HEAT PUMPS

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ABSTRACT

The UK Government has set ambitious targets for the deployment of heat pumps as the main route to decarbonising home heating. But progress is slow with the number of installations falling short. Even with increased subsidies covering most of the difference in capital cost compared with a gas boiler, most homes would need extensive improvements to their thermal efficiency and larger emitters (radiators) to achieve similar levels of warmth to that achieved with gas boilers. These improvements are both costly and disruptive. And in the best case scenario where targets are met, the resulting increase in electricity demand will stress electricity grids. A viable alternative would be the use of hybrid systems that combine a heat pump with a conventional gas boiler. Such systems deliver significant reductions in emissions while imposing lower upfront costs and smaller behavioural changes on householders. By allowing the gas boiler to take over on the coldest days warmth is maintained and electricity demand contained. This is now the preferred solution in the Netherlands, and should be given strong consideration in the UK.

About Watt-Logic

Watt-Logic is an independent energy consultancy founded by Kathryn Porter. Watt-Logic was established in 2016, initially as a blog which grew into a consulting business that now works with clients around the world projects across the energy supply chain. Projects include assisting clients on negotiating commercial contracts and gas and electricity trading arrangements; assisting businesses in evaluating new investments in solar generation, behind-the-meter storage and energy-from-waste; advising on various regulatory matters such as the impact of changing market price formation, and acting as an expert witness in energy-related disputes.

Watt-Logic's founder, Kathryn Porter has extensive experience of physical and financial electricity, gas and oil markets, as well as significant experience in financial services across risk management/hedging and debt and equity financing in both public and private markets.

Watt-Logic is entirely self-funding and receives no external capital from any sources. It is therefore independent of any other business, individual or special interest groups. The views contained within this report are solely those of the author.

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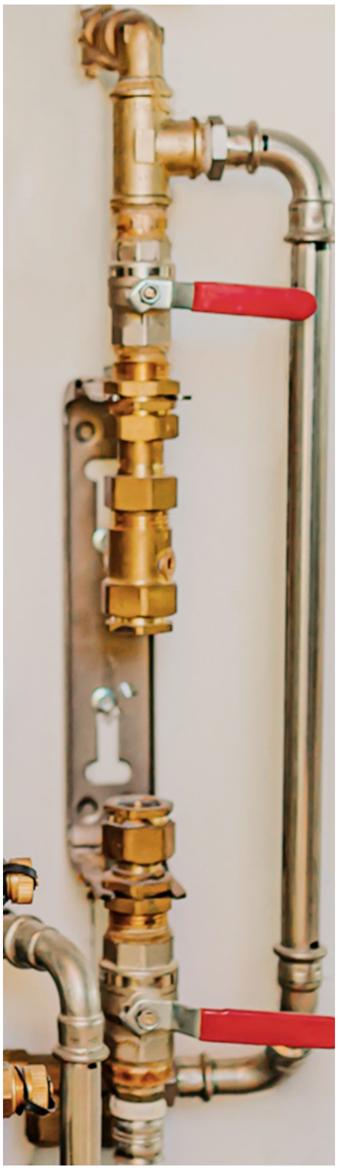


Executive Summary

The UK Government has entered into a legal commitment to reduce the country's net carbon dioxide emissions to zero by 2050, and as such is committed to reducing the carbon dioxide emissions related to the domestic heating sector. As part of this commitment, the Government has set a target of installing 600,000 heat pumps each year to move the heating sector away from the use of gas for heating, towards electrification. In October 2023, the Government clarified that heat pumps and heat networks will be the primary low-carbon technology for decarbonising home heating over the next decade and will play a key role in all pathways to 2050.

The Climate Change Committee has estimated that £162 billion of additional investment will be required to install low-carbon heating in existing UK homes between 2020 and 2050. This could involve installing a heat pump, connecting to a low-carbon heat network or potentially using hydrogen instead of natural gas. However, in October 2023, the National Infrastructure Commission, which advises the government on major long-term infrastructure challenges, recommended that the Government should not support hydrogen for home heating. The Government maintains that it needs to establish the evidence base before taking decisions on hydrogen, but has also stated that no one should hold back on installing a heat pump or connecting to a heat network on the basis that hydrogen might be an option later.

If hydrogen is put to one side at least for now as a solution to the decarbonisation of residential heating, outside of high density urban settings, heat pumps are the main alternative to conventional gas boilers. However, progress towards the Government's targets, which are in themselves modest when set against the large number of households in the UK, has been slow, and on current trajectories, will not be met.

There is a number of reasons for the slow progress. Currently, heat pumps are both more expensive to install and significantly more expensive to run than conventional gas boilers. For many homes, their installation will require both significant changes to the property through the installation of additional insulation and larger emitters (such as radiators), and a change in the way heating systems are used, from short periods of high temperature operation to longer periods of low temperature operation. There are sundry other concerns around the space needed for the outdoor units and the risk of noise disturbance. While the Government has introduced a subsidy to cover most of the difference in capital cost between a heat pump and gas boiler, the other changes would largely need to be funded by the householder.

But should the installation rate increase and the targets be met, it is widely believed that this will create challenges for electricity grids. Electricity system operator, National Grid ESO ("NG ESO") has suggested that people will need to heat their homes to lower temperatures and consider installing thermal storage to help manage peak demand, and that households would need to avoid operating their heating during such high demand periods. It has also expressed concerns about the possibility for an increase in domestic cooling, which can be facilitated by heat pumps, indicating that it hopes people will choose other options for cooling such as fans and curtains. These concerns about the impact on the electricity grid echo those evident in the Netherlands which has been much more successful in installing heat pumps and now has widespread challenges with electricity grid congestion and is now promoting hybrid systems as the primary solution, alongside heat networks, to the decarbonisation of heating.

Hybrid systems combine a conventional gas boiler with a heat pump, allowing the boiler to provide high temperature heat to supplement the low temperature heat provided by the heat pump in cold weather. This makes it much easier to maintain comfort levels with lower levels of insulation and smaller emitters – ie homes would not need to undertake the extent of retrofitting that would be needed for a heat pump alone. It also allows gas boilers to step in to protect the grid in times of high demand – smart heating controls could be used to switch between the two, potentially without the need for input by the householder. Hybrid systems have been shown to deliver significant reductions in gas use (possibly as much as 80%), thereby accelerating progress towards decarbonisation targets.

To date, the UK Government has resisted calls for hybrid solutions, preferring a one-step approach to decarbonising heating. But this policy is currently failing, and risks maintaining carbon dioxide emissions from heating at higher levels for longer. The purpose of decarbonisation is not to only reach net zero in 2050, it is to immediately reduce emissions as much as possible. Continuing to focus on full electrification when it will clearly be out of reach for many years means that emissions will remain higher for longer.

A better approach would be to embrace hybrid solutions to stimulate consumer demand. Consumers would be much more likely to accept heat pumps if they came with less up front cost and upheaval, and the risk of cold weather underperformance was removed. Consumers are much more likely to accept solutions which involve incremental change, rather than the major change both to heating equipment (including upgrades to insulation), and the way that the equipment is used (long periods of low-temperature operation versus short periods of higher temperature operation). An incremental approach will also provide the time to implement the necessary expansions to electricity networks. A more pragmatic approach is needed, particularly around the use of hybrid solutions, if meaningful progress is to be made in the near term.

Decarbonisation of heating

Final energy demand for heating and cooling in buildings is essentially determined by the following factors:

- Thermal losses: the thermal efficiency of the building envelope and air exchange;
- Thermal passive gains: solar gains (mainly through windows) and internal heat loads (eg from people or appliances); and
- Active thermal systems for heating and cooling.

Therefore, the final energy demand may be managed by passive measures that reduce the net useful energy demand (insulation, glazing) or active systems that deliver heating and cooling. The term "energy efficiency" is frequently used to mean "thermal efficiency" in that a more "energy efficient" building would be more thermally efficient and have lower heat losses.[1]

According to the International Energy Agency ("IEA")[2], over one-sixth of global natural gas demand is for heating in buildings, a figure which rises to one-third in the European Union. According to the European Commission[3], about 50% of all the energy consumed in the EU is used for heating and cooling, with over 70% of heating and cooling still being based on fossil fuels, mostly natural gas. In the residential sector, about 80% of final energy consumption is used for space and water heating. Heating is also responsible for 10% of global greenhouse gas emissions. Replacing gas boilers with lower carbon alternatives is therefore considered to be a key priority for delivering on decarbonisation targets.

> "Heat pumps, powered by low-emissions electricity, are the central technology in the global transition to secure and sustainable heating,"
>
> - International Energy Agency, The Future of Heat Pumps

Around 10% of space heating needs globally were met by heat pumps in 2021, but the pace of installation is growing rapidly. The share of heat pumps is comparable to that of fuel oil for heating and of other forms of electric heating but lower than the over 40% of heating reliant on gas heating and the 15% reliant on district heating. In some countries, heat pumps are already the largest source of heating. In Norway, 60% of buildings are equipped with heat pumps, with Sweden and Finland at over 40%, undercutting the argument that heat pumps are unsuitable for cold climates (although as described later, secondary heating with wood is widespread in Scandinavia). Global sales grew by nearly 15% in 2021, double the average of the last decade.

Growth in the European Union was around 35%, and is slated to accelerate further in light of the energy crisis, with sales in the first half of 2022 roughly double over the same period last year in Poland, the Netherlands, Italy and Austria. China continues to be the largest market for new sales, while North

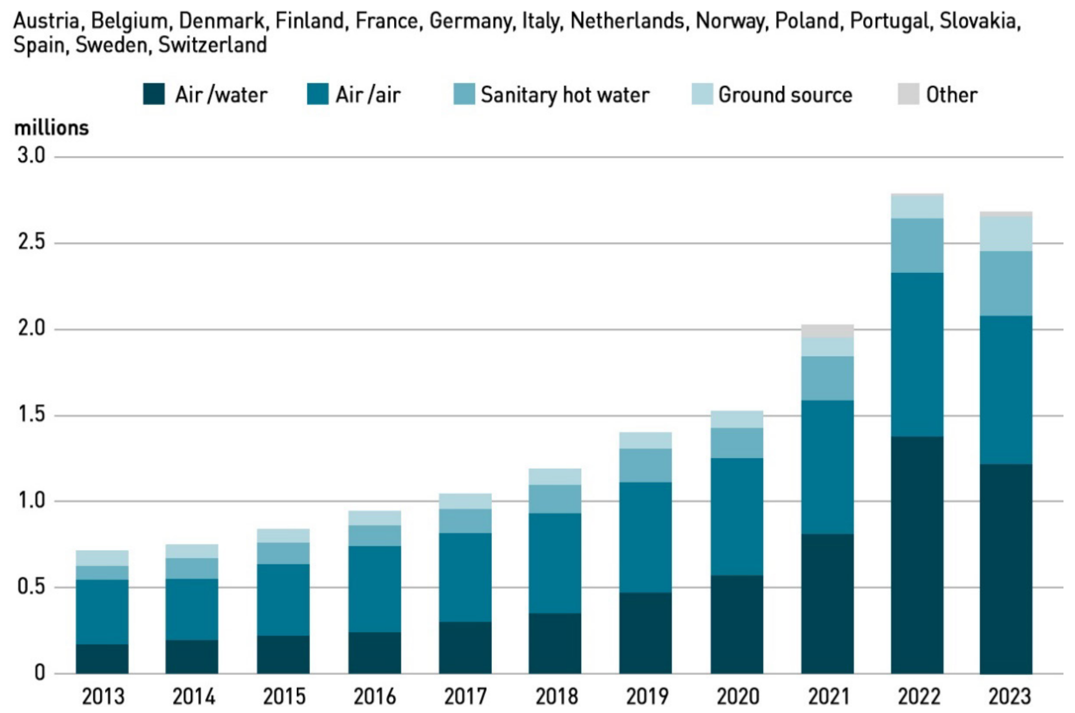
[1] Technically, "energy efficiency" refers to the efficiency with which energy is converted from one form to another eg a more efficient system has higher energy outputs for the same energy input as a less efficient system. A gas boiler might be 90% efficient in that it delivers 90 units of heat energy for every 100 units of gas energy.

[2] https://www.iea.org/reports/the-future-of-heat-pumps

[3] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13771-Heat-pumps-action-plan-to-accelerate-roll-out-across-the-EU_en

America has the largest number of homes with heat pumps today. Together, these regions, along with Japan and Korea, are also major manufacturing hubs, home to the industry's largest players.

Heat pump sales trends across Europe



Source: European Heat Pump Association

However, growth slowed after 2022 when sales fell by 5% to 2023[4]. In the first half of 2024, European sales of heat pumps fell by 47%[5]. The decline, after a decade of continuous growth, has been attributed to a combination of factors:

- The major increase in energy prices following the Russian invasion of Ukraine which made electric heat pumps less financially attractive in light of high electricity prices;
- Economy stagnation since the summer of 2022, leading to persistently high inflation, weak consumer demand, and tightening monetary policy. In the context of high interest rates, inflation, and overall economic uncertainty, investment in construction and renovation projects declined, impacting demand for heat pumps;
- A backlash against green policies, together with reduced ambition at both EU and national level, has further dampened confidence in the heat pump market. Uncertainty about subsidy schemes in some countries contributed to the decline in sales.

The fall was not uniform – in some countries sales continue to grow but elsewhere large falls were observed. Falling sales were seen across the Nordics with the exception of Norway where sales were flat, however, Denmark and Finland saw declines of 36% and 42% respectively. Benelux on the other

[4] https://www.ehpa.org/wp-content/uploads/2024/04/Pump-it-down-why-heat-pump-sales-dropped-in-2023_EHPA_April-2024.pdf

[5] https://www.ehpa.org/news-and-resources/news/europe-avoiding-5-5-billion-cubic-metres-of-gas-with-heat-pumps/

had saw sales continue to rise, with Belgium experiencing growth of 72% and the Netherlands of 53%. The UK also experienced a modest sales increase in 2023 of 4%.

UK Government policy

The UK Government is committed to reducing the country's net carbon dioxide emissions to zero by 2050, and it is therefore necessary to reduce the carbon dioxide emissions related to the domestic heating sector. However, prior to the General Election in July 2024 we had seen some softening in climate goals, with a five-year delay announced to the ban on the sale of new petrol and diesel cars from 2030 to 2035, and the target to ban gas boilers entirely in 2035 reduced[6] to a phasing out of 80%. These moves reflected concerns about the cost impact on consumers with the Government saying that "revised plans will ease the burden on working people, as the Prime Minister forges a credible, transparent path to net zero that maintains public consent".

In recent years there has been a multitude of policy announcements affecting the heating sector and its decarbonisation. They are summarised below, and described in more detail in Appendix I.

Green Growth Strategy

The Green Growth Strategy[7] (2017) set out plans for "improving the energy efficiency of our homes" providing £3.6 billion of investment to upgrade around a million homes and an ambition for all fuel poor homes to be upgraded to Energy Performance Certificate ("EPC") B and C by 2030 and for as many homes as possible to be EPC Band C by 2035 where "practical, cost-effective and affordable".

Specifically in relation to low carbon heating, the Government set out plans to build and extend heat networks and phase out the installation of high carbon fossil fuel heating in homes currently off the gas grid during the 2020s.

Ten Point Plan

The Ten Point Plan[8] (2020) included a claim that "developing greener buildings could deliver…support for around 50,000 jobs in 2030, around £11 billion of private investment in the 2020s, savings of 71 MtCO2e between 2023 and 2032, or 16% of 2018 UK emissions".

> "We will put our homes, workplaces, schools and hospitals at the heart of our green economic recovery, supporting 50,000 jobs and building new supply chains and factories in the UK. Making our buildings more energy efficient and moving away from fossil fuel boilers will help make people's homes warm and comfortable, whilst keeping bills low."
>
> - UK Government Ten Point Plan

6 https://www.gov.uk/government/news/pm-recommits-uk-to-net-zero-by-2050-and-pledges-a-fairer-path-to-achieving-target-to-ease-the-financial-burden-on-british-families

7 https://www.gov.uk/government/publications/clean-growth-strategy

8 https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution/title#point-7-greener-buildings

The specific targets identified were 600,000 heat pumps installations per year by 2028 compared with the roughly 1.8 million gas boilers which are currently installed each year, homes built to the Future Homes Standard being "zero-carbon ready" with 75–80% lower carbon dioxide emissions than those built to existing standards, and green home finance initiatives to improve the "energy efficiency" of around 2.8 million homes, improving around 1.5 million homes to EPC C standard by 2030.

Heat and Buildings Strategy

The Heat and Buildings Strategy[9] (2021) re-iterated many previous targets and commitments eg the intention to install at least 600,000 heat pumps per year by 2028, and potentially replacing 1.7 million fossil fuel boilers per year by the mid-2030s. There was a commitment to invest £338 million over 2022/23 to 2024/25 into a Heat Network Transformation Programme to scale up low-carbon heat network deployment, and to make a decision on the role of hydrogen by 2026.

The Government outlined an ambition to phase out the installation of natural gas boilers beyond 2035, saying the future would likely see a mix of low-carbon technologies for heating, including hydronic (air-to-water or ground-to-water) heat pumps, heat networks and potentially switching the gas in the grid to low-carbon hydrogen.

Affordability was emphasised, with plans to work with industry to reduce heat pump costs by at least 25-50% by 2025 and towards parity with boilers by 2030, and supporting consumers who switch early with the new £450 million Boiler Upgrade Scheme providing £5,000 Boiler Upgrade Scheme grants.

In September 2023, the Government announced[10] a delay to the ban on installing oil and Liquified Petroleum Gas ("LPG") boilers, and new coal heating, for off-gas-grid homes to 2035, instead of phasing them out from 2026. Many of these homes are not suitable for heat pumps, so this delays the requirement for these households to make investments estimated to be around £10,000 - £15,000 to switch to electric heating.

Boiler Upgrade Scheme

The Boiler Upgrade Scheme[11] (2022) provides grants to cover part of the upfront costs of replacing a gas boiler with a heat pump or biomass boiler. At inception the scheme provided grants of up to £5,000 and was available to existing buildings excluding social housing and private new-build properties that met certain insulation criteria. In March 2024, the maximum grant was increased by 50% to £7,500, and restrictions relating to insulation were removed[12]. This change was introduced after Ministers observed that heat pump prices had risen, prompting the Government to refer the sector to the Competition and Markets Authority.

The Government also introduced an exemption to the requirement to end the use of fossil fuel boilers, including gas, in 2035, "so that households who will most struggle to make the switch to heat pumps or other low-carbon alternatives won't have to do so". Policies to force landlords to upgrade the energy efficiency of their properties, were also abandoned.

9 https://www.gov.uk/government/publications/heat-and-buildings-strategy

10 https://www.gov.uk/government/news/pm-recommits-uk-to-net-zero-by-2050-and-pledges-a-fairer-path-to-achieving-target-to-ease-the-financial-burden-on-british-families

11 https://www.legislation.gov.uk/uksi/2022/565/contents/made

12 https://www.gov.uk/government/news/heat-pumps-will-be-cheaper-and-easier-to-install

Clean Heat Mechanism

The Clean Heat Market Mechanism[13] (2023) - In 2023 the Government consulted on a new market-based mechanism to support the development of the market in low-carbon electric heat pumps to be implemented from April 2025, under which boiler manufacturers would be required to sell a certain proportion of heat pumps each year. Immediately prior to the General Election, a consultation[14] into delaying the start date of the scheme to April 2025 closed. The results of this are not yet known, or whether the new Government will continue with the plans, although recent media speculation suggests it will revert to the original version of the scheme despite public opposition.

Future Homes and Buildings Standard

The Future Homes and Buildings Standard[15] (2024) was consulted on earlier this year and proposed that new homes built from 2025 would be "zero carbon ready", with low-carbon heating technologies such as heat pumps installed as the standard in new properties. The key requirements of the Future Homes Standard include:

- Building fabric: improved insulation for walls, floors and roofs;
- Low-carbon heating and hot water systems: the use of low-carbon systems is emphasised, in particular air and ground source heat pumps. Gas boilers will not be compliant;
- Renewable energy readiness: while not mandatory, the standard encourages incorporating wiring or space allocation for the installation of solar panels in future;
- EV charging: new homes must have one charging point installed or the necessary cabling for future installation;
- Ventilation: efficient ventilation designs for new and existing homes are encouraged, that do not compromise the air-tightness of the building envelope.

There are signs that the construction industry is struggling to be ready for the expected implementation of the standard next year, with almost half (49%) of housebuilders saying that their business is not prepared for the standard and won't be ahead of its implementation next year, and 61% think it will be extremely

13 https://www.gov.uk/government/consultations/clean-heat-market-mechanism

14 https://www.gov.uk/government/consultations/clean-heat-market-mechanism-adjustment-to-scheme-introduction-date/clean-heat-market-mechanism-proposal-to-change-the-scheme-start-date-to-1-april-2025

15 https://www.gov.uk/government/consultations/the-future-homes-and-buildings-standards-2023-consultation/the-future-homes-and-buildings-standards-2023-consultation

challenging to meet the legislation, according to a recent survey[16] of 100 UK housebuilders.

Confusion around the role of hydrogen to decarbonise homes

The National Audit Office ("NAO")[17] found that certain aspects of the Government's plans to test the feasibility of hydrogen for home heating are behind schedule or have been cancelled, which could make it harder to meet its target of making decisions on the role of hydrogen in 2026, which could in turn slow the progress of decarbonising home heating. Some stakeholders told the NAO that the lack of policy certainty is unhelpful given the large capital requirements for decarbonising home heating, and could limit the ability of local authorities and industry to develop plans and investments in this regard.

The Government has also not determined how to decarbonise home heating in the homes – around 20% of the total - that may be exempt from the 2035 phase-out of new fossil fuel boilers. These homes could include those requiring significant retrofitting of insulation or electrical connection upgrades, lack of space for a heat pump, or being located in areas likely to be connected to a heat network. The Government recognises it needs to set out how it expects these homes will be heated, and how to ensure these householders are not unfairly penalised.

[16] https://probuildermag.co.uk/news/industry-not-prepared-for-the-future-homes-standard
[17] https://www.nao.org.uk/press-releases/low-heat-pump-uptake-slowing-progress-on-decarbonising-home-heating/

The benefits and disadvantages of heat pumps

Heat pumps are generally more environmentally sustainable than gas boilers

The main benefit of heat pumps is that they are more environmentally sustainable than gas boilers in use since they do not involve directly burning fossil fuels. They run on electricity, and while a significant proportion of electricity is still generated through burning natural gas, increasing amounts are generated with zero carbon sources such as nuclear power and renewable sources, such as solar and wind power. Even today, the round trip emissions when considering the source of the electricity are lower for heat pumps than for gas boilers.

However, there are some questions about the manufacturing processes. Components can be imported from countries which still rely heavily on coal to generate electricity meaning more emissions are involved in their manufacture. Heat pumps have more components and require more materials than gas boilers and the supply chains for these can have problems with sustainability and other environmental and social concerns.

Unlike gas boilers, heat pumps provide a facility for cooling

A major benefit of heat pumps, and one which is frequently overlooked, is the ability of most models to provide cooling as well as heating. Although the UK cannot be considered to be a “hot” country, once temperatures rise above c 25°C during the day and 15°C during the night, things can become uncomfortable, and sleep in particular becomes harder. Householders can benefit significantly from the cooling potential of heat pumps, and this is likely to emerge as a major benefit to heat pump users. However it will likely have an adverse impact on electricity grids, creating summer demand for “heating” which is currently absent and is not always factored in to system planning, as will be discussed later.

Heat pump efficiency is higher than for gas boilers

Heat pumps are more efficient than gas boilers. They can produce up to four units of energy for each until of electricity although this is more likely to be 300%. This compares with efficiency rates of 80-90% for boilers up to ten years old. However, this does not take account of the efficiency of the electricity system – once the efficiency of electricity generation and transmission is taken into account, heat pump efficiencies are nearer to 210%.

The lower round-trip efficiency matters from a whole system perspective, but is less relevant to householders. Within the household, the higher heat pump efficiency can be a benefit, meaning less energy is required for heating. This is not straightforward since the heat generated by the heat pump has a lower temperature, so it may be harder to achieve comfort levels and, in some cases, additional heating sources may be required.

Heat pumps are less effective in cold weather

The use of additional heating systems is particularly true in colder countries since heat pumps are less efficient in cold weather, particularly if temperatures are below freezing. Much is made of the use of heat pumps in Nordic countries, but it is common in these countries to have a secondary heating system, either a second heat pump or a wood burning stove. Nordic homes are also better insulated than their British equivalents.

For effective heating with heat pumps homes may need to be upgraded

In order for the system to work effectively, it may be necessary to install larger radiators or underfloor heating, and to upgrade insulation due to the fact that heat pumps generate less heat than gas boilers. It is important that the system is well designed and that heat-loss calculations are performed correctly to ensure adequate comfort levels without incurring high bills. If an unsuitable heat pump is specified or if it is set up incorrectly, energy costs might be higher than with a gas boiler heating system.

In addition, because heat pumps provide low grade heat, it is more important for the home to be well insulated compared with homes heated with gas boilers. Retrofitting insulation can create additional cost and disruption for householders.

Impact of ASHP noise on neighbours

Heat pumps require enough space outside the home for the condenser unit and indoors for a hot water cylinder. The outdoor unit can also be noisy due to the operation of fans. This can cause disruption to both the householder and neighbours, and there are concerns that current rules around noise disturbance are on a property by property basis and do not consider the potential impact of multiple ASHPs in close proximity, for example terraced or multi-occupancy housing. Heat pump manufacturers have also expressed concern[18] over the possibility that tighter noise restrictions would increase costs due to the need to install more noise control measures.

Although to date the number of noise complaints relating to heat pumps has been low, location and the proximity of ASHP units to neighbouring properties has emerged as a key cause of complaints. Complaints generally centred around disturbed sleep and installers reported they were typically resolved through moving or replacing the ASHP. Current guidelines fail to take account of background noise, so a heat pump unit could be perceived to be more disruptive in areas with typically low noise levels, particularly at night.

Both the upfront and operating costs of heat pumps can be higher than for gas boilers

The upfront costs of heat pumps are significantly higher than for gas boilers – around £13,000 for an air source heat pump compared with around £3,000 for a gas boiler. The UK Government's Boiler Upgrade Scheme provides grants of up to £7,500 for the installation of heat pumps, with a view to making the capital costs of the units broadly equivalent to the installation of a gas boiler. However, taken with the need to upgrade insulation and install larger heat emitters, for most households, the installation of a heat pump would be more expensive than a like-for-like gas boiler replacement even after the grant.

The operating costs of heat pumps also tend to be higher than for gas boilers because electricity is more expensive to buy than gas. While the most efficient heat pumps may be cheaper to run than gas

[18] https://www.ioa.org.uk/news/review-recommends-improving-air-source-heat-pump-noise-assessments

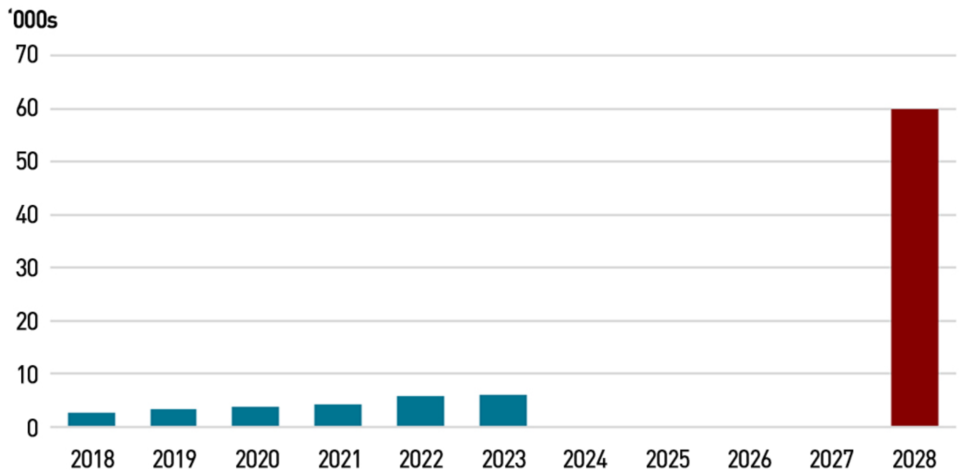
boilers, most households are likely to see an increase in heating costs if switching to an air source heat pump unless they are able to access preferential heat pump tariffs.

Key challenges to meeting heat pump targets

The Government is targeting 600,000 heat pump installations per year by 2028 – an eleven-fold increase on 55,000 heat pump sales in 2022[19]. By 2035, Government wants to see up to 1.6 million heat pumps installed annually. However, according to the National Audit Office the number of heat pump installations by December 2023 was less than half of planned projections; and uncertainty around the role of hydrogen in home heating is hampering investment and effective planning.

According to the NAO, the Government is "relying on optimistic assumptions about consumer demand and manufacturer supply of heat pumps increasing substantially to achieve 600,000 installations per year by 2028". Heat Pump Association data indicate that 55,000 heat pumps were sold in the UK in 2022, meaning the 600,000 target will require an elevenfold increase 2022 to 2028, using sales as a proxy for installations.

Heat pump sales and installation target



The data from 2018 to 2022 show annual heat pump sales since the Government does not track installations data. The 2028 figure represents target installations and illustrates the size of increase required over the coming years

Source: Watt-Logic, based on Heat Pump Association and UK Government data

The NAO believes the Government's assumptions about levels of consumer demand and manufacturer supply are optimistic, after a third of respondents to the 2023 consultation on the Clean Heat Market Mechanism reported that Government's targets would be unachievable (although this pre-dated the increased grant available through the Boiler Upgrade Scheme). The flagship Boiler Upgrade Scheme has also underperformed, installing just 18,900 heat pumps between May 2022 and December 2023 compared with Government expectations of 50,000 installations by this point.

[19] https://www.heatpumps.org.uk/wp-content/uploads/2023/12/HPA-Unlocking-Widescale-Heat-Pump-Deployment-in-the-UK.pdf

The NAO says that a key issue behind lower-than-expected heat pump uptake is their cost to use and install. The Government has delayed its planned work to reduce running costs, by rebalancing gas and electricity prices, for example by moving some levies and charges from electricity to gas bills, although it has said that price rebalancing remains an essential policy but is challenging to implement.

Currently it is illegal for gas and electricity costs to be cross-subsidised, so gas costs cannot be recovered through electricity bills and vice versa. However, there is nothing to prevent these levies from being recovered through general taxation rather than through energy bills, and many in the energy industry believe that this would be more equitable since the current approach is seen as regressive.

Heat pump installation costs also fell more slowly than the Government hoped.

Low levels of public awareness

The NAO also found that the Government has no overarching long-term plan to address the low levels of awareness among households about the steps necessary to decarbonise their heating systems. Decarbonising home heating will require almost every household to make a decision that will have a significant impact on their homes, but public awareness around this is low: around 30% of respondents to a 2023 Government survey had never heard of, or hardly knew anything about the need to change the way homes are heated in order to reach net zero.

The Government has promoted heat pumps as part of its *Welcome Home to Energy Efficiency*[20] communications campaign, and provides information online. However, research by the Energy Saving Trust[21] indicated that homeowners are unsure where they can get independent, impartial advice on making improvements to reduce the carbon dioxide emissions of their homes.

Possibly at least in part due to lack of awareness, uptake of the Boiler Upgrade Scheme[22], a Government grant for people in England and Wales for the installation of a heat pump or a biomass boiler, has been lower than the Government expected. As a result the size of the available grants was increased to £7,500 for air or ground source heat pumps (and £5,000 for biomass boilers), with the intention that the residual cost paid by the homeowner would be similar to that for installing a gas boiler. Between May 2022 and December 2023, just under 19,000 heat pumps were installed in England and Wales as a result of the Boiler Upgrade Scheme, against an initial target of 50,000. As a result around £100 million less was spent on the grants than had been budgeted.

The grant is expected to cover almost 60% of the average cost of installing a heat pump, based on the average cost in 2023, following the increase in its size. The number of grant applications under the scheme increased by almost 50% in December 2023 compared with December 2022, and applications in January 2024 increased by nearly 40% compared with January 2023. However, the NAO found that the Government does not track the reasons that some grant applications do not progress to heat pump installation.

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[20] https://energy-efficient-home.campaign.gov.uk/

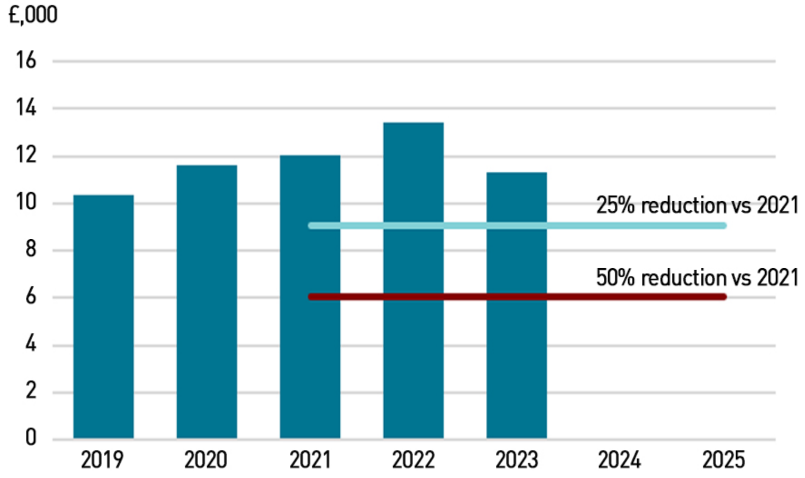
[21] https://energysavingtrust.org.uk/report/national-or-local-retrofit-advice/

[22] https://www.find-government-grants.service.gov.uk/grants/boiler-upgrade-scheme-1

High capital and operating costs

Cost is clearly a key driver behind the uptake or otherwise of heat pumps, and while there are now larger grants available and average installation costs have fallen, these reductions have been slower than the Government had hoped, and there has been no progress on reducing running costs. A survey[23] of heat pump installers by Nesta found that 45% of survey participants believe that home owners do not progress with a heat pump installation after receiving a quotation as the costs are too high.

Heat pump installation costs in 2021 prices



This figure presents the average (mean) cost of MCS-certified installations of air, ground and water source heat pumps in UK homes, based on MCS data. The costs are self-reported by MCS-certified installers and should cover "the full cost of the installation that is charged to the consumer" which includes materials and labour.

MCS does not monitor whether grants are deducted from the cost values entered onto MCS certificates, so some cost entries may include the grant value and others may not. However, Ofgem provides guidance to Boiler Upgrade Scheme installers on what to include so the Government expects the vast majority of Boiler Upgrade Scheme installers to report costs inclusive of the grant.

Installations that cost below £1,000 and above £100,000 plus the remaining top and bottom 5% of the data have been excluded. These average costs do not factor in cost per kilowatt capacity, so changes in average cost could also be due to changes in the distribution of heat pump capacities being installed.

Source: National Audit Office, based on MCS (Microgeneration Certification Scheme) data

According to the NAO, at the end of 2023, the average cost to replace a gas boiler with a heat pump was around four times higher than replacing it with another gas boiler. In 2021, the Government set a target for a 25–50% reduction in installation costs by 2025 and to ensure heat pumps are no more expensive to buy and run than gas boilers by 2030. However between 2021 and 2023, installation costs only reduced by 6% in real terms, meaning that costs would need to fall three times faster over the next two years if even the lower end of the target is to be met. The Government told the NAO that global supply chain pressures were responsible for the slow pace of cost reductions, including, shortages of semiconductors that are a key component in heat pumps, manufacturers being unable to keep up with increased global demand; and high energy prices increasing the cost of manufacturing processes.

[23] https://www.nesta.org.uk/report/how-to-install-more-heat-pumps-insights-from-a-survey-of-heating-engineers/

However, for many households, the installation of a heat pump goes beyond the heat pump equipment itself. Since heat pumps deliver low grade heat compared with the high grade heat delivered by gas boilers, it is more important for buildings to be well insulated, and larger emitters (eg radiators) may be required. These involve both additional costs and significant upheaval and disruption to homeowners.

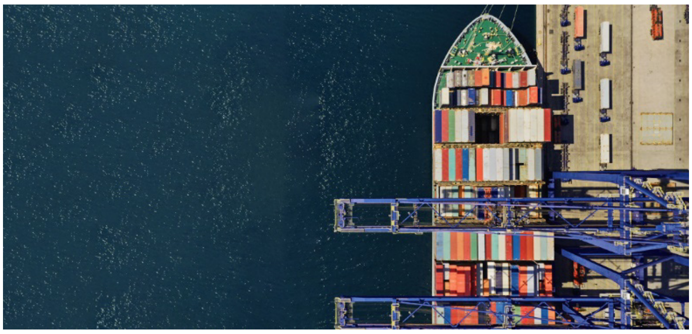
It is not just the installation cost that inhibits heat pump update, running costs are also higher than for gas boilers since electricity is more expensive per unit than gas. The government has committed to "rebalance" energy prices over the course of the 2020s, including potentially shifting energy levies and obligations from electricity to gas bills, but plans to do this have been delayed by nearly two years. The Government has said that price rebalancing remains essential but is "politically challenging".

The Government believes that a combination of the Boiler Upgrade Scheme, the Clean Heat Market Mechanism and other energy "efficiency" and low-carbon heating retrofit schemes such as the Social Housing Decarbonisation Fund and the Energy Company Obligation will be sufficient to deliver its installation targets. However, a third of respondents to the 2023 consultation on the Clean Heat Market Mechanism reported that these targets would be unachievable (although this pre-dated the increase in the Boiler Upgrade grant). In addition, both the Boiler Upgrade Scheme and Clean Heat Market Mechanism are set to expire in 2028.

Supply chain constraints

A major barrier to meeting heat pump installation targets is a lack of capacity in the supply chain. Two thirds of heat pumps installed in the UK are manufactured abroad, compared with under half of gas boilers. The majority of heat pumps sold in the UK are imported from Asia (China, South Korea and Japan) and Europe[24].

As of 2020, there were at least 33 manufacturers supplying ASHPs in the UK, three of which manufacture in the UK (Mitsubishi, Global Energy Systems and Big Magic Thermodynamic Box, accounting for total market share of 32%). The market is dominated by Mitsubishi, Daikin, and Samsung which together accounted for almost two-thirds of annual sales in the UK in 2019. The rest of the market is distributed amongst around 30 firms. Leading UK-based boiler manufacturers are also beginning to produce heat pumps but so far their market share is limited.



In a 2020 survey, carried out by Eunomia Research & Consulting Ltd on behalf of the Department for Business, Energy and Industrial Strategy, manufacturers reported being very confident that they could increase heat pump supply into the UK market, through a combination of imports and domestic manufacture, by a minimum of 25-30% year on year for the next 15 years. Such increases have been achieved before, but not consistently for many years, or decades as is now required. Also, the extent to which demand could be met from UK-based manufacturing is unclear.

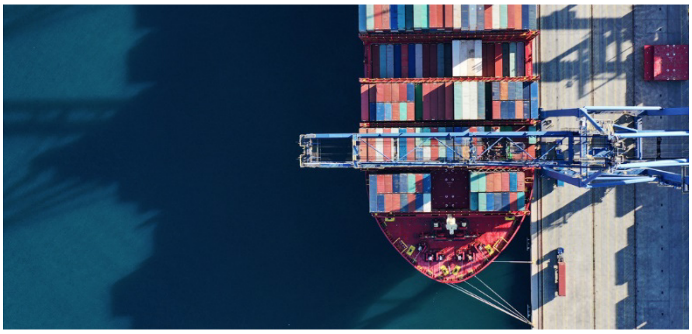
[24] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/943712/heat-pump-manufacturing-supply-chain-research-project-report.pdf

Manufacturers said they would consider opening manufacturing facilities in the UK if there was a "significant increase" in demand that would give greater certainty of an attractive return on investment. What constituted a "significant increase" varied between manufacturers, and they also indicated that demand increases alone would not necessarily be enough to justify developing UK-based production capacity. They cited the following additional requirements:

- A clear long-term strategy and commitment from the Government providing clarity on the need for heat pumps;
- A stable regulatory system;
- Additional standards and quality requirements on heat pumps installed in the UK, although care would be needed to avoid making heat pumps uncompetitive;
- Lower-cost space for manufacturing through tax-breaks, start-up grants or interest-free loans, to make the UK more competitive compared with other European countries, and support for up-skilling and re-skilling; and
- Innovation funding to focus on areas identified with added value to the UK, such as smart control systems to facilitate demand-side response and management, efficient use of hybrid heat pumps, improved performance monitoring, increasing heat pump output temperature and/or greater integration with other low-carbon technologies.

The majority of heat pump components are sourced from outside the UK, with the exception of compressors where one UK manufacturer – Emerson Copeland of Northern Ireland, serves a large proportion of the UK heat pump market. Several factors drive the location of manufacture beyond the UK. Currently, there is not enough heat pump manufacturing demand in the UK to support local components manufacture, and producers of these components also serve several other markets such as cooling, ventilation, and air conditioning, so growth in heat pump manufacturing may not be enough to stimulate re-location.

European and Asian manufacturers have the volumes necessary to justify investment in automation and other efficiency technologies. Survey respondents suggested that this divergence has become so entrenched that it would be effectively impossible to establish large-scale manufacturing in the UK for specialised components as these markets are all international, and have been developing in the absence of the UK for so long, the barrier to entry would now be prohibitive. This was not seen as a determining factor in the growth of UK heat pump manufacturing. In the boiler market many of the components are imported for assembly in the UK.



The Government believes the development of UK-based heat pump manufacturing will have a positive impact on the UK economy. In addition, an increase in domestic heat pump production would mitigate the risk of job losses in boiler manufacturing.

To support this growth, the Government has introduced the Heat Pump Investment Accelerator Competition[25] which offered £30 million to support domestic heat pump manufacturing. UK registered businesses could apply for grant funding of up to £15 million per project, for major investments in the manufacture of heat pumps and strategically important components. Applications closed in October 2023 and the results have yet to be announced.

The Government also intends to impose obligations on boiler manufacturers through the Clean Heat Market Mechanism to sell a certain number of heat pumps, however there is limited evidence from other countries as to the success of such schemes, and as the obligation can be met through imported heat pumps, it may not have the desired impact on UK manufacturing capacity.

Lack of skilled installers is hampering installations

There is no currently formal definition of who is and who isn't recognised as a heat pump installer, and no data on the number of people currently carrying out such installations. It is agreed, however, that the sector is small. According to the Heat Pump Association[26], the number of people who completed a short training course to become qualified heat pump installers increased by 166% between 2022 to 2023, from just under 3,000 in 2022 to close to 8,000 in 2023. MCS[27] reports there are 1,500 businesses with MCS accreditation currently installing heat pumps.

According to the Nesta survey cited earlier, only 16% of sole traders they surveyed and 42% of companies with one to five employees were MCS certified, compared to 87% of companies with six or more employees. MCS certification is not a requirement for heat pump installation. In contrast there are around 150,000 gas boiler engineers[28] on the Gas Safe Register (which replaced the CORGI scheme) in the UK. Since the installation of gas boilers does require certification, there is more certainty around the numbers.

The Heat Pump Association estimates that the equivalent of 33,700 full time employed heat pump installers will be needed to support the Government's installation ambitions, however MCS expects 50,000 installers will be needed.

The Government has put in place the £5 million Heat Training Grant[29] for heating installers, which supports trainees in England taking short training courses relevant to heat pumps. Training providers offering the grant are able to provide trainees with a discount or rebate of up to £500. Since the courses typically cost £500-600, the grant will cover the bulk of the cost. The Government has also launched the Low Carbon Heating Technician apprenticeship[30], which will be available across England and has been designed by industry experts. This apprenticeship will allow new entrants into the heating sector to learn how to install low carbon heating technologies including heat pumps, and will "offer sustainable long term career opportunities".

A survey by Nesta of 345 heat pump installers found smaller businesses do not generally focus solely on heat pump installation - only 16% of sole traders and 43% of companies with one to five employees reported that they mostly or only install heat pump systems. Respondents reported that their largest

[25] https://www.gov.uk/government/publications/heat-pump-investment-accelerator-competition

[26] https://www.heatpumps.org.uk/166-increase-in-qualified-heat-pump-installers/

[27] https://mcscertified.com/uk-on-track-for-best-year-ever-for-renewable-energy-and-heat-installations/

[28] https://www.gassaferegister.co.uk/about-us/what-is-gas-safe-register/

[29] https://www.gov.uk/government/publications/training-providers-how-to-offer-the-heat-training-grant-for-heat-pumps

[30] https://www.gov.uk/government/news/thousands-of-low-cost-training-spaces-available-in-boost-to-green-jobs-sector

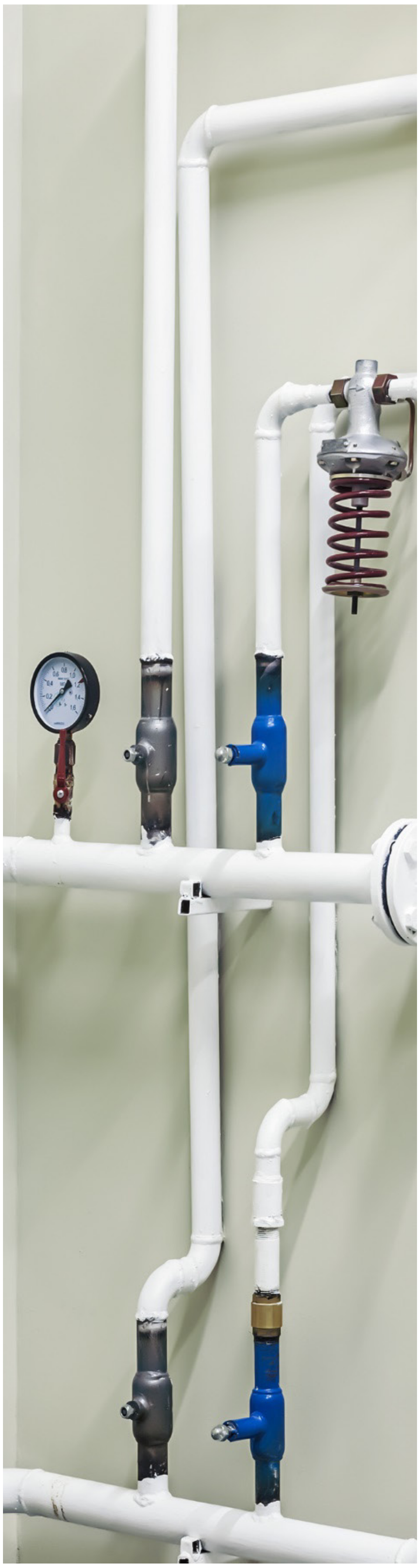
challenge with increasing heat pump installations was either: a lack of customer demand (41%), an inability to find additional suitable staff (30%), and the time spent on unnecessary tasks or administration (19%). The survey found that administrative tasks may be a bigger barrier to increasing installations than elements of the job relating to physically installing the heat pump, and that finding ways to make these tasks less time intensive, could allow engineers to increase the number of installations they complete.

The survey also found a strong preference among employers to hire experienced staff, and that employers expect a much higher level of practical heat pump installation experience than apprenticeship graduates currently have. Fewer than 10% of company owners said they were confident or very confident that recent graduates from apprenticeship schemes are trained to an appropriate level, with 61% having no or very little confidence in their training. Almost half of company owners believe the training on general plumbing and heat pump installation skills are most in need of improvement. The smallest companies reported reluctance to take on apprentices as they are unable to find appropriate candidates and the costs of doing so are too high. This may undermine the success of Government apprenticeship initiatives, and financial support for companies that take on apprentices may increase their attractiveness to employers and be more effective in increasing the numbers of junior installers in the sector.

Practical skills are so important to employers that 34% reported that they would not recruit candidates whose qualifications did not include work-based learning even with other incentives or support schemes. 29% of respondents said they would be encouraged to take on such people if their salary was initially supported, with salary support being the most popular incentive amongst respondents. This suggests a need for non-apprenticeship courses to include a greater element of work-based learning, or for the creation of pathways to support those who obtain such qualifications with securing on-the-job training after graduating.

It is clear that there is currently a lack of skilled heat pump installers, and that existing Government schemes to grow their number are likely to prove insufficient.

Cost analysis of heat pumps



In a 2023 report, the UK Energy Research Council[31] ("UKERC") found that there had been little or no reduction in the average total installed cost of heat pumps over the previous decade, although some cost reductions were reported internationally. It found that most UK forecasts suggest a reduction in total installed costs for heat pumps by 2030 of around 20-25%, with savings higher for non-equipment costs (through more efficient and more competitive installations) than for equipment costs (which are relatively mature). However, it found that almost all cost reduction forecasts are significantly less than UK policy targets, suggesting that actual progress is unlikely to match policy goals.

According to the UKERC study, equipment costs typically make up around 60% of total heat pump installed costs, and non-equipment costs around 40%. Equipment costs are generally evenly shared between the heat pump unit itself and ancillary equipment (including the buffer tank, hot water tank, radiators, piping and valves), although this varies by design and context. On average, labour costs make up around 60% of non-equipment installed costs, with other costs including system design, commissioning, distribution and overheads.

Heat pump costs vary significantly with technology type (eg air source or ground source; air-to-air or air-to-water, high or low temperature heat output, with or without hot water provision, monobloc or split unit design, and so on), and with ancillary equipment costs, labour costs and wider installed costs, including any upgrades to the building fabric or heating system. Average installed costs for new build and existing homes are typically similar, although the balance between equipment and non-equipment cost varies - new build installations typically incur lower non-equipment costs, but higher ancillary equipment costs.

In the UK, installed costs for domestic gas boilers and heat pumps vary considerably, depending on technology design and building context, but typical estimates are of around £3,000 for a gas boiler and £13,000 for an air-to-water ASHP[32]. Achieving cost parity in ASHP installed costs would therefore require a 70% reduction. For this to be achieved by 2030 an experience rate – the rate of cost reductions achieved through the learning achieved and therefore improvements delivered by doing a thing - of around 26% would be required, well above the international median average experience

31 https://ukerc.ac.uk/publications/heat-pump-cost-review/

32 https://www.delta-ee.com/wp-content/uploads/2021/12/Whitepaper-What-is-the-potential-for-cutting-the-cost-of-an-installed-heat-pump.pdf

rate for total installed costs of 14%. It is also above the highest reported rate internationally of 24%, for Switzerland between 1991 and 2008. There are few published forecasts of heat pump experience rates, but the indicative UK rate is less than the highest forecast rate for total installed costs, of 30% for the 35 year period 2015-2050[33].

> "In effect, realising the UK policy ambitions for heat pump deployment and cost reduction implies a radical change, from international laggard to leader, in less than a decade,"
>
> - UK Energy Research Centre, Decarbonising Home Heating: An Evidence Review of Domestic Heat Pump Installed Costs

A reduction in total installed costs of 70% by 2030 is over three times greater than the median average percentage cost reduction forecast identified in the UKERC review of 20%, and almost double the highest single figure of 38%. The Climate Change Committee's[34] "Balanced Pathway" to net zero assumes a 20% installed cost reduction by 2030, and up to 30% under more optimistic assumptions. The UK innovation agency Nesta[35] concluded that even under optimistic assumptions, heat pump installed costs would still be more than double those for gas boilers by 2030, although these estimates ignore the impact of possible subsidies and other forms of support from the Government.

According the UKERC, many of the heat pump cost studies it analysed did not provide sufficient detail on cost assumptions to allow the data to be normalised for different assumptions.

33 https://link.springer.com/article/10.1007/s12053-018-9710-0
34 https://www.theccc.org.uk/publication/sixth-carbon-budget/
35 https://www.nesta.org.uk/report/reduce-the-cost-of-heat-pumps/

International cost comparisons

There are limited data available internationally, which is troublesome since the heat pump markets outside the UK are considerably more mature, so these data would be useful in assessing the reasonableness of equipment cost reduction forecasts in particular – there is nothing unique to UK heat pump design, so if the technology is already mature in international markets, the scope for equipment cost reductions will be limited. It is also difficult to adjust for the impact of regulatory change, improvements in heat, for example tighter standards on heat pump performance may lead to increased equipment costs, particularly in the short term.

The UKERC study considered the experience in four countries in order to assess the causal factors behind reported experience rates which can lead to cost reductions: Switzerland, Sweden, the Netherlands and the UK. Each country has a distinctive pattern of heat pump deployment trends, costs and suggested causal effects:

Switzerland

Switzerland has longstanding experience of heat pump deployment since the 1980s. From the mid-1990s, Switzerland has seen market growth combined with substantial reductions in installed costs, and high experience rates – of around 20% for ground source heat pumps. In addition to technical improvements, savings have been enabled by supply chain competition and component importing.

Total sales of ASHPs and GSHPs grew from c.4,000 in 1995 to c.26,000 p.a. in 2017, with most being ASHPs. Market growth encouraged learning in design, manufacture and installation for heat pump units and wider system components, including smaller and cheaper heat exchangers, improved assembly methods and system integration. Importing of cheaper components from Asia (particularly compressors) has also been important.

Sweden

Heat pump deployment in Sweden also has a long history, with a gradual development of manufacturing and installer expertise, and technical advances. Sweden is one of the largest markets for heat pumps in Europe. Cost reduction has been modest, with recent increases in GSHP costs. Evidence suggests that this reflects an emphasis on domestic manufacturing and local supply chains.

Total annual sales grew from c10,000 to c135,000, between 1994 and 2008. GSHP sales rose from c2,000 to 40,000 over the same period. Sales growth was slower in the 2010s. The policy emphasis has been on performance improvements (such as the introduction of inverters and advanced controls) rather than cost reduction. There has been limited supply chain competition and importing, with close links between domestic manufacturers and local sellers and installers. A subsidy scheme in the mid-2000s led to price increases because of limited supply capacity.

Netherlands

The Netherlands has much less experience of heat pump deployment, but with strong policy support, it has seen rapid recent growth in installations, particularly for ASHPs (both air-to-air and air-to-water). Heat pumps now dominate domestic heating sales for new homes in the Netherlands. While evidence is limited, this appears to be associated with significant cost reductions, driven by supply chain competition.

The Netherlands experienced rapid market growth since the mid-2010s, from 51,000 total annual sales in 2015 to 118,000 in 2018, and 250,000 in 2020, almost all ASHPs. There has been learning in manufacturing and installation of both heat pumps and wider system components, including smaller and cheaper heat exchangers, cheaper assembly methods, cheaper system integration and the use of cheaper components imported from Asia. Policy support has also been key, particularly a capital subsidy support scheme introduced in 2016.

United Kingdom

The UK has little experience in heat pump deployment, and has only seen modest market growth in recent years. Policy support has been weak, and there has been little evidence of cost reduction or learning in technology development or installation practices. Recent increases in costs, especially for non-equipment costs, are reflected in negative experience rates.

Annual installations rose from 18,500 in 2011 to 31,200 in 2019 and 55,000 in 2021 with over 90% being air-to-water heat pumps. Policy instability, and policy costs imposed on electricity (and not on gas) have restricted market growth. Efforts to increase demand in a historically small market with few qualified installers has caused upward cost pressure, with increased ASHP costs being due mostly to non-equipment costs, such as more demanding installation requirements, labour, overheads, commissioning and distribution costs.

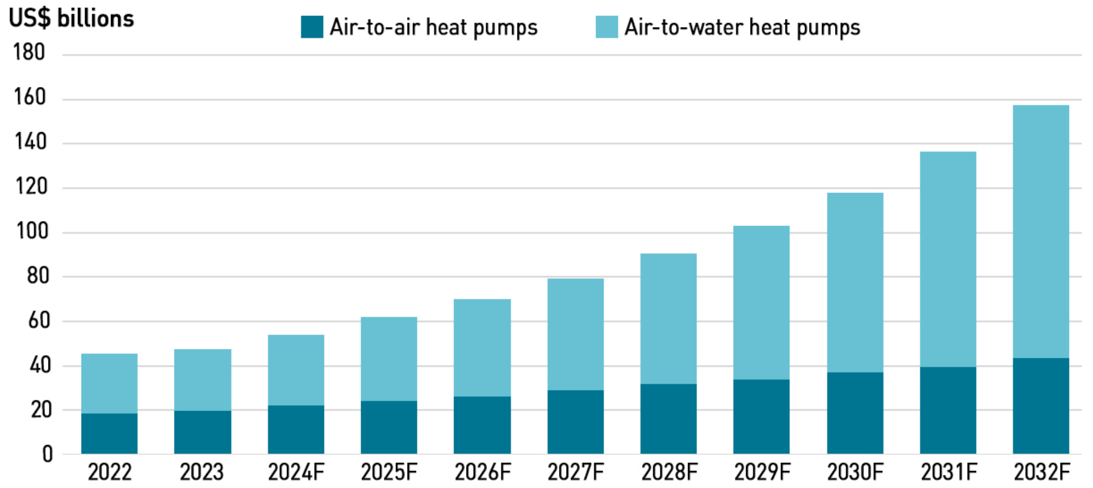
The experience rate studies examined by UKERC suggested that neither market growth nor technology innovation necessarily drive installed costs reductions (and not all policy intent drives at cost reduction for example in Sweden where performance is a key priority). In addition, although high experience rates tend to be associated with countries in which heat pumps have a long history of deployment and with a gradual development of manufacturing capacities and supply chains, such as in Switzerland, significant cost reductions and experience rates have also been reported in countries with a shorter market history such as the Netherlands.

UK Government expectations on cost reductions may be unfounded

UKERC found that expectations of high heat pump cost reductions both by the Government and some businesses operating in the sector reflect a belief in a significant increase in supply chain efficiency and improved installation practices in the UK. According to the Heat and Buildings Strategy, heat pump cost reduction will be achieved through a combination of market competition, economies of scale and new financing models. A UK Net Zero Research and Innovation Framework[36] aimed to "reduce costs and improve efficiency, for example, industrialised manufacture and supply chain innovation".

[36] https://www.gov.uk/government/publications/net-zero-research-and-innovation-framework/uk-net-zero-research-and-innovation-framework

Heat pump market share by technology type



Source: GM Insights

The UK expects that hydronic, that is air or ground to water heat pumps will be the dominant heat pump technologies used in the UK, reflecting the widespread use of water-based (ie radiators) rather than air-based (ie ducts and vents) central heating systems. Hydronic heat pump systems have the largest market share globally and are already widely installed, undermining the hypothesis that the market is immature, and that material manufacturing cost savings can be achieved.

In common with other green policies, the Government believes that the heat pump sector provides opportunities for the creation of jobs in particular through increased manufacturing. The Government is targeting a 30-fold increase in the number of heat pumps manufactured and sold in the UK by 2030, to over 300,000 units a year by 2028. The 2020 Energy White Paper[37] said that "the domestic market for smart systems equipment and related services could support 10,000 jobs by 2050, with a further 14,000 jobs supported by export markets". UKERC described this ambition as "particularly dramatic" when compared with other countries.

The experience in the Netherlands calls into question aspects of this strategy. The UKERC study suggests that one of the drivers of success in the Netherlands was a willingness to access imported components which are cheaper than domestic equivalents. Indeed, since the UK would be building up supply chains from a lagging position, it is questionable whether this can be achieved within the desired timeframe in a way that is cost-competitive against international manufacturers.

[37] https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future/energy-white-paper-powering-our-net-zero-future-accessible-html-version

Impact of electrification on GB energy markets

NG ESO and the Climate Change Committee ("CCC") both indicate that changes will need to be made to the way people heat and maintain warmth in their homes as they move to using heat pumps. As noted earlier, ESO expects houses to be maintained at lower temperatures than is currently the case, and in its sixth carbon budget[38], the CCC suggested that people would "pre-heat" their homes, by turning on central heating earlier than it's needed, before people come home from work, in the hope that the house would be warm enough to allow the heat pump to be turned off once people get home, a time which coincides with the evening peak of electricity demand. For this to work, houses would need to be highly thermally efficient. However, since heat pumps deliver low grade heat, continuous low-temperature operation is more likely, so while it may be possible to pause active heating during peak demand periods, the concept of "pre-heating" does not really make sense.

NG ESO, in its Future Energy Scenarios 2023[39] report suggests that people should install large thermal storage in their homes to help manage peaks and troughs in heating and related electricity demand. Going further, UK FIRES, a research programme funded by UK Research & Innovation which is itself government funded, has indicated that people should use 60% less energy than they do at the moment and for heating to be "powered on for 60% of today's use". These suggestions all indicate concerns over the impact the electrification of heating will have on electricity demand, and electricity grids.

> "Thermal energy storage can be used to reduce electricity demand at times of low supply or peak demand, or to increase it at times of higher supply. For example, a heat pump warms a hot water tank or a dedicated thermal store when prices are low, which then supplies heat to the house for 3-4 hours over a system stress period. Increased electrification of heat demand occurs across all scenarios, and so thermal storage will become increasingly important…
>
> The extent to which consumers (residential, industrial, and commercial) embrace dynamic tariffs and thermal storage will have a significant impact on balancing the energy system. The electrification of heat has the potential to significantly increase peak electricity demands, and so the adoption of smart controls, thermal storage and DSR for heating systems plays an important role in mitigating this increase and reducing the need for additional generation capacity and electricity network reinforcement,"
>
> \- National Grid ESO Future Energy Scenarios 2023

The Future Energy Scenarios published in 2024 show an overall reduction in energy demand of 28-50% and of residential energy demand of 23-64%. Some of this is due to a move from less efficient gas boilers to more efficient heat pumps, but where heat pumps are powered by intermittent renewables,

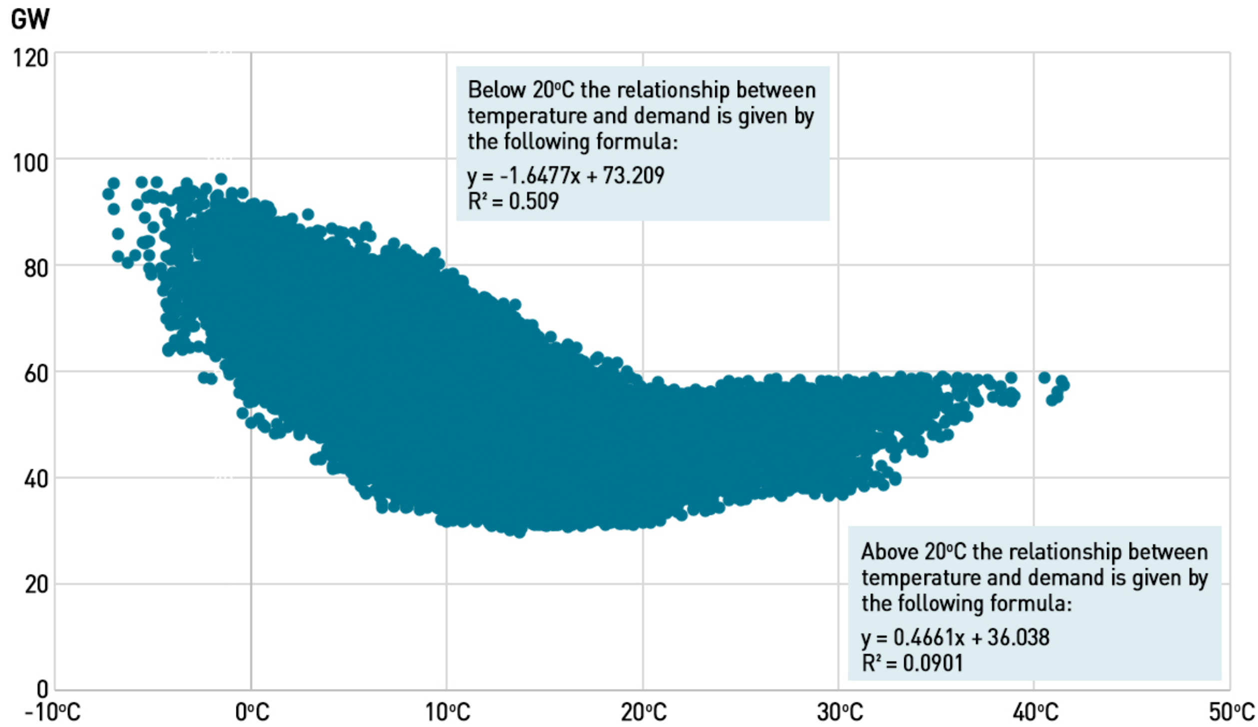
[38] https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf
[39] https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes/fes-documents

overall efficiency will be lower since supply will not always match demand meaning electricity needs to be sourced from elsewhere or stored. The component parts used to model residential energy demand are appliances, lighting, insulation, air conditioning, home energy management systems and heating technologies.

NG ESO identifies demand reduction as a key requirement for reaching net zero targets, which it says will be delivered through improved energy efficiency and changes in consumer behaviour, and it points to the way consumers cut heating demand during the recent affordability crisis as evidence such changes are achievable. However, changes people make *in extremis* due to financial hardship are unlikely to be repeated out of choice and there is little discussion of this. There is also an assumption that consumers will be more engaged with the energy system, in order to provide flexibility, with demand-side flexibility identified as a key means of managing peak system demand.

Once heating is electrified, not only will electricity demand be higher, it will also become more temperature sensitive, meaning that demand will increase faster and to higher levels than it does today when temperatures drop (and there could be similar increases when temperatures rise if there is an increase in domestic cooling). These effects are already observed in countries with higher levels of electric heating than Britain, such as France. Currently, when the weather turns colder, France turns from being a net exporter of electricity to a net importer, including from Britain, and experiences increases in both electricity demand and electricity prices.

Relationship between temperature and demand in the French electricity market (2015 – 2019)



Source: Entsoe Transparency Platform, Visual Crossing Weather Data, Watt-Logic

The chart above shows the relationship between temperature and demand in the French electricity market. The years 2015 to 2019 inclusive were chosen, to provide a reasonable dataset excluding the years when covid impacted demand. The relationship clearly differs at higher temperatures. Below 20°C, changes in temperature explain just over half of the change in demand explained by temperature changes. For each degree that temperature falls, demand rises by 1.65 times. Above 20°C temperature has very little effect of demand, explaining just 9% of the change in demand levels.

Demand-side flexibility may mitigate increased electricity demand from heating

Countries with higher levels of electric heating rely more on demand-side flexibility than Britain does, although in the past couple of years, a demand-side service for households has been introduced in GB as well (the Demand Flexibility Service[40] ("DFS")). Under this scheme, participating consumers are notified of a need to reduce demand the following day and are paid for any reductions they achieve against a baseline level of consumption their supplier has determined for them.

The scheme has had mixed success – in its first year of operation some consumers were able to game the system by increasing electricity use during the re-calibration window used to determine the baseline consumption, for example by charging their electric cars and heating swimming pools. This meant that normal consumption levels were then rewarded as being reduced during the DFS period. Meanwhile less affluent consumer struggled to earn meaningful rewards since high prices meant they had already reduced consumption to the bone. These consumers resorted to turning off every possible appliance and sat in the cold and dark during the DFS period, earning pennies in the process.

In the second year, the re-calibration process was tightened to reduce the scope for gaming, but there have been no real solutions to the problems of poorer consumers engaging in self-harm, and there is still poor understanding of this problem among energy professionals with some seeing these behaviours as more of an "adventure" for consumers than a sign of desperation.

Since electric heating has been widespread in France for many years, the French grid operator Le Réseau de Transport d'Électricité ("RTE") has developed more sophisticated demand flexibility tools. Traditionally, large industrial consumers represented the principle source of demand response. In the 1990s, the potential of demand response that could be mobilised was estimated to be around 5-6 GW, but this potential has remained roughly static in the interim, although RTE expects the contribution from flexibility to be significantly higher in the future (See Appendix III for more details).

However, despite the very long history of variable tariffs, only 500,000 or 1.6% of households are on the variable Tempo tariff offered by market leader EDF, against a target of 5 million[41]. The vast majority of households prefer to be on the regulated tariff. Although some studies[42] have shown that up to 100% of households would be better off on Tempo than the regulated tariff, it suffers from low public awareness, and structural problems[43].

[40] https://www.nationalgrideso.com/industry-information/balancing-services/demand-flexibility-service-dfs

[41] https://www.bfmtv.com/economie/entreprises/energie/electricite-en-quoi-consiste-l-offre-tempo-d-edf-qui-cartonne-depuis-un-an_AV-202311050237.html

[42] https://www.lite.eco/blog/tempo-edf-des-tarifs-inedits-qui-incitent-fortement-a-la-flexibilite/

[43] https://www.kelwatt.fr/fournisseurs/edf/tempo/avis

The relatively low number of households using the time-of-use tariff in France, despite this type of tariff having been a feature of the French market for decades suggests that realising the potential for demand-side flexibility from the residential sector could be challenging in Great Britain as well. Currently both Tempo in France and the DFS in Britain depend on consumers taking active steps to reduce consumption – grid operators hope that automated energy management systems will deliver larger results, but there are considerations to be resolved around customer autonomy and consent.

Approaches taken by other countries to decarbonise heating

EU Heat Pump Action Plan

In 2023, the European Commission consulted on an action plan for the deployment of heat pumps across the bloc. The action plan was designed to (i) address the slow progress in energy-system decarbonisation; (ii) provide a framework for shifting to renewable and efficient heating and cooling in buildings, industry and networks; and (iii) support the competitiveness of the EU clean-energy industry, and set a target for the installation of at least 10 million additional heat pumps by 2027, the phase-out of stand-alone boilers by 2029, and a total additional deployment of 30 million or more heat pumps by 2030 compared to 2020 (including hybrids).

The Commission believes that the roll-out of heat pumps risks being slowed down by factors on both the demand and the supply side, including:

- Structural barriers including current heating infrastructure and systems, the high upfront costs of heat pumps, insufficient electricity grid capacity, and the technical unsuitability of buildings for lower-temperature heating;
- Information barriers including information gaps on existing heat pump solutions and necessary enabling works, and low customer and installer awareness and acceptance;
- Market failures: immature or underdeveloped energy-performance business models in the heating sector, split incentives, a mismatch between financing needs for renovation projects and the typical products offered by financial institutions, a lack of attractive financial

products, limited use of mechanisms that leverage public capital to attract private investment, and the limited uptake of “energy-efficiency”, and certain renewable and smart technologies;

- A regulatory and policy framework that is not sufficiently supportive in terms of product standards and labels, permitting procedures, national building regulations, centralised district heating and planning, favourable energy taxation, and demand-side response possibilities;
- Industry and value-chain limitations that do not yet allow the EU industry to fully use the required industrial and financial resources and scale up manufacturing to mass-production levels; and
- Skills gaps across the value chain, and a growing lack of trained advisers and installers.

The action plan, which is yet to be finalised, is intended to include both regulatory and non-regulatory instruments and enabling tools; financing, communication and skills-use aspects; and engage at the EU, national and local or regional levels to deliver an increase in heat pump installations. The main focus was on the “softer” levers, for example developing partnerships between the Commission, Member States, the heating sector, as well as financial institutions and training providers with a view to scaling up manufacturing, and “creating the right national conditions including a favourable electricity/gas price ratio, and cross-cutting standardisation and interoperability aspects to ensure that heat pumps can be widely rolled out without undermining power-grid stability”. There is also a focus on raising awareness and providing better access to information for consumers.

The Commission outlined plans for updated legislative rules to ensure a sufficiently strong policy signal for the heat pump market. These rules include the recast EPBD and EED, the Article 122 emergency measure on permitting for renewables, the revised RED, the revision of electricity market design legislation, the Net-Zero Industry Act, the Critical Materials Act, and the Commission’s proposals for the recast of the Energy Taxation Directive and for a regulation on fluorinated greenhouse gases. The Commission also wants to incentivise more accessible financing for heat pumps.

The plan had been due to be published in early 2024 but was delayed until after the EU elections in June 2024, and at the time of writing has still not been published. In July 2024, the European Heat Pump Association wrote[44] that the EU’s 2030 climate targets around heating will be missed by a significant amount if current trends in heat pump sales continue. 3.02 million heat pumps were sold in the 21 countries analysed (18 EU members, plus Norway, Switzerland and the UK) in 2023 bring the total installed heat pumps in these countries to 23.96 million. If annual sales remain at this level (3 million a year), around 45 million heat pumps would be installed by 2030 which is about 25% short of the EU target.

[44] https://www.ehpa.org/news-and-resources/news/eu-could-end-up-15-million-heat-pumps-short-of-2030-ambition/

Netherlands

Overview

The Netherlands is an interesting case study. Like the UK, the Netherlands has relied on its own natural gas resources, and actively encouraged the use of natural gas for space and water heating. However, since the mid-2010s, the Government pivoted and began to incentivise heat pumps, and by 2023, 1.9 million domestic heat pumps were in use, representing 23% of all households (assuming one heat pump per household, which is not necessarily the case). However, this success has been a double-edged sword, with heat pump related electricity demand adding to problems with electricity grid congestion. Since 2022, the Dutch Government has actively incentivised the installation of hybrid heat pumps as the preferred route in the short term for the decarbonisation of heating.

Dutch approach to decarbonisation of heating

In 2020, 90% of Dutch homes had a connection to the natural gas network. Gas had been encouraged for heating due to the abundance of gas being produced through Dutch gas fields. However, since 2018 the Dutch government has reversed its position on the deployment of natural gas, in part due to its climate commitments, and in part due to the rising risk of earthquakes in the Groningen region as the gas field became increasingly depleted. Production from the Groningen field ended in 2023.

Under the Dutch Climate Agreement, the Netherlands aims to significantly reduce its reliance on natural gas. In 2018, the Dutch Government announced an ambition to “close the gas valve” for 30,000 to 50,000 houses every year from 2021[45], and to make 1.5 million buildings natural-gas-free by 2030[46]. This transition is partly facilitated by promoting the use of heat pumps.

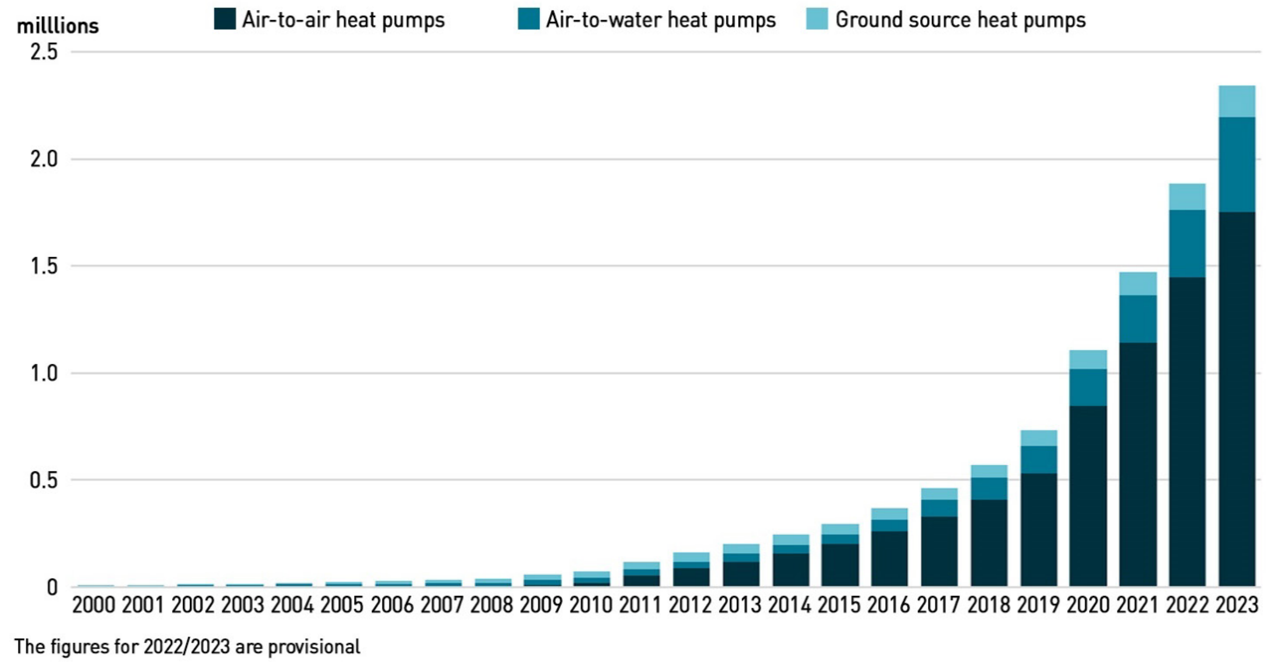
The first heat pumps were installed in the Netherlands during the early 1980s – well before either climate goals or issues at Groningen arose. However, sales growth was slow and the number of installed units in homes and businesses did not exceed 1 million until 2020.

[45] https://zoek.officielebekendmakingen.nl/kst-33529-457.html

[46] https://www.government.nl/topics/climate-change/national-measures

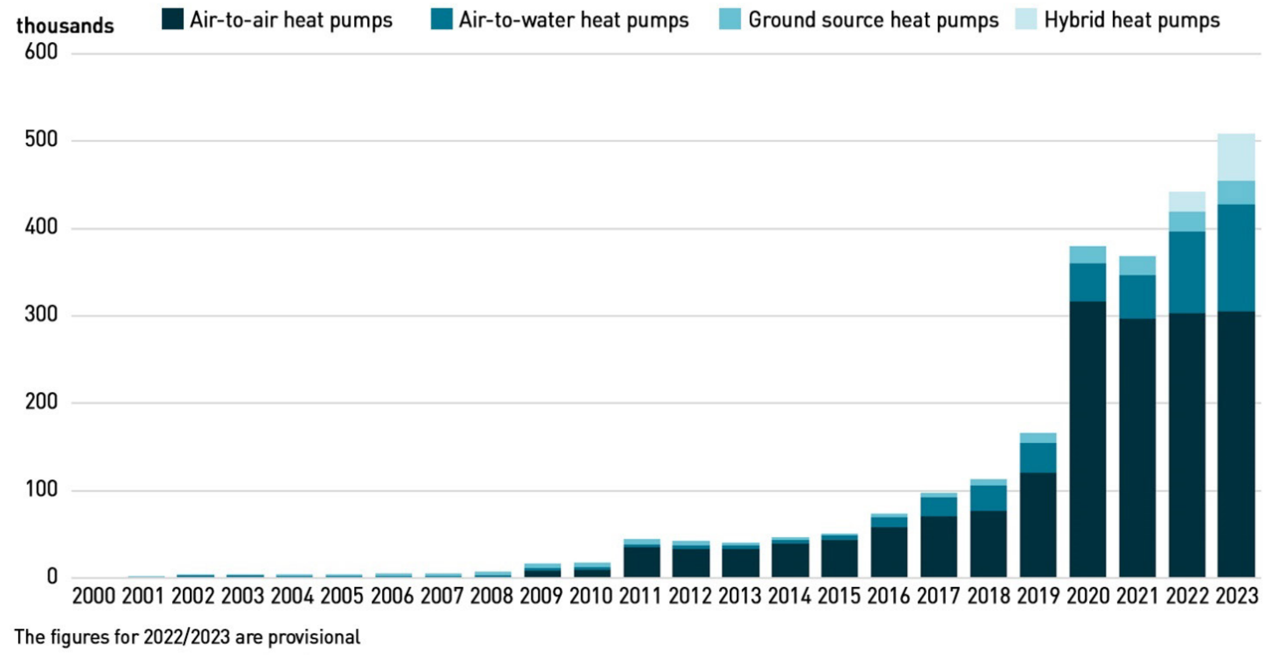
Watt-Logic

Number of installed heat pumps in the Netherlands at year-end



Source: Statistics Netherlands (CBS)

Number of heat pumps sold per year in the Netherlands



Source: Statistics Netherlands (CBS)

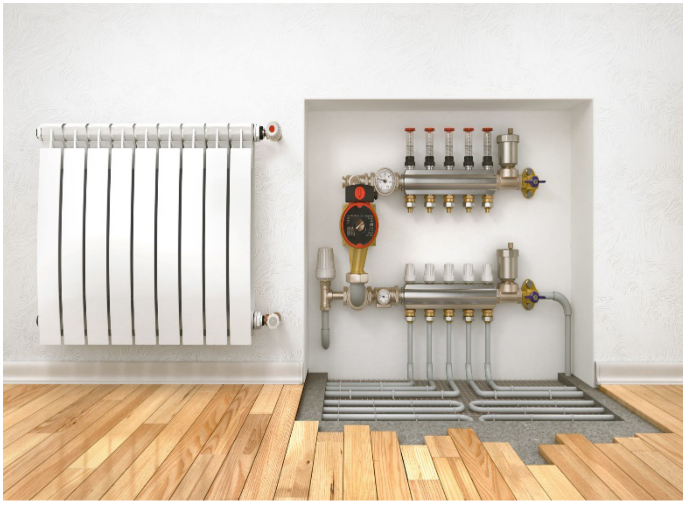
Air-to-air heat pumps have the highest market share while ground source heat pumps have the lowest share since these are difficult to install in densely populated areas such as the Netherlands due to their space requirements. Data for hybrid systems was reported by Statistics Netherlands (CBS - the Centraal Bureau voor de Statistiek) from 2022 with sales of hybrid air-water systems of 23,165 in 2022 and 54,167 in 2023.

ISDE subsidy scheme

The Dutch Government began to encourage heat pump use in the mid-2010s. It created the "Investeringssubsidie duurzame energie en energiebesparing" ("ISDE") subsidy scheme in 2013 and it came into effect in 2016. This provides grants for the renewable energy systems, including heat pumps, solar boilers, pellet stoves and biomass systems. This programme supports both homeowners and businesses.

The amount of the subsidy[47] depends on the type of heating system and the number of sustainability measures that have been installed in the property. For example, a homeowner could receive a maximum of €780 installing ground insulation, but up to €4,100 for the installation of a solar boiler. For heat pumps the available amounts are from a minimum of €500 to a maximum of €7,650 depending on the type of system[48]. The scheme is additive, so if more measures are introduced, higher amounts can be claimed. Homeowners can apply for a subsidy within 24 months after implementing the first measure. From 1 February 2024, the costs for removing a gas connection were removed.

The ISDE subsidy was originally more generous, and intended to expire on 31 December 2020. The introduction of ISDE had a measurable impact on heat pump sales which showed a 44% increase on the prior year. The scheme was reduced at the end of 2019[49] with a halving of the subsidy amount for small (sub 1kW) installations and expiry of the subsidy for devices that were installed in buildings for which the environmental permit was applied for after 30 June 2018 – private individuals were given a six-month grace period to 30 June 2020 to submit their subsidy applications. However, in 2020, the rules were relaxed[50] – the grace period was extended in light of covid restrictions, and the subsidy amounts were increased for appliances with energy efficiency ratings of A+ and A++ by €150 and €300 respectively. The ISDE scheme closed for new buildings in 2020 as expected but was extended for retrofits and is now due to run until 2030.



Despite the covid restrictions, heat pump sales increased significantly in 2020, and continued at the higher level in the subsequent years. While the growth in sales between 2018 and 2019 could be attributed to the anticipated closure of the ISDE scheme, the growth in 2020 is likely to be attributable to factors other than the ISDE. However it is important to note that air-to-air heat pumps are often purchased for the purposes of air conditioning rather than heating[51], and as such these data are excluded from the European Heat Pump Association's heat pump analyses as it considers the bulk of such units are sold for cooling not heating. Units purchased for air conditioning purposes are not eligible for the ISDE.

[47] https://www.rvo.nl /subsidies-financiering/isde/woningeigenaren
[48] https://www.isde.nl/isde-subsidie-warmtepompen.html
[49] https://zoek.officielebekendmakingen.nl/stcrt-2019-66566.html
[50] https://zoek.officielebekendmakingen.nl/stcrt-2020-65131.html
[51] https://www.vakbladwarmtepompen.nl/7257/groei-in-nederlandse-warmtepompverkoop-valt-op-binnen-europa

From 1 January 2022, the subsidy for hybrid systems increased from 20% of the unit cost to 30% of the unit cost as the Government decided to increase the incentives for hybrid systems relative to fully gas-free systems.

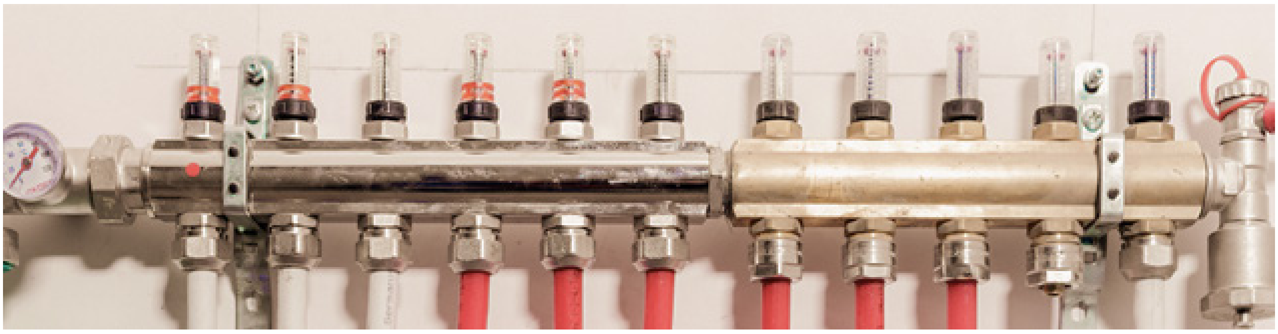
National Heat Fund (Nationaal Warmtefonds)

The Government also provides support in the form of loans. The National Heat Fund (Nationaal Warmtefonds)[52] offers affordable financing for improvements to the sustainability of homes and other buildings such as schools. The Heat Fund was founded in 2013 (then as the National Energy Savings Fund) and operates on behalf of the central government. For some heat pumps, the whole capital cost can be financed with an interest-free Energy Saving Loan[53], as long as the term is less than 20 years. For a term of 20 years, it is only possible to finance a heat pump as long as the cost does not exceed one third of the loan amount. As air conditioning systems, air-to-air heat pumps not eligible for financing under the scheme. Different loans are available as follows:

- Loans of up to €15,000 with a term of 7, 10 or 15 years;
- Loans amounts between €15,000 and €25,000 with a term of 7, 10, 15 or 20 years; or
- Loan amounts above €25,000 with a term of 7, 10, 15, 20 or 30 years.

This initiative has made it easier for homeowners to invest in heat pumps, even if they cannot afford the upfront costs, and the fund's accessibility has helped broaden the demographic reach of heat pump adoption.

Due to the income requirements, not everyone is eligible for a regular Energy Savings Loan. As a result, the Energy Saving Mortgage was introduced for special target groups. The basic principle is to ensure homeowners do not experience financial hardship as a result of this additional loan - the monthly repayment and interest depend on what the homeowner can afford, based on existing lending standards. In extreme cases, the loan is completely repayment-free and interest-free and borrowers do not have to repay any residual debt upon the sale of their home or at the end of the mortgage term. Eligible homeowners include those whose current mortgage is too high or the income is too low to be able to borrow more, those with a seriously impaired credit rating and people over the age of 75.



Incentivising hybrid heat pumps

There is a specific focus on hybrid heat pumps in the Netherlands, which combine an electric heat pump with a traditional gas boiler. These systems allow for significant reductions in natural gas usage

52 https://www.warmtefonds.nl/over-ons

53 https://www.warmtefonds.nl/particulieren/energiebesparende-maatregelen/warmtepomp

while still providing reliable heating, even in cold weather. Despite the growth in heat pump installations, the Dutch heating industry had developed concerns by 2021 that climate targets relating to heating were not on track. This led a coalition of industry bodies and other stakeholders to lobby[54] the Government to specifically support hybrid solutions with an annual subsidy of €120 million until 2026. The coalition believed that this could stimulate demand for between one and two million hybrid systems by 2030, with a target of 100,000 installations per year from 2024.

According to the industry coalition, the use of between one and two million hybrid heating systems would reduce annual natural gas consumption in the Netherlands by 1.1 - 2.2 billion cubic metres, and create additional electricity demand of 2.2 - 4.5 TWh. The installation of 100,000 hybrid heat pumps would result in a reduction in carbon dioxide emissions of 0.13 million tonnes, while meeting the coalition's hybrid system installation targets would save 1.3 – 2.6 million tonnes of carbon dioxide emissions, which it said would be a significant contribution to Dutch climate targets.

In addition to a financial subsidy, the coalition called upon the Government to provide clear policy support for hybrid systems including Government targets, to work with the coalition on providing reliable information to consumers about such systems, and to promote an increase in skilled hybrid system installers. The coalition also called for the development of hybrid heat pump pilot schemes to demonstrate their benefits to consumers and other stakeholders. It set out the following benefits of hybrid systems:

- Hybrid heat pump technology is a technically feasible and affordable way to reduce CO_2 emissions from homes and commercial buildings;
- Hybrid heat pumps are a cheap solution for CO_2 reduction in neighbourhoods that are not yet collectively natural gas-free;
- Installation can take place in line with the natural replacement cycle, such as when replacing the central heating boiler, a major renovation or moving;
- Installation requires minimal adjustments in the home;
- Existing energy networks can be maintained.

In 2023 the Government of the Netherlands introduced[55] €9.3 billion of funding support for the built environment and tightened the efficiency standards of heating installations from 2026. In 2022 the Government had announced plans to make the replacement of gas boilers with low carbon alternatives including heat pumps mandatory from 2026, with hybrid heat pumps becoming the standard for heating homes, shops, schools and offices. However, the recently elected Government has indicated its intention[56] to remove this obligation.

In May 2022 the Government announced[57] that it would prioritise the installation of hybrid heat pumps, saying that from 2026 they would be the standard for replacing conventional gas boilers for homes not connected to a heat network. It also announced that a subsidy would be available for the purchase of a hybrid heat pump available starting in 2022. The Government allocated €150 million per year in addition to the interest-free financing available through the National Heat Fund.

A recent study involving 120 homes has shown that on an annual basis gas use with a hybrid heat pump, is on average 75% lower than with a central heating boiler alone. This equates to an additional

[54] https://www.technieknederland.nl/stream/verklaring-coalitie-hr-hybide-21-4-2021
[55] https://www.rijksoverheid.nl/actueel/nieuws/2023/05/01/warmtepomp-de-norm-vanaf-2026-goed-voor-klimaat-en-de-energierekening
[56] https://www.installatie.nl/nieuws/kabinet-trekt-stekker-uit-norm-hybride-warmtepomp
[57] https://www.rijksoverheid.nl/actueel/nieuws/2022/05/17/hybride-warmtepomp-de-nieuwe-standaard-vanaf-2026

2,360 kWh of electricity use per year. Given the relative costs of gas and electricity in the Netherlands, this generates a saving of almost a thousand euros on the annual energy bill. The first results of the research, (A Demonstration Project for Hybrid Heat Pumps in the Built Environment[58]), were published in June 2024. The study involves 200 homes which have not had any structural changes other than the installation of the hybrid heating system.

Concerns over grid congestion drive interest in hybrid solutions

Recently the Dutch authorities have begun to worry about the impact the growth in heat pumps will have on electricity demand, and consider that without action to strengthen electricity grids, 1.5 million SMEs and households could experience a power outage in the period to 2030[59], in the worst case scenario. One option under consideration is to use the ISDE subsidy to incentivise heat pumps with smart controls which would prevent all units drawing power from the grid at the same time, effectively staggering demand (subject to ensuring consumer protections around consent), however such measures are unlikely to be introduced before 2026.

In 2022, grid operators saw an explosive growth in demand for electricity connection requests[60] - more than 53 GW of transmission capacity were requested from TenneT, compared with a historic average of just 6 to 8 GW. The whole country is to one degree or another being affected by grid congestion. Problems on the high-voltage network are already affecting large energy users, who can no longer get a grid connection in some areas. The Minister for Climate and Energy Policy, Rob Jetten, warned in a letter to the Dutch Parliament that small users - including households - may face the same problems, and be unable to secure grid connections. If no flexible electricity capacity can be found, the "physical limits" of the grid could be reached in some areas as early as 2025, with a risk of outages affecting households between 2026 and 2029[61].

Grid congestion concerns are also driving policy interest in hybrid systems, with ministers suggesting that homes considering switching to fully electric systems should first consider whether there is electricity grid congestion in their area. One of the challenges with heat pumps is that they must be sized for the maximum annual heating requirement which in the Netherlands can involve ambient temperatures of -10°C. However, such low temperatures may only occur for ten days each year. Sizing a heat pump to manage this heating requirement can require a larger unit with a larger grid connection, possibly necessitating grid reinforcement, particularly if

58 https://www.demoprojecthybride.nl/

59 https://www.rijksoverheid.nl/documenten/kamerstukken/2024/04/25/kamerbrief-versnelling-en-uitbreiding-maatregelen-netcongestie-flevoland-gelderland-en-utrecht-fgu

60 https://www.tweedekamer.nl/kamerstukken/brieven_regering/detail?id=2023D27812&did=2023D27812

61 https://www.rijksoverheid.nl/documenten/kamerstukken/2023/10/18/nieuwe-maatregelen-netcongestie

multiple households are specifying similarly large systems. A hybrid system allows smaller heat pumps to be used because the low temperature requirement can be covered by the gas boiler. Since the number of very cold days on which gas would be required is typically low, the climate impact of this choice is similarly small. Hybrid heat pumps would also be compatible with the use of green gas.

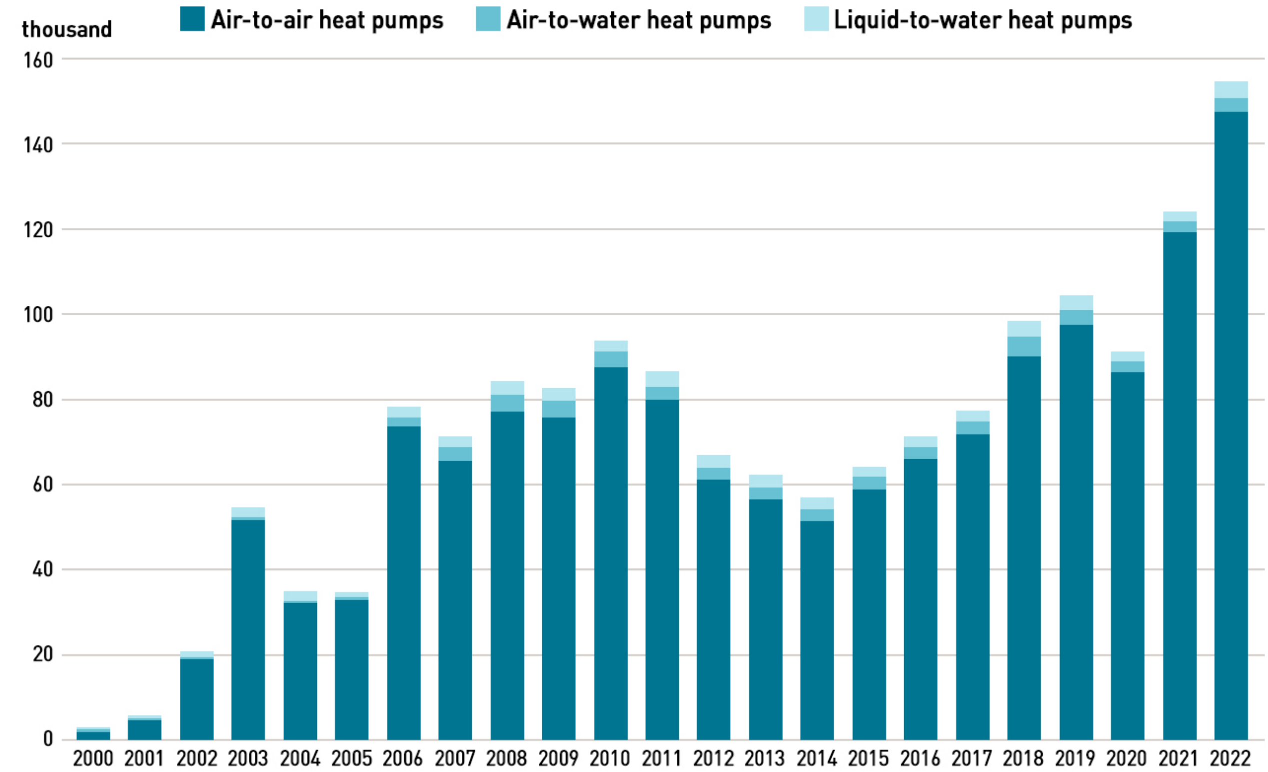
In his October 2023 letter to the House of Representatives, Minister Jetten said that hybrid systems allow users to switch between using gas and electricity and are therefore less burdensome for the electricity grid – hybrid systems can switch to gas at times of peak electricity grid demand if necessary to maintain security of electricity supplies. This solution is considered temporary, but is being evaluated for new buildings – the Netherlands, like the UK, has a housing shortage, and the ability to deliver the required number of low carbon homes is threatened by electricity grid constraints. The Government would like to ensure that grid constraints do not undermine the delivery of housing targets. Electric central heating boilers have already been banned as a result of congestion concerns, and the Minister also outlined plans to enforce the ban more strictly.

Norway

Overview

Buildings account for more than half of the electricity consumption in Norway, and electricity accounts for almost 80% of the total energy consumption in buildings, the majority of which is used for heating. In 2023 Norway saw the largest deployment of heat pumps per thousand households of any European country, according to the European Heat Pump Association. The first heat pump in Norway was built in 1918, a large installation used to produce salt by steaming seawater. Heat pumps were not common in Norway before the 21st century due to the high installation cost and availability of cheap hydropower electricity.

Number of heat pumps sold per year in Norway



Source: Prognosesenteret AS

However, Norway faced a dry period at the start of the 21st century that caused a rapid rise in electricity prices, so the Government created state-owned corporation, Enova, in 2001, with the responsibility for developing efficient alternative energy resources. Enova offered subsidies for heat pump installation, resulting in Norway having the highest number of heat pumps per capita in Europe. By 2020 the number of heat pumps in Norway was estimated to be 1.3 million[62], with 60% of homes having a heat pump by 2022[63].

[62] https://www.sciencedirect.com/science/article/pii/S2213138822008773
[63] https://www.nature.com/articles/s41560-022-01104-8

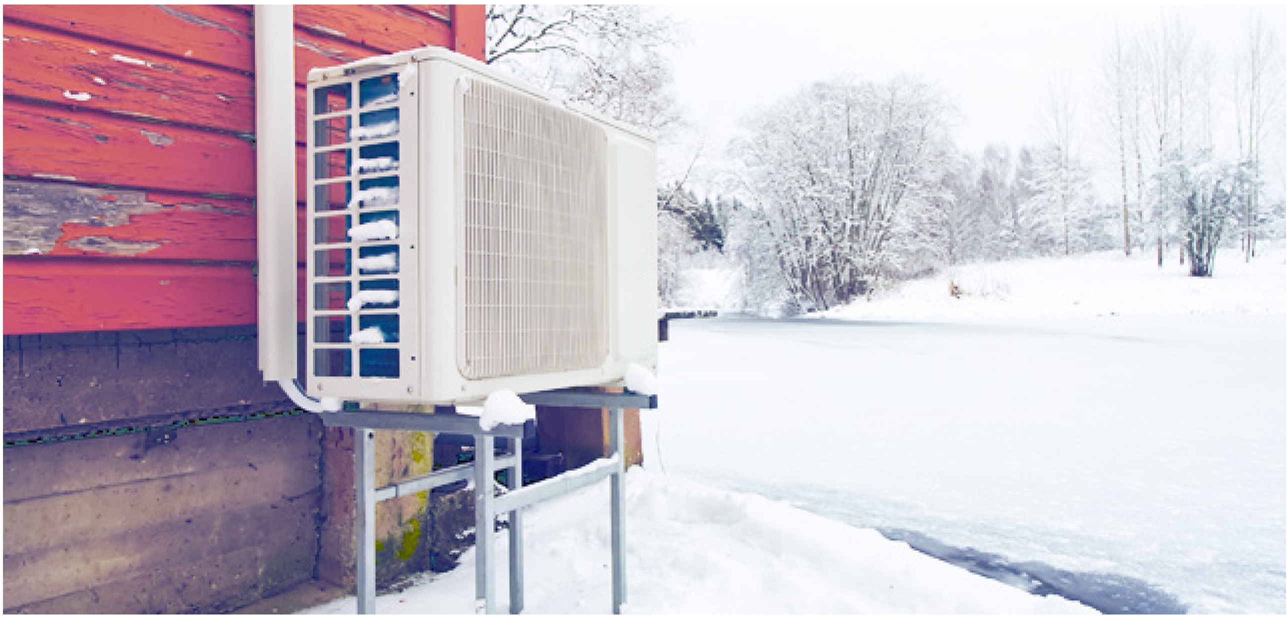
Key Policies Supporting Heat Pumps in Norway

Heat pumps have been supported through a variety of policy levers including subsidies, tax breaks and building regulations:

Enova grants: Enova SF is a government enterprise responsible for promoting energy efficiency and renewable energy, which offers subsidies to households and businesses that install heat pumps. In 2003, Enova had a subsidy scheme[64] where households received NOK 5,000 for the installation of an air-air heat pump. About 50,000 people applied for this support. In 2006, a new support scheme for energy efficiency measures was established, including subsidies for hydronic heat pump systems. Air-air heat pumps no longer receive Enova support, as this market is considered mature and the installation cost-effective without support however some municipalities continued to provide support for air-to-air heat pumps after Enova's schemes ended. Between 2006 and 2011, about 50,000 grants were awarded for energy efficiency measures, of which about 25,000 were for air-water heat pumps.

The most popular schemes currently funded by Enova are balanced ventilation systems which retain 70-90% of the heat in the air leaving the building (up to NOK 5,000 / £360), solar systems (up to NOK 32,500 / £2,340) and liquid-to-water heat pumps (up to NOK 10,000 /£720).

Energy labelling and certification: The requirement for energy labelling of buildings was introduced by law in Norway in 2010. The energy label consists of an energy rating and a heating rating. The energy rating is based on the calculated energy delivered to the system boundary, including any distribution and other heat losses. The use of heat pumps and thermal solar that utilise ambient heat have annual power factors that far exceed losses in distribution and output, so attract higher energy ratings. The heating rating evaluates the proportion of energy demand that can be met by non-fossil and non-direct-acting electric heat. This rating can be positively influenced by the installation of a heat pump.



64 https://publikasjoner.nve.no/rapport/2016/rapport2016_60.pdf

Like the UK, Norway has a building energy certification scheme[65], but it is considered more rigorous than the UK equivalent since it focuses on heat losses and carbon dioxide emissions rather than heating cost, and involves detailed calculations of heat losses reducing subjectivity.

Building codes and regulations: Norway has stringent building codes that require new buildings to meet high energy efficiency standards. The TEK17 Building Code forbids the use of fossil-fuel based heating in new buildings and has maximum energy demand levels for buildings[66] that can be more easily met using heat pumps. The SAK10 Building Regulations impose liabilities[67] on building companies to ensure compliance with energy efficiency and energy performance standards in Norwegian buildings. If a building does not meet the required energy performance standards, the building company could be held liable. This includes potential legal and financial liabilities if the building fails to comply with regulations, leading to penalties or the need for costly rectifications.

Public awareness campaigns: The Norwegian government, through Enova and other agencies, has run public awareness campaigns to educate citizens about the benefits of heat pumps, including cost savings, environmental impact, and long-term efficiency.

Research and development funding: The Norwegian government also invests in research and development to advance energy efficiency and decarbonisation of heating[68]. Research institute, SINTEF, which is partly funded by the Norwegian government, has an extensive programme[69] relating to heat pumps.

Recent developments

In 2023 the Norwegian Government announced[70] its intention to evaluate a new target of reducing the energy consumption of buildings by 10 TWh by 2030, compared with 2015. The Government proposed an increase in the allocation to Enova by NOK 180 million in 2024 to strengthen efforts to promote more efficient energy use and a more flexible energy system. In 2023, Enova's budget was up to NOK 2 billion. The Government also proposed an increase in the Housing Bank's subsidy scheme for municipal rental housing, care homes and nursing homes to a total of NOK 300 million in 2024 - the scheme is in high demand and helps to raise the energy standard in the municipal housing stock and is particularly targeted at low income households.

The Government also proposed to increase funding for the Norwegian Building Quality Agency (DiBK) in 2024 and to ask DiBK to consider changes to the Building Technology Regulations and the Building Application Regulations to facilitate increased thermal efficiency, energy flexibility and local energy production in new and existing buildings.

According to the Norwegian Heat Pump Association[71], the number of heat pumps sold decreased across all categories in 2024, with the total number of units sold down 22% compared to 2023, returning to 2021 levels. The Association considers that new building regulations expected later in the year will

[65] https://www.enova.no/energimerking/om-energimerkeordningen/om-energiattesten/
[66] https://www.dibk.no/regelverk/byggteknisk-forskrift-tek17/14/14-2?_t_q=varmepumpe
[67] https://www.dibk.no/regelverk/sak/3/12/12-6?_t_q=energieffektivitet
[68] https://www.forskningsradet.no/portefoljer/energi-transport-og-lavutslipp/portefoljeplanen-for-energi-transport-og-lavutslipp/prioriteringer/tematiske-prioriteringer/
[69] https://www.sintef.no/ekspertise/sintef-energi/varmepumpeteknologi/
[70] https://www.regjeringen.no/no/dokumenter/handlingsplan-for-energieffektivisering-i-alle-deler-av-norsk-okonomi/id2998036/?ch=1
[71] https://www.novap.no/artikler/nedgangen-fortsetter-i-andre-kvartal

stimulate renewed demand, with more efficient models gaining popularity as well as a possible move away from the all-electric models that are currently dominate the market.

Prevalence of secondary heating in Norway

Norway is often held out as a heat pump success story and evidence that heat pumps work well in cold climates. But this is misleading – very many Norwegian homes use secondary heating. A 2017 survey of urban homes[72] found that the main heating source was electricity which represent 61%, followed by heat pumps (15%), district heating (9%), wood burning (7%), oil (4%) and other (4%). Around 62% of the responders had wood burning as a secondary heating source, and 7% as primary source. Previous studies referenced by the researches had concluded that fuelwood, along with heat pumps, are intensively used in detached houses in Norway and are used to reduce electricity consumption for residential heating.

A 2019 study by the Norwegian Institute for Air Research[73] found that there were an estimated 2.1 million domestic wood burning heating installations in the 2.4 million Norwegian households, with an additional 900,000 in the 1 million cabins and summer houses of Norway. In other words, 87.5% of Norwegian households have a wood-burning stove and 90% of cabins and summer houses. And far more Norwegian homes have a wood burner than a heat pump. By this measure, more homes have a wood stove than a heat pump.

According to a 2022 survey by Norstat on behalf of Norsk Varme[74], nine out of ten Norwegians who have a fireplace use it, with one in five Norwegians burning wood as their main source of heating. Record high electricity prices at the time provided a strong incentive for the use of wood burning stoves, with many households lighting fires earlier in the year as a result, rather than waiting for the coldest weather. The survey found that half of Norwegians use their wood fires every day and 80% use them at least once a week. Between 2020 and 2022, 340,000 homes installed new wood stoves. Norwegians are increasingly installing outdoor fireplaces with 30% of homes having a fire pan for outdoor heating.

While the Norwegian Government does not encourage the use of wood burning stoves, it does try to encourage people to replace older stoves with more modern versions which are more efficient and have lower emissions. It is also true that irrespective of intent, the use of wood burning stoves helps to

[72] https://www.sciencedirect.com/science/article/pii/S0301479717300269
[73] https://acp.copernicus.org/preprints/acp-2019-95/acp-2019-95-manuscript-version4.pdf
[74] https://norskvarme.org/nordmenn-elsker-a-fyre-med-ved-halvparten-av-befolkningen-fyrer-daglig-nar-det-er-hoye-strompriser/

protect the electricity grid at times of peak demand since on the coldest days people supplement or replace their heat pump use with wood fires which have a higher heat output. Electricity grid operator Statnett, in common with its counterparts elsewhere, has emphasised the need for alternative sources of heating to help support the power grid at times of peak cold weather demand. A 2022 report by Thema Consulting Group[75] available on the Norwegian Government's website found that over the next decade, the power balance will be weakened, and there may be a power deficit in normal years if the scenarios of high consumption growth and low output growth materialise.

Norway and the Netherlands have both been successful in incentivising significant uptake of heat pumps, but both countries are facing challenges with balancing their electricity grids in the face of the higher demand from the electrification of heating, and in both countries alternative measures are being sought. Although the Norwegian Government would like to see the use of wood burning stoves decline, their widespread use as a means of secondary heating is unlikely to fall in the near future, in part because of high electricity costs, and in part because they offer superior heating on cold days. Were the Government to succeed in persuading people to move away from the use of wood, it would exacerbate expected challenges for the electricity grid, particularly on cold days.

[75] https://www.regjeringen.no/contentassets/5f15fcecae3143d1bf9cade7da6afe6e/no/sved/vedlegg4.pdf

Conclusions

The deployment of heat pumps has been slower than policymakers would like, but with the ongoing uncertainty around the possible use of hydrogen (all of the domestic hydrogen trials have been cancelled), there are currently no alternatives to decarbonising heating available to British consumers.

However, the challenges to increasing uptake are significant. Even if the Boiler Upgrade Scheme covers most of the capital cost of the heat pump, most households still need to spend significant amounts on retrofitting insulation and changing emitters to ensure comfort levels are maintained, and there are doubts over the ability of heat pumps to truly deliver the required warmth on the coldest days without the use of secondary heating. If solutions to the financial challenges could be found, there would still be an issue with supply chains and availability of installers – it is unclear how far these can be scaled to accommodate policy targets.

Should these hurdles be overcome, the resulting increase in electricity demand could present major difficulties for the electricity grid, with NG ESO, which operates the high voltage electricity network, expecting that consumers will need to both accept lower levels of warmth and avoid using their heating at peak times in order to protect the grid. In other words, electrification of heating may require rationing of electricity if blackouts are to be avoided.

There is widespread resistance among policymakers, and other stakeholders to the idea of hybrid heating systems due to a desire to decarbonise in one step. However this is unlikely to be realistic, particularly for existing building stock. But hybrid systems, as the Dutch Government has recognised, solve a great many of the problems created by fully electric systems. They reduce the need to retrofit expensive home upgrades such as insulation and larger emitters, since on the coldest days the gas boiler can fire up to deliver high temperature heat.

The ability to switch between the boiler and heat pump also provides in-built insurance for the electricity grid since boilers can be used if electricity demand becomes too high, allowing consumers to maintain warmth without risking blackouts. This would be particularly beneficial for vulnerable consumers who could face health risks if they were unable to maintain adequate indoor temperatures. While hybrid systems still involve some use of fossil fuels, even if the electricity grid is fully decarbonised, the emissions associated with heating would be greatly reduced from current levels.

In refusing to consider hybrid heating systems as part of the solution to the decarbonisation of heating, policymakers are effectively making “the perfect the enemy of the good”. They are also forgetting that the purpose of decarbonisation is not to only reach net zero in 2050, it is to immediately reduce emissions as much as possible. Continuing to focus on full electrification when it will clearly be out of reach for many years means that emissions will remain higher for longer.

A better approach would be to embrace hybrid solutions to stimulate consumer demand. Consumers would be much more likely to accept heat pumps if they came with less up front cost and upheaval, and the risk of cold weather underperformance was removed. Consumers are also more likely to accept solutions which involve a small change rather than a large change – currently installing a heat pump means a major change both to heating equipment and the way that the equipment is used (long periods of low-temperature operation versus short periods of higher temperature operation).

Higher demand would provide the market signals necessary for manufactures to scale up production, and for heating companies to recruit and train more installers. It is not a perfect solution, and there will still be delivery challenges, but this approach could deliver more emissions reductions faster, meaning that overall emissions between now and 2050 would be lower than would otherwise be the case based on realistic uptake projections.

The Dutch experience illustrates what is needed to achieve higher uptake of heat pumps, but it also illustrates the challenges this brings. Policymakers in Britain should pay attention to these lessons, and adopt a more pragmatic approach to the decarbonisation of heating, rather than the current all-or-nothing approach which is unlikely to succeed.

Appendix I – Government policy

Green Growth Strategy

The Green Growth Strategy in 2017 set out plans for "improving the energy efficiency of our homes" providing £3.6 billion of investment to upgrade around a million homes through the Energy Company Obligation, and to extend support for home "energy efficiency" improvements until 2028 at the existing level of ECO funding. The Government set out its ambition for all fuel poor homes to be upgraded to Energy Performance Certificate ("EPC") Band C by 2030 and for as many homes as possible to be EPC Band C by 2035 where "practical, cost-effective and affordable". It also outlined an intention to develop a long term trajectory to improve the energy performance standards of privately rented homes, with the aim of upgrading as many as possible to EPC Band C by 2030, and to consult on how social housing could meet similar standards over this period.

There were also plans to consult on the energy performance standards for new and existing homes following the outcome of the independent review of Building Regulations and fire safety, "including futureproofing new homes for low carbon heating systems" and to offer all households the opportunity to have a smart meter by the end of 2020.

Specifically in relation to low carbon heating, the Government set out plans to build and extend heat networks across the country, underpinned with public funding (allocated in the Spending Review 2015) out to 2021, and phase out the installation of high carbon fossil fuel heating in new and existing homes currently off the gas grid during the 2020s, starting with new homes. There were plans to improve standards on the 1.2 million new boilers installed every year in England and require installation of energy saving control devices.

£4.5 billion of funding was earmarked through the Renewable Heat Incentive to support innovative low carbon heat technologies in homes and businesses between 2016 and 2021, and £184 million was allocated to innovation programmes to develop new energy efficiency and heating technologies to enable lower cost low carbon homes.

Ten Point Plan

Decarbonising buildings also featured in the 2020 Ten Point Plan, with a claim that "developing greener buildings could deliver…support for around 50,000 jobs in 2030, around £11 billion of private investment in the 2020s, savings of 71 MtCO2e between 2023 and 2032, or 16% of 2018 UK emissions".

The specific targets identified were 600,000 heat pumps installations per year by 2028 compared with the roughly 1.8 million gas boilers which are currently installed each year, homes built to the Future Homes Standard being "zero-carbon ready" with 75–80% lower carbon dioxide emissions than those built to existing standards, and green home finance initiatives to improve the "energy efficiency" of around 2.8 million homes, improving around 1.5 million homes to EPC C standard by 2030.

Heat and Buildings Strategy

In 2021 the Government launched its Heat and Buildings Strategy, re-iterating many of its previous targets and commitments eg the intention to install at least 600,000 heat pumps per year by 2028, and potentially replacing 1.7 million fossil fuel boilers per year by the mid-2030s. There was a commitment to invest £338 million over 2022/23 to 2024/25 into a Heat Network Transformation Programme to scale up low-carbon heat network deployment, and to make a decision on the role of hydrogen by 2026.

The Government outlined an ambition to phase out the installation of natural gas boilers beyond 2035, stating this would be a gradual transition, and that no-one would be forced to remove an existing gas boiler. It said the future would likely see a mix of low-carbon technologies used for heating, with the electrification of heat for buildings using hydronic (air-to-water or ground-to-water) heat pumps, heat networks and potentially switching the gas in the grid to low-carbon hydrogen. It expected hydronic heat pumps to be a key technology for new buildings and buildings not connected to the gas grid, and heat networks to be a key technology in areas of high-density heat demand and where there are large low-carbon heat sources.

Affordability was emphasised, with plans to work with industry to reduce the costs of heat pumps by at least 25-50% by 2025 and towards parity with boilers by 2030, and supporting consumers who switch early with the new £450 million Boiler Upgrade Scheme providing £5,000 Boiler Upgrade Scheme grants. The Government also expressed a hope that action to remove distortions in energy prices would mean that heat pumps would be no more expensive to buy and run than existing boilers. The Heat and Buildings Strategy also included policies for improving the thermal efficiency of buildings, such as the Home Upgrade Grant and the Social Housing Decarbonisation Fund.

In September 2023, the Government announced a delay to the ban on installing oil and LPG boilers, and new coal heating, for off-gas-grid homes to 2035, instead of phasing them out from 2026. Many of these homes are not suitable for heat pumps, so this delays the requirement for these households to make investments estimated to be around £10,000 - £15,000 to switch to electric heating.

Boiler Upgrade Scheme

Launched in 2022, the Boiler Upgrade Scheme provides grants to cover part of the upfront costs of replacing a gas boiler with a heat pump or biomass boiler. At inception the scheme provided grants of up to £5,000 and was available to existing buildings excluding social housing and private new-build properties that met certain insulation criteria.

In March 2024, the maximum grant available to consumers under the Boiler Upgrade Scheme was increased by 50% to £7,500, and restrictions which required homeowners to install cavity wall or loft insulation to use the scheme, were removed. This change was introduced after Ministers observed that heat pump prices had risen, prompting the Government to refer the sector to the Competition and Markets Authority.

The Government also introduced an exemption to the requirement to end the use of fossil fuel boilers, including gas, in 2035, "so that households who will most struggle to make the switch to heat pumps or other low-carbon alternatives won't have to do so". This is expected to affect about a fifth of homes, including off-gas-grid homes – including those that will need expensive retrofitting or a very large electricity connection in order to make the switch. Policies to force landlords to upgrade the energy efficiency of their properties, were also abandoned.

Clean Heat Market Mechanism

In 2023 the Government consulted on a new market-based mechanism to support the development of the market in low-carbon electric heat pumps. The Government committed to implementing the Clean Heat Market Mechanism from April 2025, under which boiler manufacturers will be required to sell a certain proportion of heat pumps each year. The Government also intends to impose obligations on boiler manufacturers through the Clean Heat Market Mechanism to sell a certain number of heat pumps.

Immediately prior to the General Election, a consultation into delaying the start date of the scheme to April 2025 closed. The results of this are not yet known, or whether the new Government will continue with the plans, although recent media speculation suggests it will revert to the original version of the scheme despite public opposition. The scheme would place an obligation on the manufacturers of heating appliances to meet targets for the proportion of low-carbon heat pumps they sell each year, relative to fossil fuel boilers. These targets will increase year-on-year, to incentivise investment in the heat pump market.

For the first year of the scheme, 2024/25, the intention had been for manufacturers of fossil fuel heating appliances to hold low-carbon heat pump credits corresponding to 4% of their relevant gas boiler sales above 20,000 units and 4% of their relevant oil boiler sales above 1,000 units (excluding exports). For the second year, 2025/26, the credit target would increase to 6% of relevant gas boiler sales above 20,000 units of and 6% of relevant oil boiler sales above 1,000 units. Under the proposed delayed start to the scheme, the targets would continue to apply to the originally planned years, ie 6% for 2025/26. Companies with boiler sales less than 20,000 relevant gas boilers and 1,000 relevant oil boilers, corresponding to roughly 1% of the UK market, will be exempt, as will Small Companies with respect to the Companies Act 2006.

Future Homes and Building Standard

The Future Homes and Building Standard consultation closed in March, proposing that new homes built from 2025 are “zero carbon ready”, with low-carbon heating technologies such as heat pumps installed as the standard in new properties, avoiding the need for future retrofit, and prohibiting the installation of fossil fuel-powered heating.

The development phase for the Standard ran from 2020 to 2024, with extensive consultations with various stakeholders including industry professionals, environmental groups, and consumer organisations. The Future Homes and Buildings Standards were formally consulted on in 2023 with further refinements based on feedback. The necessary legislation was expected to be passed in 2024, but it is unclear whether the General Election and change in government will have a bearing on this.

Assuming the necessary legislation does pass in 2024, there would potentially be a transitional period of six to 12 months to allow the construction industry time to adjust and prepare for the new regulations, during which time new developments could comply with either the existing Building Regulations or the Future Homes Standard. Full implementation would be from 2025.

The key requirements of the Future Homes Standard include:

- Building fabric: improved insulation for walls, floors and roofs;
- Low-carbon heating and hot water systems: the use of low-carbon systems is emphasised, in particular air and ground source heat pumps. Gas boilers will not be compliant;
- Renewable energy readiness: while not mandatory, the standard encourages incorporating wiring or space allocation for the installation of solar panels in future;
- EV charging: new homes must have one charging point installed or the necessary cabling for future installation;
- Ventilation: efficient ventilation designs for new and existing homes are encouraged, that do not compromise the air-tightness of the building envelope.

There are signs that the construction industry is struggling to be ready for the expected implementation of the standard next year, with almost half (49%) of housebuilders saying that their business is not prepared for the standard and won't be ahead of its implementation next year, and 61% think it will be extremely challenging to meet the legislation, according to a recent survey of 100 UK housebuilders.

Appendix II – Heating technologies

Gas boilers

Before looking at heat pumps, it is worth briefly describing the dominant form of heating used in the UK ie gas boilers. Conventional boilers burn gas in the combustion chamber of the boiler to generate hot jets that move through a heat exchanger usually made of copper, where heat is transferred from the gas to water which is heated to 60°C.

The heated water is pushed through the central heating system using an electric pump. The heated water flows around a closed loop inside each radiator, entering at one side and leaving at the other - as each radiator gives off heat, the water is cooler when it leaves a radiator than it is when it enters. After heated water passes through all the radiators, the now cooled water returns to the boiler to be heated again. Waste heat from the boiler is dispersed into the air as flue gas through a smokestack.

In condensing gas boilers the flue gases pass through a heat exchanger that warms the cold water leaving the radiators, reducing heating work to be done by the boiler. As such condensing boilers achieve higher efficiencies compared to conventional boilers. Condensing boilers are so called because the temperature of the flue gases is lower so the moisture in it "condenses", this water drains away through the bottom of the boiler.

"Combi" gas boilers are used to provide hot water as well as for space heating. They typically have two independent heat exchangers - one is connected to the radiators for space heating and the other for hot water supply. Combi boilers provide instant hot water as they are constantly on standby – when a request for hot water is trigged by someone turning on a hot tap, the boiler starts heating water which is then delivered to the tap. Hot water is not stored in a tank for future delivery to hot taps. Control valves inside the combi boiler operate in different directions to direct water to either the central heating system or hot water taps as required. Typically, the cold water for combi boilers is delivered from the water mains – houses that are not connected to a normal main (ie use a private borehole) would not generally be able to use a combi boiler and would need to install a hot water tank, using a conventional boiler.

Heat pumps

Heat pumps use electricity to provide both heating and cooling to buildings, by transferring heat from one place to another: in winter, a heat pump provides heating by extracting heat from outside the building and moving it inside, while in summer, it provides cooling by moving heat from the inside to the outside. Air source heat pumps and air conditioning units are similar in operation, and many air conditioners are also able to provide heating. The main difference is that air conditioning units tend to blow out hot or cold air, while heat pumps tend to heat water for circulation in radiators.

Heat pumps use technology similar to that found in refrigerators. They extract heat from a source, such as the surrounding air, geothermal energy stored in the ground, or nearby sources of water or waste heat from a factory. It then amplifies and transfers the heat to where it is needed. Because most of the heat is transferred rather than generated, heat pumps are far more efficient than conventional heating technologies such as boilers or electric heaters and can be cheaper to run.

The output of energy in the form of heat is normally several times greater than that required to power the heat pump, normally in the form of electricity. For example, the coefficient of performance (COP) for a typical household heat pump is around four, i.e. the energy output is four times greater than the electrical energy used to run it. This makes current models 3-5 times more energy efficient than gas boilers. Heat pumps can be combined with other heating systems, commonly gas, in hybrid configurations.

Air source heat pumps

Air source heat pumps transfer heat to or from the air outside the building. In winter, warmth is extracted from the outside air and used to heat the inside of the building. Although the air outside is colder than the air inside, it is warm enough to cause a liquid refrigerant to evaporate into a gas - heat pump refrigerants have very low boiling points, typically below -25°C. This gas is compressed to further raise its temperature and then passed through a heat exchanger. In British homes, this heat exchanger typically heats water in a hot water tank but in the US, it heats air which is pumped through ducts to heat rooms.

Water from the hot water tank is then pumped through radiators to heat the home, and also supplies sinks, baths and showers with hot water. The water returns to the tank to be re-heated and the coolant also circulates back through an expansion valve to the outdoor unit to be re-heated.

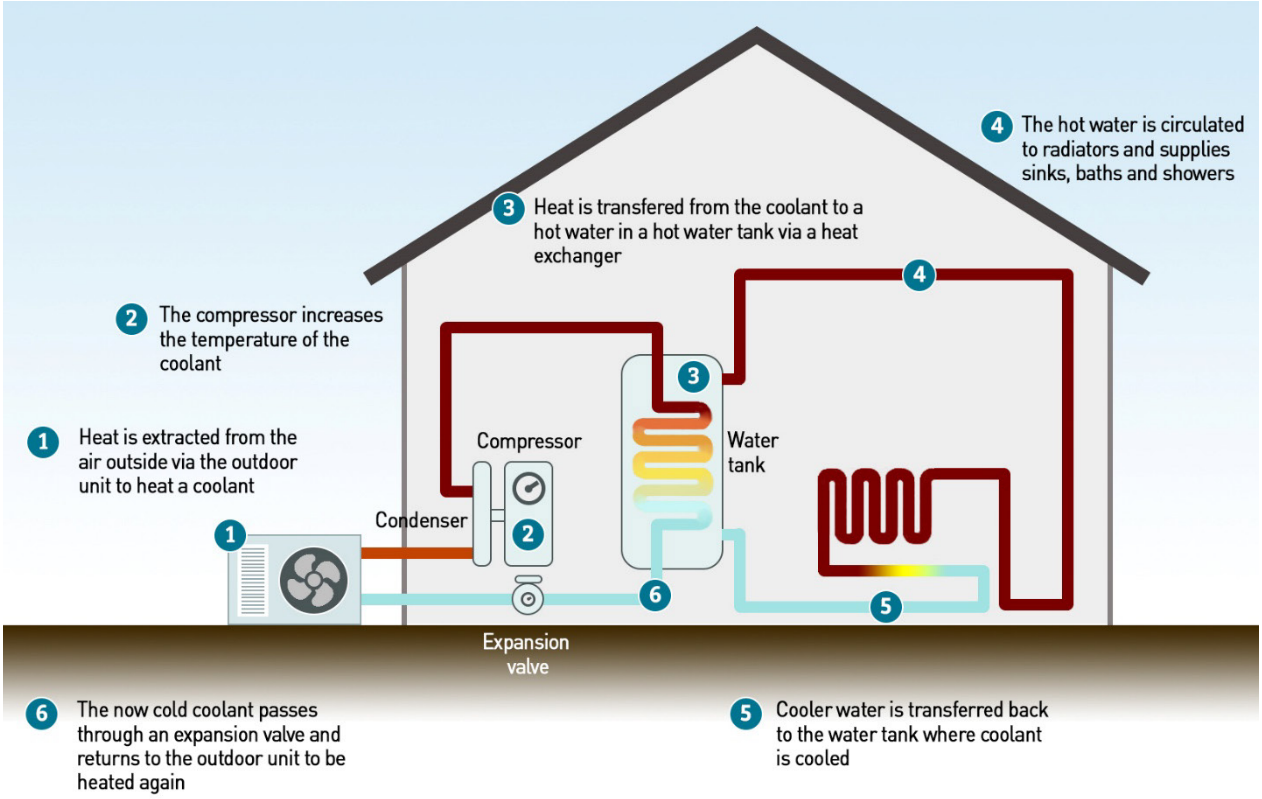
How heat pumps work

The heat pump itself consists of a compressor, which moves a refrigerant through a refrigeration cycle, and a heat exchanger, which extracts heat from the source. The heat is then passed on to a heat sink through another heat exchanger. In buildings, the heat is delivered using either forced air or hydronic systems such as radiators or under-floor heating. The process is powered by electricity.

Compared to conventional gas boilers heat pumps work most efficiently when they operate with continuous low flow temperatures which means they produce low-grade heat, that is heat that has both lower temperature and lower energy than a central heating system powered by a gas boiler. Since most people use gas boilers on demand, user education will be needed to switch heating patterns and ensure efficient, cost-effective use.

In order to heat rooms to the same temperature, a larger surface area is needed for the heat emitter (radiators, underfloor heating or fans). Heat pumps work best with underfloor heating, otherwise larger radiators are needed. They also work better where buildings are well insulated, since this reduces the required heat load, and can struggle to maintain desired comfort levels in less well insulated buildings, otherwise larger (more expensive) units are required.

Air source heat pump



Source: Watt-Logic

Installation considerations

Air source heat pumps are usually positioned outdoors at the side or back of a property, and require sufficient space around them for air to circulate. Typically, there will be either a "monoblock system" – most common in the UK - when the external unit is placed on or next to an outside wall. The external unit generates hot water and sends it into the property, or a "split system" which is used when there is a larger distance between the external unit and house. This consists of an external unit and an internal heat exchanger about the size of a small boiler. In both cases, a hot water tank is needed if the system is to provide hot water as well as space heating.

Maximising heat pump performance requires minimising the temperature difference between the heat source and heat emitter. Larger emitters transfer more heat and require a lower flow temperature (the temperature of water leaving the heat pump) to maintain the same room temperature, improving performance. Pipes need to be large enough to deliver sufficient low temperature heat to the emitters. Evidence shows that existing UK central heating systems are often poorly optimised.

Heat pumps and emitters should be sized to match the heating demand of the building - undersized heat pumps will not achieve the desired building temperatures, while oversized heat pumps will operate at partial load, which reduces efficiency. Insulation reduces the heating demand of a building, which in turn reduces heating costs and the size of heat pump required. However, the thermal efficiency of UK buildings is among the worst in Europe[76]. Additional insulation should ideally be installed before a heat pump so that the heat pump can be correctly sized.

The costs of retrofitting insulation and energy saving measures could be significant. A study[77] by Nottingham Trent University found that deep retrofits of one-bedroom bungalows cost £42,055 each and £58,369 each for three-bedroom houses. The target for the deep retrofit was to get as close as reasonably possible to the EnerPHit[78] standard (a modification of the full Passivhaus approach) to make refurbishment and retrofit more practical. This included heating and solar PV systems as well as insulation.

Planning requirements

Permitted development rights ("PDRs") allow for the installation of heat pumps in homes without a planning application, subject to certain conditions. Units cannot be sited within 1 metre of the property boundary in England, Scotland and Northern Ireland, and 3 metres in Wales. This requirement is a major barrier to siting ASHPs in back gardens of many urban homes and was introduced due to noise concerns. Unit size is restricted in England and Wales, but not in Scotland or Northern Ireland, which may be counterproductive, since larger units are generally more efficient, and have better noise insulation.

Heat pump specifications and standards

There are two key measures of heat pump performance: the Coefficient of Performance ("COP") and the Seasonal Performance Factor ("SPF").

The Coefficient of Performance is a measure of efficiency, that is the ratio of amount of work done by the machine to the amount of work given to the machine, which in the case of a heat pump is the useful heat produced per unit of electrical energy consumption. A COP of 2.5 means the heat pump supplies 2.5 times as much heat energy to the system as it consumes in electrical energy. Heat pumps do not "create" energy, they extract energy already present in the outside air (or ground) and use it indoors.

For example, a heat pump with an output of 5 kW using 2 kW of electrical energy has a COP of 2.5 and uses 3 kW of energy from outside air. For an air source heat pump, COP will be higher when outside air temperature is higher, as less electrical energy input will be needed to generate a given heat output. Conversely, when it is cold outside, the heat pump will require more electricity to produce the same internal temperature. The same is true for a ground source heat pump but ground temperature varies less and does not fall as much in winter. If the COP of a heat pump is quoted, it refers to the units of heat/cold produced per unit of electricity under test conditions.

While the COP is the efficiency of a heat pump at any given time, the Seasonal Performance Factor indicates the annual performance of the heat pump, taking account of seasonal variations in the ambient temperature. The SPF is calculated as the ratio of annual heat generated to the annual electricity consumed for the operation of the heat pump.

[76] https://www.nea.org.uk/wp-content/uploads/2020/11/ACE-and-EBR-briefing-2015-10-Cold-man-of-Europe-update.pdf
[77] https://www.ntu.ac.uk/__data/assets/pdf_file/0026/1591307/Decarbonising-heat-in-residential-homes-in-Nottingham-v5.pdf
[78] https://www.passivhaustrust.org.uk/UserFiles/File/Melissa%20Taylor-%20Ecobuild%20EnerPHit%20presentation.pdf

A 2021 study[79] found that more than 28% of the ASHPs sampled, had an SPF below the required standard of 2.5. The average heat pump SPF was 2.76 (2.71 for ASHPs and 3.07 for GSHPs). The analysis found no discernible improvement in performance after the UK standard for heat pump installation was changed in 2017. There is also confusion around the use of these measures, since their calculation depends on the system boundaries used. The European Commission argues that the energy supplied should depend on the heat pump alone and should not include parts of the heat distribution system, however, most householders would consider all electricity consumption by the heating system to be relevant.

Heat pump efficiency

Heat pumps are considered to be highly efficient. According to the IEA[80], they are around 400% efficient, meaning for every until of energy provided in the form of electricity, four units of energy are produced in the form of heat. This compares with efficiency rates of 80-90% for boilers[81] up to ten years old (older boilers have lower efficiency).

But this does not tell the whole story. Gas boilers take a "raw" energy source: natural gas (methane): and burn it to heat water in heating systems. Heat pumps use electricity which is not a "raw" energy source. Electricity is generated from a range of fuels, including natural gas, coal, nuclear power, wind, solar, hydro, and biomass. The mix of fuels used to generate electricity in Britain varies depending on the weather, and therefore the energy efficiency of the electricity grid varies depending on the mix on any given day.

Natural gas is still the dominant source of fuel for generating electricity in Britain, but gas-fired power stations are only at best 60% efficient. In addition around 2% of the electricity generated is lost as heat in the transmission system, and a further 10% is lost over the lower voltage distribution system, when it is transported from the power station to the heat pump. This reduces the round-trip efficiency of heat pumps from 400% to around 210%[82]. While this is still better than the performance of a gas boiler, the difference is small, and much smaller than the headline numbers suggest.

The fact that fossil fuels, and particularly gas, are still used to generate electricity reduces the claims of heat pumps to be "green". They are greener than gas boilers since boilers are at presently mostly use fossil gas (although some 'green' gas is present in the form of biomethane) but for as long as fossil fuels are used in electricity generation, heat pumps will also rely on fossil fuels for their operation. Over time, as the electricity system decarbonises, this will change, but for the time being, fossil fuels are still used to generate heat whether directly through boilers or indirectly through gas-fired power stations.

[79] https://www.recc.org.uk/pdf/performance-data-research-focused.pdf

[80] https://www.iea.org/reports/the-future-of-heat-pumps/how-a-heat-pump-works

[81] https://www.boilercentral.com/boiler-advice/how-efficient-is-my-boiler/

[82] Round trip efficiency calculation:
Transmission and Distribution Efficiency:
Transmission Efficiency = 1−0.02 = 0.98   Distribution Efficiency = 1−0.10 = 0.90
Combined Transmission and Distribution Efficiency = 0.98 × 0.90 = 0.882
Overall Efficiency = Gas Power Station Efficiency × Transmission and Distribution Efficiency × Heat Pump Efficiency
= 0.60 × 0.882 × 4 = 2.1168 = 211%

Impact of the lower heat output of heat pumps

A further factor to consider when considering the efficiency of heat pumps versus gas boilers is the ability of each system to deliver desired comfort levels. A survey[83] of heat pump installers found that 37% of respondents declined work as they did not believe a heat pump would heat the customer's home to a sufficient standard.

In its 2024 Future Energy Scenarios ("FES")[84], National Grid ESO ("NG ESO") suggests that in two of its three net zero compliant scenarios (the fourth scenario being the counterfactual where nothing changes from today), households would be 0.5ºC colder. This is described as being "particularly beneficial for heat pumps, as it reduces thermal demand and allows lower flow temperatures, which improves heat pump efficiencies".

NG ESO goes on to say: "our research calculates that the average indoor household temperature sits at 20.1°C, with a range to account for consumers' varying preferences, equating to 80% of consumers sitting within 15.9 to 24.1°C. Reducing thermal demand broadens household heating options while reducing required investment, allowing consumers to opt for smaller-capacity heat systems." In other words, if people are willing to be colder they will be able to use a wider range of heating systems to achieve their desired heating level. This suggests that some of these heating solutions would not be capable of delivering current average heating levels to many households.

NG ESO does not provide any evidence suggesting that people are willing to reduce their heating levels, and it mis-characterises this as "energy efficiency". It is not energy efficiency, it is closer to energy rationing. Improving insulation and so on, which is typically (if incorrectly) what is referred to as "energy efficiency" in a domestic heating context, would reduce the amount of energy required to maintain a given heating level. It would not imply that a lower heating level would be desired.

In addition, heat pumps work less well in cold weather. This can result in the need for secondary heating systems – in Nordic countries it is common for households to either install a second heat pump or to use a wood burning stove. This affects both the efficiency and carbon content of the heating system as a whole. A 2019 study found 83% of Norwegians surveyed regularly used wood stoves in winter[85], in part because it is seen as a means of reducing electricity demand, and its associated costs[86]. Collecting wood from the local area for use in stoves is commonplace for rural Scandinavian communities. Efforts to restrict the use of wood for heating in Sweden in 2017 resulted in widespread protests[87].

Heat pumps for cooling

Heat pumps can generally work in both directions: extracting warmth from the air outside to provide heating on cold days and extracting warmth from the air inside to provide cooling on hot days. While it is theoretically possible for cooling to be provided by circulating cold water through conventional radiators (or the enlarged emitters that are likely to be installed for use with a heat pump) this is not a particularly efficient means of providing cooling and can create problems with condensation.

83 https://www.nesta.org.uk/report/how-to-install-more-heat-pumps-insights-from-a-survey-of-heating-engineers/

84 https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes/fes-documents

85 https://uis.brage.unit.no/uis-xmlui/bitstream/handle/11250/2680995/Peteranderson_Michal.pdf?sequence=1

86 https://iopscience.iop.org/article/10.1088/1755-1315/352/1/012022/pdf

87 https://www.sciencedirect.com/science/article/pii/S0301421522002427

However, there are companies which specialise in providing water-based cooling systems such as underfloor[88] or in-ceiling systems such as REHAU[89].

A more effective means of providing cooling would be through the use of a fan coil unit which would blow cold air into rooms. This can be connected to the same heat pump that provides heating ie the outdoor unit remains the same, but additional ducting would be required to supply the in-room units. When the heat pump operates in cooling mode, chilled water is circulated through the coils of the fan coil unit. As air passes over these cold coils, it is cooled before being blown into the room. To manage the condensation that forms when warm air meets the cold coils, fan coil units are equipped with a drainage system.

A 2-pipe fan coil system would provide either hot or cold air at any time, while a 4-pipe system would provide both. The 2-pipe system consists of a single water coil connected to two pipes (supply and return) and one valve that can serve as either chilled water coil or hot water coil depending on the mode of the system. The 4-pipe system consists of two separate cooling and heating water coils. Each coil has its own dedicated set of pipes (supply and return) and valve.

Fan coil units can be wall-mounted, which look similar to air conditioning units, and are mounted high on walls. These are ideal for spaces where floor or ceiling space is limited. Ceiling-mounted units are installed in the ceiling, often in suspended ceilings, making them unobtrusive and are suitable for both commercial and residential buildings. Floor-mounted units are similar to radiators and are installed at floor level, while ducted units are hidden above ceilings or in cupboards, with air distributed through ducts to various rooms. They provide a centralised cooling solution that can serve multiple rooms, similar to the distribution system in air-to-air heat pumps.

In its 2024 Future Energy Scenarios, NG ESO acknowledges that consumers are increasingly likely to seek out domestic air conditioning in response to climate change. It recognises that this will impose additional strain on the electricity grid and says it hopes that other measures such as curtains and fans will be adopted instead. This seems like wishful thinking. Those consumers who think ahead may realise they can add cooling with their heat pump installation, either by using an air-to-air system or a hydronic system with fan coil units for cooling. Those who do not think ahead may simply decide to attempt cooling through cold water circulation and live with the possible condensation problems – after all, water cooling works extremely well at Victoria underground station[90] in London!

Cost of air source heat pumps

The upfront costs of heat pumps are significantly higher than for gas boilers – now over £13,000[91] for an air source heat pump compared with around £3,000 for a gas boiler. The UK Government's Boiler Upgrade Scheme provides grants of up to £7,500 for the installation of heat pumps, with a view to making the capital costs of the units broadly equivalent to the installation of a gas boiler. There is also more limited financial support available for the installation of insulation, however there is currently no support for other works such as installation of larger radiators. For most households, the installation of a heat pump together with the additional work to upgrade insulation and install larger radiators or underfloor heating would make the overall cost of a heat pump higher than the cost of a gas boiler, even after taking the grants into account.

[88] https://www.rehau.com/uk-en/specifiers/building-technology-specifiers/underfloor-heating-systems
[89] https://www.rehau.com/uk-en/products/rehau-chilled-ceiling-systems
[90] https://www.ianvisits.co.uk/articles/cooling-the-london-underground-220/
[91] https://www.gov.uk/government/statistics/boiler-upgrade-scheme-statistics-july-2024

The operating costs of heat pumps can be higher than for gas boilers because electricity is more expensive to buy than gas. In the wholesale electricity market, prices are based on the wholesale price of gas since gas-fired power stations are the "marginal" source of generation. The electricity market is organised so that cheaper sources of generation run before more expensive sources, and the most expensive sources used set the price for the whole market.

Since that is almost always a gas power station, gas prices form the basis for wholesale electricity prices, and therefore wholesale electricity prices are always higher than wholesale gas prices. In addition to the wholesale electricity price, various additional costs are incurred such as network costs, supplier operating costs, VAT and environmental and social policy costs. These environmental and social policy costs are much higher for electricity than for gas, meaning that end user electricity prices are higher than end user gas prices. In addition, gas used for electricity generation is subject to carbon charging, but gas used in domestic gas boilers is not.

Whether heat pumps are cheaper or more expensive to operate than gas boilers depends on the relative prices of gas and electricity at the time, and whether the heat pump is working efficiently, and whether it has been appropriately sized and properly installed – poor installation undermines system performance. Modern, well installed heat pumps can be run at a comparable cost to gas boilers, but for most households it is likely that they will be more expensive. The calculation is very sensitive to the Seasonal Performance Factor, and studies have shown that heat pumps in the UK both underperform expectations and similar systems installed in other European Countries. Suggested reasons for this have been poor quality installations and the poor thermal efficiency of UK homes, but there is a lack of robust, recent field trial research on the performance of heat pumps in UK dwellings on which to base firm conclusions.

Some suppliers offer preferential tariffs to heat pump owners which reduce these costs and can make them cheaper to run than gas boilers.

Ground source heat pumps

Ground source heat pumps work in a similar way to air source heat pumps, but instead of extracting heat from the air they extract it from the ground. In a ground source system, heat pumps are connected to pipes known as ground collectors, which are laid underground, either in horizontal trenches around 1.5 - 2 metres deep or in vertical boreholes, around 100 metres deep. At these depths, the ground maintains an average temperature of 10-12°C all year round.

A water/refrigerant fluid is circulated through the ground collectors, absorbing thermal energy from the ground and circulating it back to the heat pump. From there it passes through a compressor and then to a heat exchanger as with an air source system.

Ground source heat pumps tend to require more land than air source systems, and therefore are not suitable for all properties. They also tend to be more expensive and disruptive to install, given the excavation work required. Internal works are similar to those needed in air source systems. Networked GSHPs may require infrastructure works under public highways, which requires planning permission.

Appendix III – Demand-side response in France

The existing demand-side response schemes in France are managed through day-ahead forecasting and real-time adjustments, considering factors such as weather data and consumer behaviour, and include:

- The "Demand Response Block Exchange Notification" ("NEBEF"), where consumers reduce their demand in response to price signals or requests from the grid operator. This mechanism treats demand reductions similarly to energy generation, with remuneration provided to participants, and is open to consumers with demand of at least 1 MW (or aggregators who aggregate smaller loads which add up to at least this amount);

- Capacity Remuneration: this is similar to the Capacity Market in GB, where consumers and generators can receive payments for making capacity available during peak demand periods. In France, this includes both capacity (in MW) and actual energy reductions (in MWh), which are activated on request to help balance supply and demand;

- Policies and Targets: The French government has set ambitious targets for demand response as part of its Multiannual Energy Programme ("PPE"), aiming to enhance the flexibility of the electricity system in line with increasing renewable energy integration. The potential for demand response, especially from large industrial consumers and, increasingly, from residential and SME sectors, is seen as crucial for maintaining grid stability during extreme weather events.

In addition, Electricité de France ("EDF"), the main electricity supplier in France, operates a consumer tariff similar to the DFS. The "Tempo" tariff is designed to manage electricity demand and costs, incorporating a traffic light-like system with blue, white, and red days, each having different pricing. This system replaced the older "EJP" (Effacement Jour de Pointe) tariff, which had similar demand management features.

Under the Tempo system:

- Blue days are the cheapest, with users paying prices that are 30% lower at peak times (from 06:00 to 22:00) and 41% lower at off-peak times, compared to the regulatory price. This covers 300 days per year;

- White days are moderately priced, and occur on 43 days. Savings are still 10% at peak times and 34% at off-peak times.;

- Red days are the most expensive with prices three times higher than the normal rate, and limited to 22 days during winter (1 November to 31 March). The price per kWh is three times higher than the normal rate in order to encourage consumers to reduce consumption during peak demand periods, in order to manage load on the electricity grid more efficiently. Even on red days, users can save up to 16% during off-peak hours if they cut down on usage.

Clients receive an alert by SMS or email notifying them that the next day will be a red day, or are notified through the EDF app and website. The colour also shows up on their electricity meter from 20:00 the night before.

EDF has 70% of the market for individual households and 55-60% of the market for business customers. However, despite the very long history of variable tariffs, only 500,000 or 1.6% of households are on the Tempo tariff against a target of 5 million. The vast majority of households prefer to be on the regulated tariff. Although some studies have shown that up to 100% of households would be better off on Tempo than the regulated tariff, it suffers from low public awareness, and problems for households if a series of red or white days occur on consecutive days.

While there will never be more than five red days in a row, and red days cannot take place on weekends and public holidays, combinations of successive red and white days are possible, which make it difficult for consumers to manage their demand. For example, there is only so long a household can go without doing laundry. In addition, reducing heating levels for extended periods can have very detrimental health implications for vulnerable consumers for example by exacerbating respiratory or circulatory illnesses.

Due to the relatively low number of households using the Tempo tariff, the contribution to demand reduction from the residential sector remains low, despite this type of tariff having been a feature of the French market for decades. This suggests that realising the potential for demand-side flexibility from the residential sector could be challenging unless these schemes can be shown to deliver higher consumer benefits in terms of price, and are automated so that they rely on less on active demand reduction. Currently both Tempo in France and the DFS in Britain depend on consumers taking active steps to reduce consumption – grid operators hope that automated energy management systems will deliver larger results, but there are considerations to be resolved around customer autonomy and consent.

References

1. International Energy Agency, 2022: *The Future of Heat Pumps* (https://www.iea.org/reports/the-future-of-heat-pumps)
2. European Commission, 2023: *Heat pumps – action plan to accelerate roll-out across the EU* (https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13771-Heat-pumps-action-plan-to-accelerate-roll-out-across-the-EU_en)
3. European Heat Pump Association, 2024: *Pump it down: why heat pump sales dropped in 2023* (https://www.ehpa.org/wp-content/uploads/2024/04/Pump-it-down-why-heat-pump-sales-dropped-in-2023_EHPA_April-2024.pdf)
4. European Heat Pump Association, 2024: *Europe avoiding 5.5 billion cubic metres of gas with heat pumps* (https://www.ehpa.org/news-and-resources/news/europe-avoiding-5-5-billion-cubic-metres-of-gas-with-heat-pumps/)
5. UK Government Press Release, 2023: *PM recommits UK to Net Zero by 2050 and pledges a "fairer" path to achieving target to ease the financial burden on British families* (https://www.gov.uk/government/news/pm-recommits-uk-to-net-zero-by-2050-and-pledges-a-fairer-path-to-achieving-target-to-ease-the-financial-burden-on-british-families)
6. UK Government, 2017: *Clean Growth Strategy* (https://www.gov.uk/government/publications/clean-growth-strategy)
7. UK Government, 2020: *Ten Point Plan for a Green Industrial Revolution* (https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution/title#point-7-greener-buildings)
8. UK Government, 2021: *Heat and Buildings Strategy* (https://www.gov.uk/government/publications/heat-and-buildings-strategy)
9. UK Government, 2023: Press release: PM recommits UK to Net Zero by 2050 and pledges a "fairer" path to achieving target to ease the financial burden on British families (https://www.gov.uk/government/news/pm-recommits-uk-to-net-zero-by-2050-and-pledges-a-fairer-path-to-achieving-target-to-ease-the-financial-burden-on-british-families)
10. UK Government 2022: *The Boiler Upgrade Scheme (England and Wales) Regulations 2022* (https://www.legislation.gov.uk/uksi/2022/565/contents/made)
11. Department for Energy Security and Net Zero, 2024: *Heat pumps will be cheaper and easier to install* (https://www.gov.uk/government/news/heat-pumps-will-be-cheaper-and-easier-to-install)
12. Department for Energy Security and Net Zero, 2023: *Clean Heat Market Mechanism Consultation* (https://www.gov.uk/government/consultations/clean-heat-market-mechanism)
13. Department for Energy Security and Net Zero, 2024: *Clean heat market mechanism: proposal to change the scheme start date to 1 April 2025* (https://www.gov.uk/government/consultations/clean-heat-market-mechanism-adjustment-to-scheme-introduction-date/clean-heat-market-mechanism-proposal-to-change-the-scheme-start-date-to-1-april-2025)
14. UK Government, 2024: *The Future Homes and Buildings Standards: 2023 consultation* (https://www.gov.uk/government/consultations/the-future-homes-and-buildings-standards-2023-consultation/the-future-homes-and-buildings-standards-2023-consultation)
15. Professional Builder, 2024: *Industry not prepared for the Future Homes Standard* (https://probuildermag.co.uk/news/industry-not-prepared-for-the-future-homes-standard)
16. National Audit Office, 2024: *Decarbonising home heating* (https://www.nao.org.uk/press-releases/low-heat-pump-uptake-slowing-progress-on-decarbonising-home-heating/)
17. Department for Energy Security and Net Zero, 2023: *Review of Air Source Heat Pump Noise Emissions, Permitted Development Guidance and Regulations* (https://www.ioa.org.uk/news/review-recommends-improving-air-source-heat-pump-noise-assessments)
18. Heat Pump Association, 2023: *Unlocking Widescale Heat Pump Deployment in the UK* (https://www.heatpumps.org.uk/wp-content/uploads/2023/12/HPA-Unlocking-Widescale-Heat-Pump-Deployment-in-the-UK.pdf)
19. UK Government, 2023: *Welcome to home energy efficiency* (https://energy-efficient-home.campaign.gov.uk/)

20. Energy Saving Trust, 2023: *National or local retrofit advice? To cut bills, carbon and improve energy security, we need both* (https://energysavingtrust.org.uk/report/national-or-local-retrofit-advice/)
21. UK Government, 2023: *Boiler Upgrade Scheme* (https://www.find-government-grants.service.gov.uk/grants/boiler-upgrade-scheme-1)
22. Nesta, 2024: *How to install more heat pumps: insights from a survey of heating engineers* (https://www.nesta.org.uk/report/how-to-install-more-heat-pumps-insights-from-a-survey-of-heating-engineers/)
23. Department for Business, Energy and Industrial Strategy, 2020: *Heat Pump Manufacturing Supply Chain Research Project* (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/943712/heat-pump-manufacturing-supply-chain-research-project-report.pdf)
24. UK Government, 2023: *Heat Pump Investment Accelerator Competition* (https://www.gov.uk/government/publications/heat-pump-investment-accelerator-competition)
25. Heat Pump Association, 2023: *New Industry data shows a 166% Increase in Qualified Heat Pump Installers* (https://www.heatpumps.org.uk/166-increase-in-qualified-heat-pump-installers/)
26. MCS, 2023: *UK on track for best year ever for renewable installations* (https://mcscertified.com/uk-on-track-for-best-year-ever-for-renewable-energy-and-heat-installations/)
27. Gas Safe Register, 2024: *At a Glance Report 2023/24* (https://www.gassaferegister.co.uk/about-us/what-is-gas-safe-register/)
28. UK Government, 2023: *Training providers: register to offer the Heat Training Grant for heat pumps* (https://www.gov.uk/government/publications/training-providers-how-to-offer-the-heat-training-grant-for-heat-pumps)
29. UK Government, 2023: *Thousands of low-cost training spaces available in boost to green jobs sector* (https://www.gov.uk/government/news/thousands-of-low-cost-training-spaces-available-in-boost-to-green-jobs-sector)
30. UKERC, 2023: *Decarbonising Home Heating: An Evidence Review of Domestic Heat Pump Installed Costs* (https://ukerc.ac.uk/publications/heat-pump-cost-review/)
31. Delta-EE, 2021: *What is the potential for cutting the cost of an installed heat pump?* (https://www.delta-ee.com/wp-content/uploads/2021/12/Whitepaper-What-is-the-potential-for-cutting-the-cost-of-an-installed-heat-pump.pdf)
32. Knobloch, F. et al., 2019: *Simulating the deep decarbonisation of residential heating for limiting global warming to 1.5 °C* (https://link.springer.com/article/10.1007/s12053-018-9710-0)
33. Climate Change Committee, 2020: *Sixth Carbon Budget* (https://www.theccc.org.uk/publication/sixth-carbon-budget/)
34. Nesta, 2022: *How to reduce the cost of heat pumps* (https://www.nesta.org.uk/report/reduce-the-cost-of-heat-pumps/)
35. Department for Business, Energy and Industrial Strategy, 2023: *UK Net Zero Research and Innovation Framework* (https://www.gov.uk/government/publications/net-zero-research-and-innovation-framework/uk-net-zero-research-and-innovation-framework)
36. Department for Business, Energy and Industrial Strategy, 2020: *Energy white paper: Powering our net zero future* (https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future/energy-white-paper-powering-our-net-zero-future-accessible-html-version)
37. Climate Change Committee, 2020: *Sixth Carbon Budget* (https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf)
38. National Grid ESO, 2023: *Future Energy Scenarios 2023* (https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes/fes-documents)
39. National Grid ESO, 2024: *Demand Flexibility Service* (https://www.nationalgrideso.com/industry-information/balancing-services/demand-flexibility-service-dfs)
40. BFM Business, 2023: *Électricité: en quoi consiste l'offre Tempo d'EDF qui cartonne depuis un an?* (*Electricity: what does EDF's Tempo offer consist of, which has been a hit for a year?)* (https://www.bfmtv.com/economie/entreprises/energie/electricite-en-quoi-consiste-l-offre-tempo-d-edf-qui-cartonne-depuis-un-an_AV-202311050237.html)

41. Lite, 2023: *Tempo d'EDF : des tarifs inédits qui incitent fortement à la flexibilité* (*EDF Tempo tariff: unique prices that strongly encourage flexibility)* (https://www.lite.eco/blog/tempo-edf-des-tarifs-inedits-qui-incitent-fortement-a-la-flexibilite/)
42. Kelwatt, 2024: *EDF Tempo Avis 2024 : positifs ou négatifs (EDF Tempo Opinion 2024: positive or negative?)* (https://www.kelwatt.fr/fournisseurs/edf/tempo/avis)
43. European Heat Pump Association, 2024: *EU could end up 15 million heat pumps short of 2030 ambition* (https://www.ehpa.org/news-and-resources/news/eu-could-end-up-15-million-heat-pumps-short-of-2030-ambition/)
44. House of Representatives of the States General of the Netherlands, 2018: *Breif van de Minister van Economische Zaken en Klimaat* (*Letter from the Minister of Economic Affairs and Climate)* (https://zoek.officielebekendmakingen.nl/kst-33529-457.html)
45. Government of the Netherlands: *Measures to reduce greenhouse gas emissions* (https://www.government.nl/topics/climate-change/national-measures)
46. Netherlands Enterprise Agency, 2017: ISDE: *Subsidie voor verduurzaming van uw woning* (*ISDE: Subsidy for making your home more sustainable)* (https://www.rvo.nl /subsidies-financiering/isde/woningeigenaren)
47. ISDE, 2024: *Bespaar enorm op je energierekening met een (hybride) warmtepomp in combinatie met isolatiemaatregelen (Save enormously on your energy bill with a (hybrid) heat pump in combination with insulation measures.)* (https://www.isde.nl/isde-subsidie-warmtepompen.html)
48. Government Gazette of the Kingdom of the Netherlands, 2019: *Regeling van de Minister van Economische Zaken en Klimaat van 20 december 2019, nr. WJZ/ 19245579, tot wijziging van de Regeling nationale EZK- en LNV-subsidies in verband met wijziging van de subsidiemodule Investeringssubsidie duurzame energie (ISDE) (Regulation of the Minister of Economic Affairs and Climate of 20 December 2019, no. WJZ/ 19245579, amending the Regulation on national EZK and LNV subsidies in connection with the amendment of the subsidy module Investment subsidy for sustainable energy (ISDE))* (https://zoek.officielebekendmakingen.nl/stcrt-2019-66566.html)
49. Government Gazette of the Kingdom of the Netherlands, 2020: *Regeling van de Minister van Economische Zaken en Klimaat van 9 december 2020, WJZ/ 20265125, tot wijziging van de Regeling nationale EZK- en LNV-subsidies in verband met de verbreding van de subsidiemodule Investeringssubsidie duurzame energie met energiebesparende isolatiemaatregelen en aansluiting op warmtenetten* (*Regulation of the Minister of Economic Affairs and Climate of 9 December 2020, WJZ/20265125, amending the Regulation on national EZK and LNV subsidies in connection with the expansion of the subsidy module Investment subsidy for sustainable energy with energy-saving insulation measures and connection to heating networks)* (https://zoek.officielebekendmakingen.nl/stcrt-2020-65131.html)
50. Vakblad Warmtepompen, 2021: *Groei in Nederlandse warmtepompverkoop valt op binnen Europa (Growth in Dutch heat pump sales stands out within Europe)* (https://www.vakbladwarmtepompen.nl/7257/groei-in-nederlandse-warmtepompverkoop-valt-op-binnen-europa)
51. Nationaal Wamteforns, 2024: *Over het Nationaal Warmtefonds (About the National Heat Fund)* (https://www.warmtefonds.nl/over-ons)
52. Nationaal Wamteforns, 2024: *Warmtepomp* (*Heat pump)* (https://www.warmtefonds.nl/particulieren/energiebesparende-maatregelen/warmtepomp)
53. Coalitie HR-hybride, 2021: *Statement* (https://www.technieknederland.nl/stream/verklaring-coalitie-hr-hybide-21-4-2021)
54. Government of the Netherlands: *Warmtepomp de norm vanaf 2026: goed voor klimaat en de energierekening* (*Heat pump the standard from 2026: good for the climate and the energy bill)* (https://www.rijksoverheid.nl/actueel/nieuws/2023/05/01/warmtepomp-de-norm-vanaf-2026-goed-voor-klimaat-en-de-energierekening)
55. Installatie, 2024: *Kabinet trekt stekker uit norm hybride warmtepomp* (*Cabinet pulls plug on hybrid heat pump standard)* (https://www.installatie.nl/nieuws/kabinet-trekt-stekker-uit-norm-hybride-warmtepomp)
56. National Government of the Netherlands, 2022: *Hybride warmtepomp de nieuwe standaard vanaf 2026 (Hybrid heat pump the new standard from 2026)* (https://www.rijksoverheid.nl/actueel/nieuws/2022/05/17/hybride-warmtepomp-de-nieuwe-standaard-vanaf-2026)

57. Demonstratie- project Hybride warmtepompen in de gebouwde omgeving, 2024 (https://www.demoprojecthybride.nl/)

58. National Government of the Netherlands, 2024: *Kamerbrief over versnelling en uitbreiding maatregelen netcongestie Flevoland, Gelderland en Utrecht (Letter to Parliament on acceleration and expansion of grid congestion measures in Flevoland, Gelderland and Utrecht)* (https://www.rijksoverheid.nl/documenten/kamerstukken/2024/04/25/kamerbrief-versnelling-en-uitbreiding-maatregelen-netcongestie-flevoland-gelderland-en-utrecht-fgu)

59. House of Representatives of the States General, 2023: *Brief regering: Netcapaciteit, de versnelling van de energietransitie en de noodzaak van flexibiliteit (Letter from government :Grid capacity, the acceleration of the energy transition and the need for flexibility)* (https://www.tweedekamer.nl/kamerstukken/brieven_regering/detail?id=2023D27812&did=2023D27812)

60. National Government of the Netherlands, 2023: *Kamerbrief over nieuwe maatregelen netcongestie* (*Letter to Parliament on new measures for grid congestion*) (https://www.rijksoverheid.nl/documenten/kamerstukken/2023/10/18/nieuwe-maatregelen-netcongestie)

61. Norwegian University of Science and Technology, 2022: *Current status of heat pumps in Norway and analysis of their performance and payback time* (https://www.sciencedirect.com/science/article/pii/S2213138822008773)

62. Nature Energy, 2022: *Heating up the global heat pump market* (https://www.nature.com/articles/s41560-022-01104-8)

63. NVE (Norwegian Water Resources and Energy Directorate), 2016: *Varmepumper i energisystemet / Heat pumps in the energy system* (https://publikasjoner.nve.no/rapport/2016/rapport2016_60.pdf)

64. Enova, 2024: *Om energiattesten (About the energy certificate)* (https://www.enova.no/energimerking/om-energimerkeordningen/om-energiattesten/)

65. Direktoratet for Byggkvalitet (Building Quality Directorate), 2017: *Krav til energieffektivitet (Requirements for energy efficiency)* (https://www.dibk.no/regelverk/byggteknisk-forskrift-tek17/14/14-2?_t_q=varmepumpe)

66. Direktoratet for Byggkvalitet (Building Quality Directorate), 2011: *Særskilte bestemmelser om Ansvar (Separate provisions on liability)* (https://www.dibk.no/regelverk/sak/3/12/12-6?_t_q=energieffektivitet)

67. Forskingsrådet (Research Council), 2022: *Porteføljeplanen for Energi, transport og lavutslipp (The portfolio plan for Energy, transport and low emissions)* (https://www.forskningsradet.no/portefoljer/energi-transport-og-lavutslipp/portefoljeplanen-for-energi-transport-og-lavutslipp/prioriteringer/tematiske-prioriteringer/)

68. SINTEF, 2024: *Varmepumpeteknologi (Heat pump technology)* (https://www.sintef.no/ekspertise/sintef-energi/varmepumpeteknologi/)

69. The Government of Norway, 2023: *Handlingsplan for energieffektivisering i alle deler av norsk økonomi (Action plan for energy efficiency in all parts of the Norwegian economy)* (https://www.regjeringen.no/no/dokumenter/handlingsplan-for-energieffektivisering-i-alle-deler-av-norsk-okonomi/id2998036/?ch=1)

70. Norwegian Heat Pump Association, 2024: *Nedgangen fortsetter i andre kvartal (The decline continues in the second quarter)* (https://www.novap.no/artikler/nedgangen-fortsetter-i-andre-kvartal)

71. Susana López-Aparicio, Matthias Vogt, Philipp Schneider, Maarit Kahila-Tani, Anna Broberg, Journal of Environmental Management Volume 191, 2017: *Public participation GIS for improving wood burning emissions from residential heating and urban environmental management* (https://www.sciencedirect.com/science/article/pii/S0301479717300269)

72. Norwegian Institute for Air Research2019: *The MetVed model: Development and evaluation of emissions from residential wood combustion at high spatiotemporal resolution in Norway* (https://acp.copernicus.org/preprints/acp-2019-95/acp-2019-95-manuscript-version4.pdf)

73. Norske Varme, 2022: *Nordmenn elsker å fyre med ved – halvparten av befolkningen fyrer daglig når det er høye strømpriser (Norwegians love to fire with wood - half of the population fires every day when electricity prices are high)* (https://norskvarme.org/nordmenn-elsker-a-fyre-med-ved-halvparten-av-befolkningen-fyrer-daglig-nar-det-er-hoye-strompriser/)
74. Thema Consulting Group, 2022: *Har vi fleksibilitet nok til å balansere kraftsystemet fram mot 2050? / Do we have enough flexibility to balance the power system towards 2050?* (https://www.regjeringen.no/contentassets/5f15fcecae3143d1bf9cade7da6afe6e/no/sved/vedlegg4.pdf)
75. Association for the Conservation of Energy, 2015: *The Cold Man of Europe* (https://www.nea.org.uk/wp-content/uploads/2020/11/ACE-and-EBR-briefing-2015-10-Cold-man-of-Europe-update.pdf)
76. Nottingham Trent University REMOURBAN City Demonstrator Project, 2020: *Retrofit Social Housing Report– Better Homes Improve Lives* (https://www.ntu.ac.uk/__data/assets/pdf_file/0026/1591307/Decarbonising-heat-in-residential-homes-in-Nottingham-v5.pdf)
77. Passivhaus Trust, 2011: *EnerPHit The new Passivhaus refurbishment standard from the Passivhaus Institute* (https://www.passivhaustrust.org.uk/UserFiles/File/Melissa%20Taylor-%20Ecobuild%20EnerPHit%20presentation.pdf)
78. Meek, C., 2021: *Heat pumps and UK's decarbonisation: lessons from an Ofgem dataset of more than 2,000 domestic installations.* (https://www.recc.org.uk/pdf/performance-data-research-focused.pdf)
79. International Energy Agency, 2022: *The Future of Heat Pumps* (https://www.iea.org/reports/the-future-of-heat-pumps/how-a-heat-pump-works)
80. Boiler Central, 2024: *How Efficient Is My Boiler? How To Check Boiler Efficiency* (https://www.boilercentral.com/boiler-advice/how-efficient-is-my-boiler/)
81. Nesta, 2024: *How to install more heat pumps: insights from a survey of heating engineers* (https://www.nesta.org.uk/report/how-to-install-more-heat-pumps-insights-from-a-survey-of-heating-engineers/)
82. National Grid ESO, 2024: *Future Energy Scenarios (https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes/fes-documents)*
83. Michal Peter-Anderson, 2019: *Domestic Wood Burning in Norway* (https://uis.brage.unit.no/uis-xmlui/bitstream/handle/11250/2680995/Peteranderson_Michal.pdf?sequence=1)
84. IOP Conference Series: Earth and Environmental Science, 2022: *Wood burning habits and its effect on the electrical energy demand of a retrofitted Norwegian detached house* (https://iopscience.iop.org/article/10.1088/1755-1315/352/1/012022/pdf)
85. Anna Sahlberg,Bodil S.A. Karlsson,Jonas Sjöblom,Henrik Ström, 2022: *Don't extinguish my fire – Understanding public resistance to a Swedish policy aimed at reducing particle emissions by phasing out old wood stoves* (https://www.sciencedirect.com/science/article/pii/S0301421522002427)
86. REHAU: *Underfloor heating* (https://www.rehau.com/uk-en/specifiers/building-technology-specifiers/underfloor-heating-systems)
87. REHAU*: Chilled ceiling* (https://www.rehau.com/uk-en/products/rehau-chilled-ceiling-systems)
88. IanVisits, 2008: *Cooling the London Underground* (https://www.ianvisits.co.uk/articles/cooling-the-london-underground-220/)
89. UK Government Official Statistics, 2024: *Boiler Upgrade Scheme statistics: July 2024* (https://www.gov.uk/government/statistics/boiler-upgrade-scheme-statistics-july-2024)