to 30% of the total cost. Despite temporary energy price caps in 2023, the opportunity for electric heating will significantly grow due to the strong economic case for both hybrid and all-electric heat pumps compared to natural gas boilers, with analysis by the Regulatory Assistance Project showing that Tax reforms, shifting levies to fossil fuels, in the Netherlands have caused heat pumps to be more cost effective than gas boilers[185]. Post-2026 efficiency standards will further strengthen the role of hybrid heat pumps.[186]

The challenges for the electrification of heat in the Netherlands include supply chain constraints leading to long wait times for heat pumps, often up to a year. There is also a lack of installer capacity. Despite the push for electrification, natural gas boilers are expected to continue playing a significant role due to several exceptions to the efficiency standard. Additionally, the decarbonisation of the gas grid is expected to use biomethane in the short term and hydrogen in the long term. Lastly, the expansion of district heating grids, particularly in new builds, will accelerate towards the end of this decade.[187]

[185] J. Rosenow, S. Thomas, D. Gibb, R. Baetens, A. Brouwer and J. Cornillie, "Levelling the playing field: Aligning heating energy taxes and levies in Europe with climate goals," Regulatory Assistance Project, Brussels, 2022.
[186] Opportunities for Electrification of Heat in the Netherlands (Interim update) https://research.lcpdelta.com/reportaction/EHS_NL_Update_2023/Marketing?SearchTerms=Opportunities%20for%20High%20Efficiency%20Gas%20Heating%20netherland
[187] Opportunities for Electrification of Heat in the Netherlands (Interim update) https://research.lcpdelta.com/reportaction/EHS_NL_Update_2023/Marketing?SearchTerms=Opportunities%20for%20High%20Efficiency%20Gas%20Heating%20netherland

5.8.4 France - Heat pump market growth, 2018-2022[188]

Figure 17: Annual unit sales of heat pumps in France

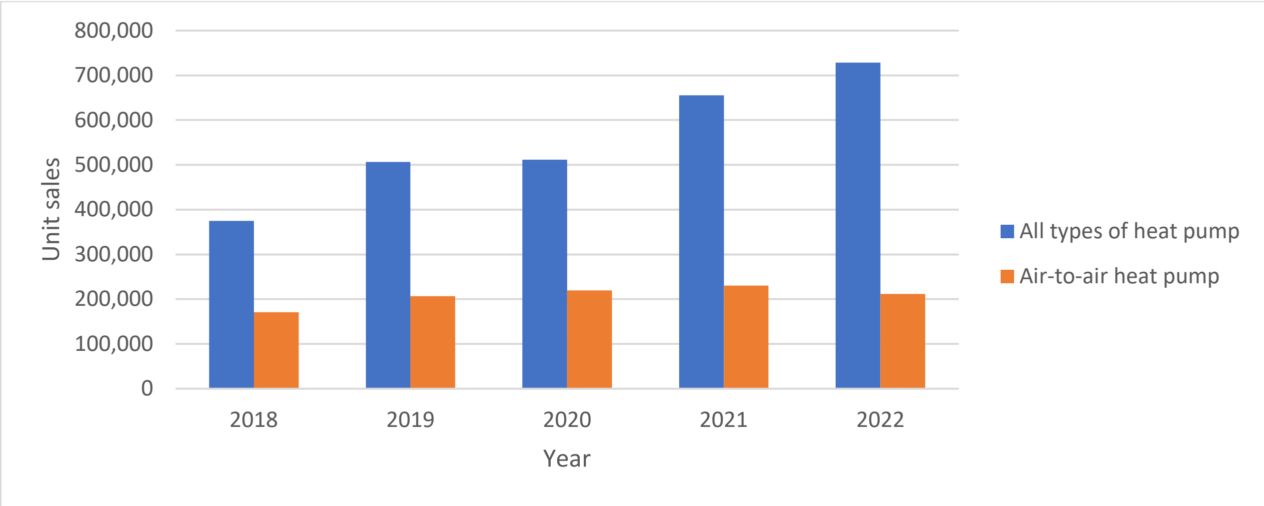
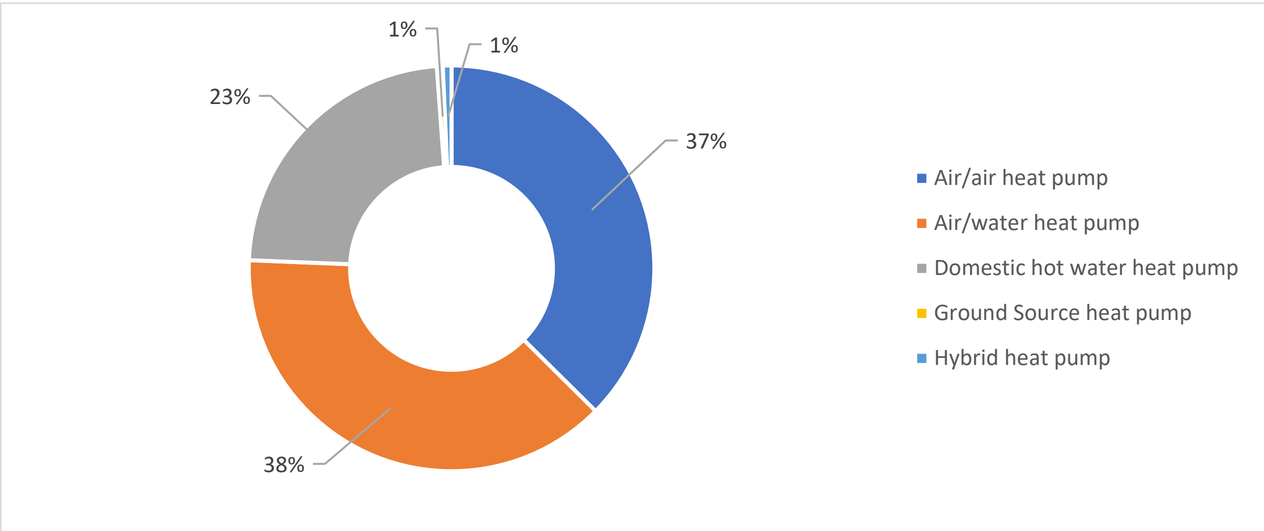


Figure 18: Total heat pump unit sales from 2018 to 2022 in France



The total sales for all types of heat pump installations in France from 2018 to 2022 showed an upward trend. The annual sales increased from 375k units in 2018 to 728k units in 2022. Looking at air-to-air heat pump installations, the annual sales also increased over the same period, from 170k units in 2018 to 212k units in 2022.

Air-to-water heat pumps comprise the largest segment at 38%, closely followed by air-to-air heat pumps at 37%, and domestic hot water heat pumps at 23%. This distribution highlights the demand for various heat pump technologies based on user-specific needs and circumstances. Furthermore, the substantial portion of total heat pump sales accounted for by air-to-air heat pumps suggests their popularity among all heat pump technologies.

[188] Opportunities for Electrification of Heat in France (Interim update) https://research.lcpdelta.com/reportaction/Opportunities_for_France/Marketing?SearchTerms=france

The majority (70%) of heat pump sales from 2018 to 2022 were for retrofit installations, with the remaining 30% being new builds.

5.8.4.1 Opportunities and Challenges

Since 2008, France has focused on the adoption of reversible air-to-air heat pumps. The country's hotter southern regions had already led to the development of a strong air conditioning industry, providing the necessary expertise, business structures, and understanding of the technology. This experience was easily applied to the implementation of hydronic heat pump technologies, leading to the widespread installation of these systems.

Despite encountering similar hurdles such as high upfront costs in the mass-scale deployment of heat pumps, France has fared better than the UK. The MCS Charitable Foundation[189] conducted a comparative study to identify the key factors behind France's superior success rate in heat pump deployment.

The result of this study shows that France's successful deployment of heat pumps can be attributed to a combination of factors including:

- Exogenous aspects like a warm climate and low supply of domestic fossil fuels
- Transferable knowledge and competences from the well-established air conditioning industry, which facilitated a streamlined, end-to-end heat pump supply chain.
- Social factors, such as President Macron's home efficiency campaign, with grants available for those making energy efficiency improvements such as installing heat pumps or insulation in their homes, and a better understanding of the technology among consumers. Support through the *MaPrimeRénov Sérénité* scheme includes air-to-air heat pumps, covering up to 50% for works costing €15,000 (i.e. a maximum of €7,500) [190].
- The macroeconomic situation, characterised by a well-established air conditioning market and low electricity prices.
- Assets and infrastructure - the country boasts a strong electricity grid and nuclear power.
- Strong electricity lobby.
- Cognitive frames like a strong discourse around energy independence and a centralised approach to heat decarbonisation.
- Supportive policies, regulations, and standards, such as a 0% interest loan, new build efficiency regulation, and improved financial schemes in 2019.

[189] Heat Pump Rollout in France and the UK: a Comparative Analysis https://mcsfoundation.org.uk/wp-content/uploads/2023/10/MCSCF-HeatPumpReport2023.pdf
[190] https://www.connexionfrance.com/practical/does-france-offer-grants-to-install-reversible-air-conditioning/122420

5.8.5 The lessons learnt from the Netherlands, Italy, France and Germany

The UK can learn valuable lessons from the experiences of France, the Netherlands, Italy, and Germany in deploying and adopting heat pumps. From France, the importance of leveraging existing industry competencies and understanding of technology is clear. The Netherlands demonstrates the positive impact of strong policy support and subsidies for heat pump adoption. Italy's growth in heat pump sales, despite energy price fluctuations and initial investment costs, shows the potential for market growth in spite of challenges. Finally, Germany's experience highlights the need for public and political backing in reducing carbon emissions from heating and the potential impact of changes in energy prices.

5.9 Successful case studies

Air-to-air heat pumps have been suggested for use in various applications, such as the following:

New constructions

Air-to-air heat pumps may be useful for newly-constructed homes with high insulation levels. A report by AECOM into overheating in new homes found that newer, better insulated, properties tended to be at greater risk of overheating than older properties[191] and air-to-air heat pumps could be used to combat this risk, as outlined in section 4.3.1. As in section 3.1.2, air-to-air heat pumps are suited to properties that do not already have a wet central heating system, where the need for radiators and other central heating pipework to be installed can be avoided.

Replacing electric heating

An air-to-air heat pump is an excellent replacement for electric heating systems, avoiding the need to install a new plumbing system for central heating. The units are versatile and easy to install, with several designs available to suit varying needs. With high energy efficiency ratings in both heating and cooling, significant savings on energy consumption can be achieved.

Energy Consumption Reduction

If the current heating system is still functional but there is a desire to lower energy consumption, an air-to-air heat pump as an additional system can be considered. This arrangement allows for the use of the heat pump for heating and cooling, while the existing system can be reserved for hot water production and heating of peripheral rooms.

5.9.1 Case studies overview

Detailed case studies on the use of air-to-air heat pumps are provided in the appendix. From these, several key themes can be identified.

[191] AECOM, “Research into overheating in new homes,” Ministry of Housing, Communities and Local Government, London, 2019.

Cooling and heating needs: Air-to-air heat pumps effectively regulate indoor temperatures, providing cooling during hot summers and heating during cold winters. This has been demonstrated in multiple cases, from family home renovations in Hertfordshire to garden rooms in Essex and Hertfordshire.

Home extensions: Air-to-air heat pumps are particularly beneficial for newly extended homes, which often face challenges related to overheating in summer and insufficient warmth in winter due to factors such as increased natural light. The case study from Hertfordshire showcases this application.

Decentralised solutions: Air-to-air heat pumps provide a decentralised solution for heating and cooling specific areas in a home without affecting other zones. This was the case in the family home in Chester, where a specific area of the house was cold and poorly insulated.

Space-saving and design consideration: The systems are compact, which can fit well with the home's design, as seen in the case studies from Brighton and the new build home.

Energy efficiency and costs: These systems are energy efficient, leading to significant savings on energy consumption. This was illustrated in the case studies from Chester and Brighton.

In conclusion, air-to-air heat pumps are versatile, energy-efficient, and effective for both heating and cooling needs. They are particularly useful in situations where specific areas need to be temperature regulated, and in homes where maintaining aesthetics is important.

6 Policy and regulation impact (WP4)

As air-to-air heat pumps can provide both heating and cooling to domestic properties, the UK government's policy approach to both themes is relevant to their deployment. This review of the policy literature therefore looks at policy for both heating and cooling in the UK and the extent to which they are integrated.

Key points:

- Overheating of buildings is a significant health risk. Heat causes excess deaths, spread unequally across the population, and it will be an increasing problem in the future as the climate changes and the UK experiences more extreme, and longer, heatwaves.
- To date there has been limited visibility of cooling considerations in UK building policy, and there is limited data on cooling practices in buildings.
- The UK takes a 'passive first' approach to cooling buildings, where overheating is managed through building design methods for new build properties such as fixed shading and glazing designs. This avoids adding waste heat externally and does not increase building energy demand. This contrasts with active cooling provided by air-to-air heat pumps.
- Both passive and active cooling approaches have limitations. Passive cooling is limited ultimately by the external ambient temperatures. Active cooling by air-to-air heat pumps has disadvantages as they use F-gases which can have high GWP and are limited under the Montreal Protocol, and they add to the electricity demand of buildings.
- Air-to-air heat pumps can provide a space heating solution for many buildings; however they are more limited than some other low-carbon heating technologies as most designs do not provide water heating.
- There is provision for air-to-air heat pumps in existing building regulations, but only in restricted circumstances and after passive cooling approaches have been considered.

There are limited grants for installing domestic air-to-air pumps, but it would be possible to expand existing policies to include them in the future.

6.1 Heating

In considering the transition of buildings to Net Zero, the UK government has focused on decarbonising heat. Decarbonising heating is a significant challenge for Net Zero. Buildings are responsible for about 30% of the UK's national emissions and most of these emissions are attributable to heating: 79% of building emissions and about 23% of all UK emissions.[192]

[192] Department for Energy Security & Net Zero. Heat and Buildings Strategy. 2021. https://www.gov.uk/government/publications/heat-and-buildings-strategy

The government has expressed a view that heat pumps and heat networks will be the primary means for decarbonising heating over the next decade and play a prominent role in all scenarios for achieving Net Zero by 2050, while decisions on the role of low-carbon hydrogen for heating are expected in 2026.[193] The Heat and Buildings Strategy, published in 2021, specifies that hydronic (air-to-water or ground-to-water) heat pumps are viewed as the key heat pump technology.[194]

Air-to-air heat pumps can provide space heating. However, unlike hydronic heat pumps or modern gas boilers, most air-to-air heat pumps do not offer a solution for hot water provision and therefore need to be installed alongside another technology to provide a fully decarbonised solution for a household. However, as noted in section 4.2, air-to-air heat pumps with the capacity to provide hot water are becoming available. This may mean that air-to-air heat pumps are a more attractive option for policy makers looking to decarbonise domestic heating in the future.

6.2 Cooling

Heat is a growing health risk with the potential to exacerbate health inequalities.[195] It is often the poorest and most vulnerable members of society who are at the greatest risk due to poorer design of homes and inability to put in place measures to mitigate excess heat.[196] The UK Health Security Agency estimates that there were 2,985 all-cause excess deaths associated with five heat episodes during the summer of 2022, which saw that highest recorded temperature in England at 40.3°C.[197] It is therefore likely that health concerns will become increasingly pertinent as a driver of policy related to cooling in the UK.

Until recently, little attention had been paid to future energy demand for cooling. As a result, there was little discussion about the cooling strategies that households apply in response to overheating events and how these need to be considered by policy for Net Zero homes. Previous reviews of the policy landscape have found that cooling is not prominent in UK energy policy and research and that, where the need for domestic cooling has been considered, the UK has prioritised a 'passive first' approach in preference to the 'active' cooling solution provided by air-to-air heat pumps.[198]

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[193] Department for Energy Security & Net Zero. Committee on Climate Change 2023 progress report: government response. 2023. https://www.gov.uk/government/publications/committee-on-climate-change-2023-progress-report-government-response
[194] Department for Energy Security & Net Zero. Heat and Buildings Strategy. 2021. https://www.gov.uk/government/publications/heat-and-buildings-strategy
[195] United Nations Environment Programme. Global Cooling Watch. 2023. https://www.unep.org/resources/global-cooling-watch-2023
[196] Arup. Addressing overheating risk in existing UK homes. 2022. https://www.theccc.org.uk/publication/addressing-overheating-risk-in-existing-uk-homes-arup/
[197] UK Health Security Agency. Heat mortality monitoring report: 2022. 2024. https://www.gov.uk/government/publications/heat-mortality-monitoring-reports/heat-mortality-monitoring-report-2022
[198] Khosrav, Lowes & Ugalde-Loo. Cooling is hotting up in the UK, Energy Policy 174. 2023.

In 2021, the UK government published a research study aiming to address the evidence gap by improving the evidence base on future cooling demand across the UK building stock and the impact of alternative policy approaches. The study examined three policy scenarios:

- No Intervention: the market determines the uptake of different measures.
- Passive First: Government intervenes to prioritise passive cooling measures.
- Efficient Technologies: the market determines the uptake of different measures, but the government requires any refrigeration cooling systems adopted to be high efficiency.

The study looked at two emissions scenarios:

- Low emissions, projected to reach a mean global temperature rise of 1.5°C by 2081-2100;
- High emissions, projected to reach a mean global temperature rise of 4.0°C by 2081-2100.

It found that in the No Intervention scenario, annual cooling energy consumption will be around 6.3TWh and 12.0TWh for the high and low emissions scenarios respectively by 2100. The study cited an estimate suggesting cooling energy consumption was approximately 6.187TWh in 2020. The Efficient Technologies reduced the High emissions scenario consumption by around 21% and the Passive First scenario reduced it by around 34%. The Passive First approach was found to cost around £20-30bn by 2050, compared to £60-70bn for the No Intervention or Efficient Technologies scenarios. The study also identified challenges around the scale and timing of peak cooling demand and potential synergies with the retrofit required to decarbonise heating.[199] In addition, the work alludes to the potential synergy between increased demand for cooling and electrification of heat, but did not attempt to quantify any benefit to heat electrification progress which could result from the appeal of cooling functionality.

Passive cooling measures have several advantages: they do not add waste heat to the environment, avoid contributing to urban heat island effects and do not increase home energy use.[200] A report by the House of Commons Environmental Audit Committee published in early 2024 recommended that ministers should adopt an approach to heat resilience that prioritises passive cooling.[201]

The Climate Change Committee has noted that the cooling potential of passive measures is fundamentally limited by the outdoor temperature and therefore may not be able to reduce indoor air temperatures to comfortable levels during intense and prolonged heatwaves,

[199] Department for Business, Energy & Industrial Strategy. *Cooling in the UK.* 2021. https://www.gov.uk/government/publications/cooling-in-the-uk
[200] Climate Change Committee (2022), Risks to health, wellbeing and productivity from overheating in buildings https://www.theccc.org.uk/publication/risks-to-health-wellbeing-and-productivity-from-overheating-in-buildings/
[201] House of Commons Environmental Audit Committee. Heat resilience and sustainable cooling: Fifth Report of Session 2023-24. 2024.

meaning that active cooling may be necessary in parts of the UK (particularly in urban areas in the South East).[202] The UK Government's Heat and Buildings Strategy was prefaced with:[203]

> "*In this strategy, our primary focus is on reducing emissions from heating, which, given the UK's climate, is the predominant source of emissions from buildings. However, we are mindful of the current and potential future demand of cooling, which we will look to consider further as we continue to develop our approach to long-term choices for low carbon heating.*"

The strategy acknowledges the need to take a whole-building and whole-system approach to decarbonisation, and therefore include the cooling needs of a building in assessment. The strategy highlights the capacity of heat pumps and some heat networks to provide cooling as well as heating as a benefit of the technology choice. The strategy notes that some cooling systems use hydrofluorocarbons (HFCs), which have a greater global warming potential than carbon dioxide, concluding that increased cooling needs will have to be met in a way that minimises contributions to climate change. The United Nations Environment Programme highlights that active cooling is a "double burden on climate change" due to greater indirect emissions from increased electricity demand, coupled with direct emissions from the potential release of refrigerant gases. This means that action is needed in three areas: implementation of passive cooling strategies, higher energy efficiency standards and norms for cooling equipment, and phasing down of HFC refrigerants.[204]

6.3 International commitments

The UK has commitments to reduce the use of HFCs, which may present a barrier to policy support for adoption of air-to-air heat pumps in domestic properties.

The 2014 European Union (EU) F-gas regulations require a 79% reduction in use of HFCs between 2015 and 2030, while the UK introduced the Fluorinated Greenhouse Gases Regulations 2015 (amended in 2018). [205]

The main objective of the F-gas Regulation is to reduce F-gas emissions by:

- Establishing rules on containment, use, recovery, and destruction of F-gases.
- Imposing conditions on placing specific products and equipment containing F-gases on the market.

[202] Climate Change Committee (2022), Risks to health, wellbeing and productivity from overheating in buildings https://www.theccc.org.uk/publication/risks-to-health-wellbeing-and-productivity-from-overheating-in-buildings/
[203] Department for Energy Security & Net Zero. Heat and Buildings Strategy. 2021. https://www.gov.uk/government/publications/heat-and-buildings-strategy
[204] United Nations Environment Programme. Global Cooling Watch 2023. 2023. https://www.unep.org/resources/global-cooling-watch-2023
[205] Department for Environment, Food & Rural Affairs, Scottish Government & Welsh Government. F gas regulation in Great Britain Assessment Report. 2022. https://assets.publishing.service.gov.uk/media/63a2f8e9e90e075878e52448/F_gas_regulation_in_Great_Britain.pdf

- Imposing conditions on the specific uses of F-gases.
- Establishing quantitative limits for placing hydrofluorocarbons (HFCs) on the market.

The Kigali Amendment to the Montreal Protocol was adopted in 2016, under which Parties to the Protocol agreed to reduce global production and consumption of HFCs. Developed countries such as the UK are required to reduce HFC production and consumption by 85% by 2036.[206]

The UK signed up to the Global Cooling Pledge initiative at COP28 in 2023, which “aims to raise ambition and international cooperation through collective global targets to reduce cooling related emissions by 68% from today by 2050, significantly increase access to sustainable cooling by 2030, and increase the global average efficiency of new air conditioners by 50%”. The pledge also sets out further commitments, including:[207]

- Support for robust action to reduce HFC consumption and promote improved energy efficiency for HCFC phase-out and HFC phase-down.
- Publishing a national cooling action plan, considering cooling when publishing a national action plan, or publishing a regulation or equivalent by 2026 and to reflect relevant efforts in designing nationally determined contributions under the Paris Agreement and HFC phase-down plans.
- Establishing national model building energy codes that incorporate market appropriate measure such as passive cooling and energy efficiency strategies at the latest by 2030.
- Establish Minimum Energy Performance Standards by 2030.
- Support collaborative research, innovation, and deployment activities at the local and international level in rural, remote, off-grid locations or research and development of cooling systems applying refrigerants with GWP less than 150.
- Maintaining up-to-date, transparent, and publicly available information on our policies and commitments.

6.4 Building regulations

The preference for passive cooling is reflected in current building regulations. Changes to Building Regulations Part O: Overheating came into force in June 2022.[208] These require that all reasonable provision must be made to limit unwanted solar gains in summer and provide adequate means to remove heat from the indoor environment, to protect the health and welfare

[206] Department for Environment, Food & Rural Affairs, Scottish Government & Welsh Government. F gas regulation in Great Britain Assessment Report. 2022. https://assets.publishing.service.gov.uk/media/63a2f8e9e90e075878e52448/F_gas_regulation_in_Great_Britain.pdf

[207] United Nations Environment Programme. Report: Global Cooling Pledge. 2023. https://www.unep.org/resources/report/global-cooling-pledge

[208] Department for Levelling Up, Housing & Communities (2021), Statutory guidance – Overheating: Approved Document O https://www.gov.uk/government/publications/overheating-approved-document-o#full-publication-update-history

of occupants. Acceptable strategies for reducing overheating risk include fixed shading devices (e.g. shutters, external blinds) and glazing design (e.g. size and orientation of windows), building design, and shading provided by adjacent buildings, structures, or landscaping. The means listed for removing excessive heat are opening windows, ventilation louvres in external walls, mechanical ventilation systems, or a mechanical cooling system.

This implies that air-to-air heat pumps can be used for cooling within the building regulations, however the regulations are clear that this must be a last resort, and that passive cooling is preferred: "It should be demonstrated to the building control body that all practicable passive means of limited unwanted solar gains and removing excess heat have been used first before adopting mechanical cooling. Any mechanical cooling (air-conditioning) is expected to be used only where [the requirement] cannot be met using openings."

Building regulations primarily drive action in the new build market. Policy and regulation relating to cooling in existing properties is largely absent.

6.5 Incentives for uptake

Air source heat pumps are among the energy saving and heating equipment subject to a zero rate of VAT. HMRC guidance indicates that air-to-air heat pumps would qualify for relief when installed in residential accommodation if they are providing heating as well as cooling, however this will depend on the specific circumstances:[209]

> "*Fixed air source heat pumps can be reversed so that they can draw heat from inside a building, thus providing cooling during the summer as well as indoor heating for colder periods of the year… HMRC's understanding is that most air conditioning units are air source heat pumps. However, in cases of doubt, deciding if any particular product is to be treated as an air source heat pump will depend on the facts of each case.*"

One of the policy levers that the UK government has adopted to increase uptake of low-carbon heating technologies is the provision of grants. Most grants available for low-carbon heating technologies do not currently support households wishing to adopt air-to-air heat pumps, though there is potential for these measures to be funded through some schemes.

The following grants and support schemes are available to cover some of the costs of households switching to low-carbon heating (with eligibility criteria depending on household characteristics and property tenure):

Boiler Upgrade Scheme – households can get a grant of up to £7,500 to cover part of the cost of replacing fossil fuel heating systems with a heat pump or biomass boiler. To be eligible for grant support, the new heating system must be capable of meeting the full space heating and hot water requirements of the property and the guidance specifies that air-to-air heat pumps

[209] HM Revenue & Customs. Guidance: Energy-saving materials and heating equipment (VAT Notice 708/6). https://www.gov.uk/guidance/vat-on-energy-saving-materials-and-heating-equipment-notice-7086

that use exhaust heat are not eligible.[210] The Boiler Upgrade Scheme regulations stipulate that to be eligible for the funding, a heat pump must provide heating “for the purpose of both space heating and hot water heating, using liquid as a medium for delivering that heat”.[211] While some air-to-air heat pump models can provide water heating, they do not use water as a medium for delivering space heating.

Energy Company Obligation (ECO) – only hydronic heat pumps can be funded through the ECO4 scheme, therefore air-to-air heat pumps are not eligible for funding.[212]

Home Upgrade Grant – guidance published in September 2022 stated that air-to-air heat pumps can be installed under the grant if suitable. The guidance stated that low temperature hydronic heat pumps are expected to be the ‘lead technology’, but that where they are found to be unsuitable for a dwelling there is a hierarchy of alternative measures that can be installed, including air-to-air heat pumps.[213] Guidance published in November 2023 does not mention air-to-air heat pumps.[214]

Social Housing Decarbonisation Fund – guidance states that “eligible low carbon heating measures must be compatible with the Standard Assessment Procedure (SAP)” and that low temperature hydronic heat pumps are expected to be the lead technology, with air-to-air heat pumps among several alternative measures listed if these are found to be unsuitable for the property.[215]

The Clean Heat Market Mechanism, designed to grow the UK market for heat pumps, only applies to the installation of hydronic heat pumps.[216]

Price signals in current energy markets do not incentivise the uptake of electrified heating solutions in general, including air-to-air heat pumps. The higher unit cost of electricity compared to gas means that heat pumps do not generally deliver significant running cost savings compared with gas boilers, despite their higher efficiency. This higher unit cost is contributed to by policy costs that are applied to electricity bills and several approaches have been suggested as a way of reducing the disparity.[217] Government has signalled its intention to address this and in *Powering Up Britain* committed to outlining a clear approach to gas vs.

[210] Ofgem. Boiler Upgrade Scheme: Guidance for Installers. 2023. https://www.ofgem.gov.uk/publications/boiler-upgrade-scheme-guidance-installers
[211] *The Boiler Upgrade Scheme (England and Wales) Regulations 2022.* https://www.legislation.gov.uk/uksi/2022/565/regulation/9/made
[212] Ofgem. Energy Company Obligation (ECO4) Guidance: Delivery. 2022. https://www.ofgem.gov.uk/publications/energy-company-obligation-eco4-guidance-delivery
[213] Department for Energy Security & Net Zero. Home Upgrade Grant: Phase 2: Guidance for local authorities. 2022. https://assets.publishing.service.gov.uk/media/6360fb6ed3bf7f04e834e112/hug-phase-2-guidance-local-authorities.pdf
[214] Department for Energy Security & Net Zero. HUG Phase 2: Delivery guidance for local authorities (updated November 2023). 2023. https://www.gov.uk/government/publications/home-upgrade-grant-phase-2
[215] Department for Energy Security & Net Zero. SHDF Wave 2.2: Competition guidance (updated 29 December 2023). 2023. https://www.gov.uk/government/publications/social-housing-decarbonisation-fund-wave-22
[216] Department for Energy Security & Net Zero. Consultation outcome: Clean heat market mechanism. 2023. https://www.gov.uk/government/consultations/clean-heat-market-mechanism
[217] Citizens Advice. Balancing Act: The implications of transferring policy levies from electricity to gas bills. 2023. https://www.citizensadvice.org.uk/policy/publications/balancing-act-the-implications-of-transferring-policy-levies-from-electricity-to-gas-bills/

electricity price rebalancing by the end of 2023/24 and making significant progress affecting relative prices by the end of 2024.[218]

[218] Department for Energy Security & Net Zero. Powering Up Britain. 2023. https://www.gov.uk/government/publications/powering-up-britain

7 Conclusions

In conclusion, air-to-air heat pumps have significant potential in the UK market due to their energy efficiency, versatility, and ease of installation. Feedback suggests that systems provide increased levels of comfort, heating properties up quickly, and users are largely satisfied with levels of noise produced. Air-to-air systems can easily be retrofitted into properties, although installation is not challenge-free, as is the case with other heat pump types. Issues remain around removal of existing systems, planning requirements, and distribution network operator approval. The UK has a large installer base skilled in the installation of air-to-air heat pumps, currently almost entirely focussed on the commercial sector.

While refrigerants in current use comply with EU and UK legislation, there are questions around whether F-gases will be phased out and the impact that would have on air-to-air heat pumps. System performance was found to vary, according to system size and model, and a gap between in-situ and rated performance was discovered throughout literature, where manufacturer literature and in-situ performance ranges were found to be 3.8-4.8 and 2.0-5.0 respectively.

Air-to-air heat pumps provide both heating and cooling capabilities and are considered cost-competitive with other types of heat pump. Some literature found them cheaper to run than fossil fuel boilers or other heat pumps, and a greener alternative to traditional heating systems. There are a range of manufacturers on the market who can provide solutions to suit a range of property types and applications, however, more than one air-to-air system or complementary heating systems are needed for larger properties. They appear to be particularly suited to flats, properties with existing electrical heating systems or no current wet heating system, and poorly insulated properties, such as those with solid walls or park homes. Air-to-air heat pump systems that can also generate hot water present an opportunity to provide a simple 'all-in-one' solution for properties, but there are currently limited models available in the UK.

In addition to heating, reversible air-to-air heat pumps can also provide cooling, supporting adaptation to increased periods of extreme heat expected as a result of climate change. While cooling can be used to benefit users, particularly the elderly or vulnerable, the literature presented some concerns in how widescale use of cooling could affect electricity demand and therefore the need to consider passive cooling solutions as well.

Air-to-air heat pumps are far more widely used in homes in some European countries, with Norway showing the highest proportion at 35% of the installed heating systems, although air-to-water sales have recently caught up with and overtaken air-to-air systems in a selection of countries studied.

Incentives and building regulations are less supportive of air-to-air heat pumps than other types, which may discourage their uptake in situations where they could be particularly beneficial, and accelerate the decarbonisation of domestic heating.

8 Recommendations and further work

This work discovered a clear lack of evidence around real-world performance of air-to-air heat pumps in domestic settings in the UK that would allow the verification of usage patterns of the systems and enable consumer feedback to be gained on comfort and appeal. Data collected by a trial could be used to model the impact of installing these systems at wider scale throughout the UK, and improve understanding of how cooling would impact electricity demand and emissions.

More clarity is needed around the characteristics of homes and occupant usage patterns for which air-to-air heat pumps could be advantageous over air-to-water, to optimally target their deployment. The size, type and age of building, type of existing heating system, occupancy patterns, and heating control preferences are examples of the variables that could be studied to understand which situations air-to-air would be best suited to. Households who prefer heating of selected rooms only, or intermittent heating schedules, may experience different outcomes with air-to-air systems compared to air-to-water. Households in fuel poverty may struggle with the common advice to run air-to-water heat pumps continuously. Greater understanding is needed to determine optimum usage patterns for air-to-air heat pumps.

A trial should also aim to test technology that incorporates hot water production, to understand the benefits in comparison to standalone solutions, and collect data to quantify OPEX and total energy use. By undertaking a trial, challenges such as the installer shortage can be explored, and data can be obtained that compares in-situ with manufacturer rated performance.

Work should also be undertaken to address the unknowns around refrigerant use, including an assessment of viable alternative refrigerants.

Households could be studied to assess whether the cooling function increases their willingness to switch to a heat pump. If the appeal of this functionality resulted in heat electrification occurring earlier than it would have done otherwise, or in households that would not have electrified otherwise, the emissions saving of this electrification could be estimated, and weighed up against the emissions from cooling demand.

9 Appendix

The following case studies are sourced from marketing materials provided by the manufacturers or installers.

9.1.1 Case Study 1: Family home renovation - Hertfordshire[219]

This case study showcases the effectiveness of using an air-to-air heat pump system for a family home renovation project in Hertfordshire, UK.

Challenge

As part of a large extension project, the homeowners wanted to incorporate a more efficient heating, cooling, and hot water system that would eliminate the use of fossil fuels, reduce their carbon footprint, and maintain a comfortable indoor environment throughout the year. The extension allowed ample natural light, but it also posed the challenge of potential overheating in summer and insufficient warmth in winter.

Requirements

The homeowners needed a heating and air conditioning solution that would reduce carbon emissions, be easy to control, and align with the design of their new open-plan living space.

Solution

To address these needs, the project utilised two M Series MSZ-LN wall-mounted air to air heat pump units for cooling and maintaining comfort in the extension. Additionally, an 11.2kW Ecodan air-to-water heat pump was installed to serve an underfloor heating system on the ground floor, while i-Life2 Slim fan-assisted radiators provided heating for the upper level. The entire system can be conveniently controlled through the MELCloud smartphone app, ensuring optimal comfort and energy efficiency.

9.1.2 Case study 2: Family home - Chester[220]

This case study showcases the effectiveness of using an air-to-air heat pump system for a house with cold and poorly insulated kitchen and dining areas in Chester.

Challenge

The main challenge was that the kitchen and dining area of the house were cold and poorly insulated, making it uncomfortable for the family. The existing heating system struggled to heat this specific zone, causing a dilemma of either making the rest of the house too warm or accepting the cold kitchen.

[219] Mitsubishi's marketing literature: https://les.mitsubishielectric.co.uk/case-studies/family-home-hertfordshire
[220] https://www.heatpumpsscotland.org/air-to-air-heat-pump-a-case-study/?utm_content=cmp-true

Requirements

The family needed a solution that could efficiently heat the kitchen and dining area without affecting the rest of the house. They wanted a heating option that was controllable, safe, and did not take up much space.

Solution

The homeowner chose the Fujitsu Inverter model for their needs. The room reportedly becomes warm within a few minutes after using the heat pump in the mornings. The use of the heat pump has also been associated with a decrease in fuel bills despite an increase in the size of the home.

9.1.3 Case study 3: Garden Rooms- Essex and Hertfordshire[221]

This case study showcases the application of Panasonic's split systems in garden rooms that had been experiencing severe seasonal temperature variations.

Challenge

The challenge revolved around the usability of garden rooms located in Essex and Hertfordshire. These rooms, often featuring large expanses of glass, were susceptible to significant solar gains and losses. This led to the rooms becoming unbearably hot during summer and freezing cold in winter. The extreme seasonal temperature changes resulted in the customers being unable to use their garden rooms effectively.

Requirements

The customers needed a practical, compact, and highly efficient solution to this problem. The solution they sought had to provide swift heating during the cold winters and equally fast cooling during the hot summers. This was a crucial requirement in order to combat the extreme seasonal climate changes that were causing discomfort and compromising the usability of their rooms.

Solution

Evergreen Air Conditioning, an air conditioning installer, tackled this challenge by utilising Panasonic's split systems. These systems feature wall-mounted air conditioning units, providing customers with efficient heating and cooling. The compact size of the units is well-suited for garden rooms.

[221] Panasonic Beats the Heat Providing Air Conditioning for Garden Rooms https://www.aircon.panasonic.eu/GB_en/cases/case/panasonic-beats-the-heat-providing-air-conditioning-for-garden-rooms/

9.1.4 Case study 4: Lounge and kitchen – Brighton[222]

This case study demonstrates the effectiveness of implementing an air-to-air heat pump system in a home with a lounge and kitchen that were previously subject to extreme temperature fluctuations in Brighton.

Challenge

Eaglereach Mechanical, an air conditioning company in Brighton, was approached by a customer who needed an efficient cooling and heating solution for their lounge and kitchen. Both rooms experienced extreme temperatures, being extremely cold during the winter and unbearably hot in the summer. The customer was open to any type of air conditioning system.

Requirements

The customer had specific requirements for their lounge and kitchen. They wanted to ensure efficient cooling and heating in both rooms, effectively addressing the extreme temperature changes. Additionally, they were seeking a cost-effective option for air conditioning installation.

Solution

Eaglereach Mechanical inspected the property and recommended a Panasonic split air conditioning system. The installation noticeably improved the temperature control in the lounge and kitchen, ensuring comfort during summer and winter

9.1.5 Case study 5: New build home[223]

This case study illustrates the effective use of Mitsubishi Heavy's ducted air conditioning system in a new build home, which previously suffered from uncomfortable heat during the summer months, in maintaining a cool and comfortable environment without compromising on aesthetics.

Challenge

A homeowner who had recently purchased a new build home approached Eaglereach Mechanical, seeking advice for the most appropriate air conditioning system for their house. While well-insulated - beneficial during winter - the house became uncomfortably hot during the summer. The customer desired efficient cooling, especially at night, to ensure comfortable sleep for their young children.

[222] Air Conditioning Installation UK Case Study – Split air conditioning system https://eaglereach-airconditioning.co.uk/air-conditioning-installation-uk-case-study/
[223] Domestic Air Conditioning Installers https://eaglereach-airconditioning.co.uk/domestic-air-conditioning-installers/

Requirements

They needed an air conditioning system that could effectively cool their home during the summer, fit into the design of their new house and avoid wall-mounted units.

Solution

Eaglereach Mechanical's team recommended a ducted air conditioning system. This system operates as a closed cycle, circulating conditioned air throughout the house and returning non-conditioned air for further cooling or heating. It is hidden in the loft, with only the controller and air supply duct visible. A compact Mitsubishi Heavy ducted unit was installed. This solution aimed to provide a cooler environment during the summer months and warmth during the winter without affecting the home's appearance.

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