The running cost of domestic heat pumps in the UK

A comprehensive evidence review and evaluation

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About the author

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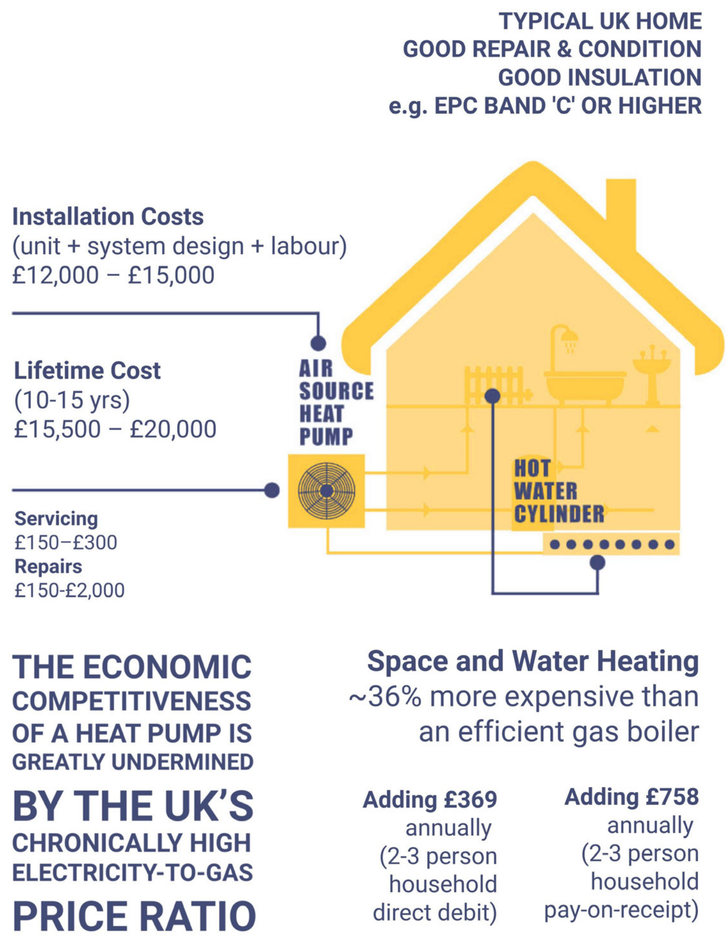
Contents

Acronyms

ASHP	Air Source Heat Pump
BUS	Boiler Upgrade Scheme
CODE	Cost Optimal Domestic Electrification
CoP	Coefficient of Performance
EtGPR	Electricity-to-gas price ratio
EST	Energy Saving Trust
FHS	Future Homes Standard 2025
FiT	Feed-in Tariff Scheme
GSHP	Ground Source Heat Pump
LCOH	Levelised Cost of Heat
LPG	Liquefied Petroleum Gas
Ofgem	Office of Gas and Electricity Markets
PBP	Payback Period
PRS	Private Rented Sector
PV	Photovoltaics
RHHP	Renewable Heat Premium Payment Scheme
RHI	Renewable Heat Incentive Scheme
SCoP	Seasonal Coefficient of Performance
SHS	Social Housing Sector
SPF	Seasonal Performance Factor
TES	Thermal Energy Storage

Executive Summary

- The relative price of electricity is the most important factor determining the economic competitiveness of heat pump running costs in the United Kingdom.
- Because the UK has historically had such a high electricity-to-gas price ratio (EtGPR), field trials, demonstrator projects and desktop modelling of monitored performance have failed to demonstrate that heat pumps can compete with efficient gas boilers in terms of running costs (ceteris paribus).
- **In unexceptional circumstances**[1] – i.e., in situations representative of the wider existing UK housing context – a heat pump is approximately **36% more expensive** to run than an efficient gas boiler, all else being equal.
- **In ideal situations** – i.e., homes where an appropriately sized heat pump can achieve a seasonal performance factor (SPF) of around 3.0 – a heat pump is approximately **9% more expensive** to run than an efficient gas boiler, all else being equal.
- Over the last twenty-five years, heat pumps have steadily become more competitive in terms of running costs as the technology, installation and setup has improved;
- A heat pump will generate economic savings for consumers (when compared to the cost of running an efficient gas boiler) if the electricity-to-gas price ratio is no more than 3:1 and the heat pump achieves a seasonal performance factor (SPF) of 3.0 or higher.
- The addition of photovoltaics (PV) and battery storage compensates for the high electricity-to-gas price ratio in ideal situations, rendering heat pumps less expensive to run than efficient gas boilers, all else being equal.



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1 Parallels might be drawn with homes in EPC band 'C' or higher with cavity and loft insulation and double-glazed windows. Homes that fall into EPC band 'D' or below should not be included in the "unexceptional circumstances" category and are unlikely to achieve such a high level of heat pump performance. Homes that fall into EPC band 'D' or below are 'exceptional' insofar as their thermal efficiency is likely so low as to directly and adversely impact the economics of heat pump performance

2 Based on averages provided by British Gas. https://www.britishgas.co.uk/energy/guides/average-bill.html

Introduction

This report provides a comprehensive evidence review concerning the running costs of heat pumps in the United Kingdom. It is the first report of its kind, where data from all available UK field trials, demonstrator projects, as well as technical modelling and simulations recorded over the past two decades have been assessed and compared to answer the question: how much does it cost to heat a domestic home with a heat pump? In particular, the economic case for heat pumps is presented in the context of the UK's dominant domestic heating source: gas[3] . In other words, this report evaluates all available evidence concerning the measured or anticipated cost savings of heat pumps compared to gas boilers and answers the question: if a homeowner replaced their gas boiler with a heat pump, how much can they expect to save on their heating bills?

Examining the relationship between the annual running costs of gas boilers and heat pumps is essential to the UK's decarbonisation agenda and meeting its Net Zero commitments. It is well understood that the high upfront cost of heat pump installation (around £12–£15,000[4]) presents something of a barrier to their widespread adoption. To meet this challenge, the UK government instituted the Boiler Upgrade Scheme (BUS) where rebate funds and vouchers for low-carbon heating systems were made available to eligible homeowners. The BUS replaced the Renewable Heat Incentive Scheme (RHI) which differed insofar as the RHI was an ongoing payment rather than a one-off sum to facilitate installation[5] . To date, neither the RHI nor the BUS have been instrumental in accelerating the necessary domestic shift away from gas boilers towards heat pumps[6] .

Part of the argument in favour of installing a heat pump – and a belief that was supposed to mitigate the high upfront costs of the unit – is that heat pumps not only greatly reduce domestic carbon emissions, they can also lower annual heating bills. There is, therefore, a belief in certain corners that the installation costs can be 'paid back' over the life of the heat pump through these savings. Frequently, however, this assertion is supported by anecdotal rather than empirical evidence[7] . Furthermore, the potential cost savings of installing a heat pump varied greatly depending on whether it replaced oil, gas, or direct electric heating[8] .

The fragmented and inconsistent data on heat pump running costs and confusion about what it means to say a heat pump is performing 'efficiently' have long frustrated policymakers. While laypeople might think a heat pump needs to provide adequate heat while being economical to run to be considered efficient, this is not necessarily how engineers or technical experts understand the term 'efficient.' By presenting all available evidence concerning heat pump running costs over the past two decades – and separating the issue of heat pump economics from its technical efficiency – this report fills a considerable research gap and will assist policymakers seeking to develop schemes or initiatives to facilitate the decarbonisation agenda and accelerate the deployment of heat pumps across the UK.

Methodology

The approach to the evidence review involved evaluating any UK studies concerned with the analysis and/or reporting of monitored and/or simulated heat pump data where the study generated results indicating the running costs of heat pumps – and, in particular, the cost to run a heat pump compared to alternative heating technologies such as oil, LPG or gas boilers. The evidence search was based on the UK nations with all publications in the English language. The evidence search drew on two digital databases: SCOPUS and the Web of Science. Searches were performed on titles, abstracts and keywords ('heat pump running cost,' 'heat pump economic,' 'heat pump demonstrator,' and 'heat pump field study.')

Table 1. Number of Records and Subsequent Sample Reduction

		Jan. 1980 – Dec 2023
Step 1	SCOPUS records	130
Step 2	Web of Science records	284
Step 3	Merging and removing duplicates	291
Step 4	Maintained after screening of titles	43
Step 5	Maintained after screening of abstracts	29
Step 6	Highly scored/relevant references	11
Step 7	Additional references (n=11, mostly grey literature)	11
Step 8	Full text not accessible	n.a.
Step 9	Reviewed references	22

Once the keyword search database returns had been screened for duplicates, 291 papers that had the potential to be relevant remained. Following a manual screening, 43 research papers remained. All abstracts were then categorised as high suitability, secondary suitability, or unsuitable. The references and footnotes of the highly suitable papers were then reviewed to identify any research material absent from the major databases ('snowballing'). Following the screening of abstracts and snowballing, 22 highly suitable research papers remained to be examined in detail.

3 https://commonslibrary.parliament.uk/constituency-data-central-heating-2021-census/

4 https://www.evergreenenergy.co.uk/heat-pump-guides/much-heat-pump-cost/

5 https://energysavingtrust.org.uk/grants-and-loans/renewable-heat-incentive/

6 https://www.theccc.org.uk/wp-content/uploads/2023/06/Progress-in-reducing-UK-emissions-2023-Report-to-Parliament-1.pdf

7 https://www.theguardian.com/money/2021/oct/23/its-been-brilliant-air-source-heat-pump-will-recoup-cost-for-owner

8 https://energysavingtrust.org.uk/setting-the-record-straight-on-heat-pumps/

Limitations

It is important to note that these 22 studies were undertaken across fifteen years and therefore influenced by the changing price of electricity relative to gas. In an ideal world, the aggregate data would be normalised to account for the changing electricity-to-gas price ratio (EtGPR) over time. Unfortunately, given the limits imposed by data opacity in the studies under review, this could not be done reliably. Nevertheless, as discussed in the "Evaluation of Evidence" section, the results are contextualised and categorised so they can be interpreted and evaluated reasonably, as a body of evidence.

Background Issues

Heat Pump Technology

From a domestic heat pump perspective, there are two commonly installed variants: air-source heat pumps (ASHP) and ground-source heat pumps (GSHP). The former uses outside ambient air as their heat source (i.e., the medium through which the refrigerant is pumped causing it to boil), and the latter uses soil ~100m down a borehole (or slinky pipes laid along a cut trench) for the same purpose. Because the ground temperature at this depth is on average warmer than the air when we enter the coldest months of the year, GSHPs can deliver higher SPFs (ceteris paribus) than ASHPs in certain parts of the UK[9] . Despite having the potential for higher efficiency, GSHPs are considerably more expensive to install and have more demanding physical space requirements. Due to these higher barriers to entry, GSHPs are less commercially popular than ASHPs. According to Ofgem numbers for 2022, 69% of heat pumps in England are ASHPs while 14% are GSHPs[10] .

For ease of comparison, the running cost figures presented in this report are all for ASHPs (even where particular field trials may have also installed and monitored GSHPs). It should be understood, however, that whatever running cost savings can be attributed to ASHPs apply equally to GSHPs – and, if anything, the GSHPs tend to generate greater savings concomitant with their higher SPFs in colder climates.

Heat Pump Performance

When discussing the performance of a heat pump, a variety of technical and descriptive terms appear across the literature. Variously, authors refer to the 'efficiency' of a heat pump, the manufacturer's 'specifications,' the coefficient of performance (CoP), the seasonal performance factor (SPF), or the seasonal coefficient of performance (SCoP). These terms differ and should not be treated interchangeably.

When measuring heat pump performance, CoP, SCoP and SPF figures are used depending on the context. Broadly, each refers to the factor of energy leveraging (efficiency) generated by the heat pump. For example, a coefficient of performance (CoP) of 3.0 (at a source temperature of 7°C) indicates that for each (1) unit of electricity when the source is 7°C, the heat pump is producing three (3) units of heat. Importantly, however, both CoP and SCoP are measures used when heat pumps are monitored or modelled in a laboratory setting. Furthermore, for a CoP or SCoP to make sense, the source temperature must also be given. Consequently, when discussing the monitored performance of a heat pump in situ (i.e., when a heat pump has been installed into an actual existing home), the best measure to use is the seasonal performance factor (SPF). The SPF refers to the average efficiency of the heat pump across the heating season in a specific location.

From a technical point of view, a heat pump is said to perform 'efficiently' when it is leveraging energy into heat according to the manufacturer's specifications. Mitsubishi's Ecodan R32, for example, suggests a SCoP of 3.57 (at -7°)[11] . Numerous factors can influence the performance of a heat pump in situ including: unit size, emitter size, flow temperature, and building fabric. For example, better fabric efficiency means you can run the HP with a lower flow temperature – this as well as larger emitters have been shown to improve SCoP[12] .

Although it may seem counterintuitive, this means the issue of 'efficiency' is separate from whether or not (a) the heat pump is providing enough heat for a given space, or (b) the heating system is economical to run. In other words, a heat pump might be operating 'efficiently' even if occupants report the home is not warm enough or the heating bills are higher than expected. In these cases, it could be that the heat pump is working efficiently but the unit may be incorrectly sized to the property or perhaps the property lacks the insulation and airtightness to allow its operation to be economical.

This distinction between efficiency and everyday experience may sound strange to non-experts who would assume that for a heat pump to be considered 'efficient' it ought to be economical while providing adequate heat. Nevertheless, these semantics are important to consider since technical experts might resist claims that heat pumps don't work 'efficiently' in certain homes, whereas they might concede the same heat pump isn't providing sufficient heat or its running costs are too high.

Carbon Savings

It is important to note that this report is not focused on data indicating the carbon savings (CO2 emissions) of heat pump technologies. This is principally because that is something of a settled issue. Heat pumps are, by design, an emissions savings technology. When operating at a seasonal performance factor (SPF) of 3.0, a heat pump produces 1/3 the CO2 of direct electric heating (ceteris paribus) and between 27%–85% less CO2 than a gas boiler[13] . Moreover, since heat pumps rely on electricity, they have the potential to become zero carbon emission

9 https://energysavingtrust.org.uk/air-source-heat-pumps-vs-ground-source-heat-pumps/

10 https://www.ofgem.gov.uk/sites/default/files/2022-07/Domestic%20RHI%20Annual%20Report%202021-22_0.pdf

11 https://library.mitsubishielectric.co.uk/pdf/book/Ecodan_PUZ-WM60VAA_Monobloc_Air_Source_Heat_Pump_Product_Information_Sheet#page-2

12 Dongellini, Matteo., Valdiserri, Paolo., Naldi, Claudia and Gian Luca Morini. 2020. "The Role of Emitters, Heat Pump Size, and Building Massive Envelope Elements on the Seasonal Energy Performance of Heat Pump-Based Heating Systems." Energies 13, no. 19: 5098. https://doi.org/10.3390/en13195098

13 https://www.isoenergy.co.uk/latest-news/isoenergy-news/carbon-savings-from-a-heat-pump;

heating systems if and when electricity is itself exclusively generated from renewables.

Fuel Poverty

Aside from determining the 'payback period' for their installation, the business case for landlords, or the economic benefits for owner-occupiers and tenants alike, understanding the running costs associated with heat pumps is important in the context of fuel poverty in the UK. Although designated by degrees – in England and Wales, a household in fuel poverty is one that "cannot keep their home warm at a reasonable cost[14]." According to the latest government figures, fuel poverty estimates range across the UK from 13% of English households to 25% of those in Scotland[15]. The charity, National Energy Action, suggests as many as 6.5 million households "struggle to pay their energy bills[16]." If heat pumps are found to reduce household heating bills – the cost of installation aside – they may represent a technological response to the problem of fuel poverty. On the other hand, if the evidence suggests heat pumps are less economical to run than existing heating systems, their adoption may well exacerbate fuel poverty rather than address it. Indeed, the Chartered Institute of Housing reports that housing associations, councils, and other providers in the social rented sector are deferring the replacement of gas boilers over concerns that heat pumps may increase heating bills for their tenants[17].

Building Fabric

Although the air-tightness and U-value (i.e., the rate at which heat is lost) of a home is critical to the performance and, therefore, the economics of a heat pump, this report is not preoccupied with this question. Previous CaCHE research has demonstrated that the more airtight and lower a home's U-value, the higher the seasonal performance factor (SPF) that can be expected from a heat pump (ceteris paribus)[18]. Suffice it to say that according to the laws of thermodynamics, the better the building fabric (i.e., the better the insulation, ventilation, seals, and joins) the more thermally efficient the home, and the more thermally efficient the home the better a heat pump will perform. The positive relationship between building fabric and heat pump performance concerns both thermal comfort and heating economics. All else being equal, the heat pump in the home with the better fabric will be cheaper to run. As it is, however, the UK's existing housing stock is on average older, leakier and less thermally efficient than many of our European neighbours[19]. As a result, and because heat pumps perform better (ceteris paribus) in homes with higher thermal efficiency, many providers in the social rented sector have opted for a 'fabric first' approach – i.e., prioritising insulation as well as energy and thermal efficiency before "investing in clean heat[20]."

Electricity Price

The issue of a heat pump's running costs cannot be separated from the retail price of electricity in the United Kingdom. The cheaper electricity is the lower the annual running cost of a domestic heat pump. Furthermore, the closer the price of electricity is to that of gas, the more attractive the idea of exchanging a gas boiler for a heat pump becomes. The reverse is also true: the more expensive electricity is relative to gas, the harder it is to make a business case for heat pumps. According to research body, Nesta, when the electricity-to-gas price ratio (EtGPR) is 3:1 (that is to say, when the price of electricity is 3 times greater than gas), heat pump running costs "reach parity with gas boilers[21]." Nesta suggests the 'ideal' ratio is 21/2:1 – when a heat pump becomes "cheaper than a gas boiler over the same lifespan[22]." Presently, however, the electricity-to-gas price ratio in the UK is around 4.4:1 (i.e., the price of electricity is more than four times greater than gas), with gas around 8p per kWh and electricity around 35p per kWh[23].

The UK has been living with an EtGPR above 3:1 since the mid-2000s and although increased supply through renewables should in theory bring the price of electricity down, analysts with Cornwall Insight take a more pessimistic view arguing the price of electricity will remain stubbornly high across the coming decades[24]. The UK's energy context – characterised by low gas prices and deep network penetration on the one hand, and chronically high electricity prices and suboptimal grid capacity on the other – is perhaps the single most important aspect of this nation's decarbonisation and Net Zero challenge. The high relative price of electricity makes the low average thermal efficiency of the UK's existing building stock more consequential, constrains policy options in the context of fuel poverty, and, generally speaking, undermines the business case for low-carbon heating systems.

Photovoltaics (PV)

Many of the field trials and demonstrator projects evaluated in this report included photovoltaics (PV) as part of their overall retrofit or design scheme. In other words, PV was installed alongside heat pumps to lower the net energy consumption of the home and reduce overall energy costs. However, since the present investigation concerns the running costs of heat pumps (and, in particular, heat pump running costs compared

14 https://www.ons.gov.uk/peoplepopulationandcommunity/housing/articles/howfuelpovertyismeasuredintheuk/march2023Scotland defines fuel poverty as: "after housing costs, the total fuel costs needed to maintain a satisfactory heating regime are more than 10% of the household's adjusted net income… [and]… if, after deducting fuel costs, housing costs, benefits received for a care need or disability, and childcare costs, the household's remaining adjusted net income is insufficient to maintain an acceptable standard of living."

15 https://commonslibrary.parliament.uk/research-briefings/cbp-8730/

16 https://www.nea.org.uk/who-we-are/about-nea/

17 https://www.housingtoday.co.uk/in-focus/the-price-of-electricity-is-holding-back-the-rollout-of-heat-pumps-in-social-housing/5126669.article

18 https://housingevidence.ac.uk/wp-content/uploads/2023/11/Heat-Pumps-Report-Nicholas-Harrington-v4.pdf

19 https://www.tado.com/gb-en/press/uk-homes-losing-heat-up-to-three-times-faster-than-european-neighbours

20 https://www.housing.org.uk/globalassets/files/climate-and-sustainability--energy-crisis/07085855-9cf8-456c-8099-9506a6839b5d.pdf

21 https://www.nesta.org.uk/report/how-the-uk-compares-to-the-rest-of-europe-on-heat-pump-uptake/electricity-gas-and-other-fuel-prices-across-europe/

22 https://www.nesta.org.uk/blog/the-electricity-to-gas-price-ratio-explained-how-a-green-ratio-would-make-bills-cheaper-and-greener/

23 https://www.globalpetrolprices.com/United-Kingdom/

24 https://www.cornwall-insight.com/press/new-forecast-warns-power-prices-to-remain-elevated-until-late-2030s

to the dominant heating system in the UK – i.e., gas boilers) the figures offered in this report will not include the added benefit of PV even if certain reports provided this data. That is to say, where a field trial or demonstrator provided data for the running costs both including and excluding the energy rebate of the PV, only the figure excluding the PV is reported.

Thermal Comfort

Quite apart from the running costs associated with heat pumps is the question of their thermal performance. That is to say, can heat pumps provide a suitable level of thermal comfort? Or, how well does a heat pump heat a home? The answer to these questions concern (a) the thermal efficiency of the home – i.e., how well-insulated and airtight is the home in question; (b) the size and output of the unit (given in kW) and its emitters; and (c) the flow temperature to which the unit is set. Once again, we are dealing with the laws of thermodynamics. Poor insulation and leakiness can be compensated for with an increase in unit or emitter sizing or flow temperature, while, conversely, the better insulated or airtight a home the lower the flow temperature and (ceteris paribus) the smaller the unit required. As a general rule, there is no such thing as a home that cannot be adequately heated with a heat pump[25] . However, there will always be an energy consumption trade-off in such cases. The bigger the heat pump, the smaller the emitter area, or the higher the flow temperature the less economical heating a home with a heat pump becomes relative to other heating systems (ceteris paribus). Therefore, one really ought to say, that while there is no such thing as a home that cannot be adequately heated with a heat pump it comes at a cost.

Other Fuels

This report is particularly interested in comparing the running costs of heat pumps with those of efficient gas boilers. This is not because alternative heating fuels such as oil, liquefied petroleum gas (LPG) or direct electricity are unimportant. Rather, it is because gas is the most relevant competition for heat pumps in the domestic heating sector. As a general rule, given current energy prices, gas boilers are a more economical heating system than oil, LPG and direct electricity[26]. Therefore, whatever can be said about the relationship between heat pumps and gas boilers applies in one direction concerning the other fuels. If installing a heat pump in a particular home would result in a 5% reduction in heating costs compared to a gas boiler, the savings would only be amplified if the heating system being replaced relied on oil, LPG or direct electricity (ceteris paribus).

Installation Costs

The cost of installing a heat pump into an existing home depends on a variety of factors: (a) the architectural style of the property; (b) upgrades that may be required to the heating system; (c) whether the heat pump being installed is air- or ground-source; (d) the home's state of physical repair and condition; and, (e) the physical situation of the property. In addition, upon physical inspection of a given property, a surveyor, heating technician or heat pump installer may recommend additional fabric improvements be undertaken to increase the unit's SPF.

Despite all these variables, the average cost of installing an air-source heat pump (excluding any additional fabric upgrades, repairs or maintenance) is understood to be between "£12-£15,000 inclusive of system design and installation[27]" While the average cost of installing a ground-source heat pump (excluding any additional fabric upgrades, repairs or maintenance) is reported in the "range of £17,000 – £45,000[28]." Heat pumps should be serviced once a year before the coldest months and attract a charge of between £150 – £300 for ASHPs and £200 – £350 for GSHPs. Repairs range between £150 (electrical issue) and £2,000 (component replacement, e.g., compressor)[29] . Contrast these figures (as per Table 2.) with those for an efficient gas boiler which can be installed for around £2,000 – £4,500[30], serviced for £100 and repaired for £100 – £500[31] .

Table 2. Comparative Capital Costs: Heat Pumps and Gas Boilers.

Technology	Unit + Installation	Servicing	Repairs	Lifetime	Estimated Lifetime Cost[32]
ASHP	£12,000 – £15,000	£150– £300	£150- £2,000	10-15 yrs	£15,500 – £20,000
GSHP	£17,000 – £45,000	£200– £350	£150- £2,000	10-15 yrs	£21,000 – £50,750
Gas boiler	£2,000 – £4,500	£80– £120	£100- £500	10-15 yrs	£6,500 – £11,250

It is worth noting that in Sweden the installation costs for an ASHP are around SEK 120,000 (i.e., ~ £9,100) and SEK 200,000 (i.e., ~ £15,100) for a GSHP[33] . This suggests that as the heat pump market matures in the UK, prices for units and their installation might come down due to economies of scale.

25 https://energysavingtrust.org.uk/from-flats-to-terraced-houses-heat-pumps-are-suitable-for-all-property-types/

26 https://carnegiefuels.co.uk/oil-vs-gas-which-best-to-heat-home/https://heatable.co.uk/boiler-advice/lpg-vs-natural-gas

27 https://www.evergreenenergy.co.uk/heat-pump-guides/much-heat-pump-cost/

28 https://www.greenmatch.co.uk/ground-source-heat-pump/cost

29 https://www.checkatrade.com/blog/cost-guides/heat-pump-servicing-and-repair-cost/

30 https://www.checkatrade.com/blog/cost-guides/new-boiler-cost/

31 https://www.checkatrade.com/blog/cost-guides/boiler-service-cost/

32 Estimated as 3/4 x 'average' repairs + annual servicing + unit & installation costs over lifetime.

33 https://ctc-heating.com/blog/heat-pump/how-much-you-save-with-a-heat-pump

Overview of Evidence

A survey of all available data relating to the running costs of heat pumps in the United Kingdom over the past twenty-five years permits certain top-level observations. The following statements are illustrated in Figure 1, below:

1. With the exception of one demonstrator project which was reported in 2023, all field trials, demonstrators, modelling and simulations of heat pump performance over the last fifteen years have generated data indicating that heat pumps are more costly to run than efficient gas boilers (all else being equal);

2. There is a great deal of variance in the reported differences in running costs between heat pumps and gas boilers across the available studies. At one end of the spectrum, we find data indicating a running cost saving of 12.1% compared to a gas boiler in the same home. At the other end, we have data suggesting heat pumps are 55.2% and 70% more costly to run than an efficient gas boiler;

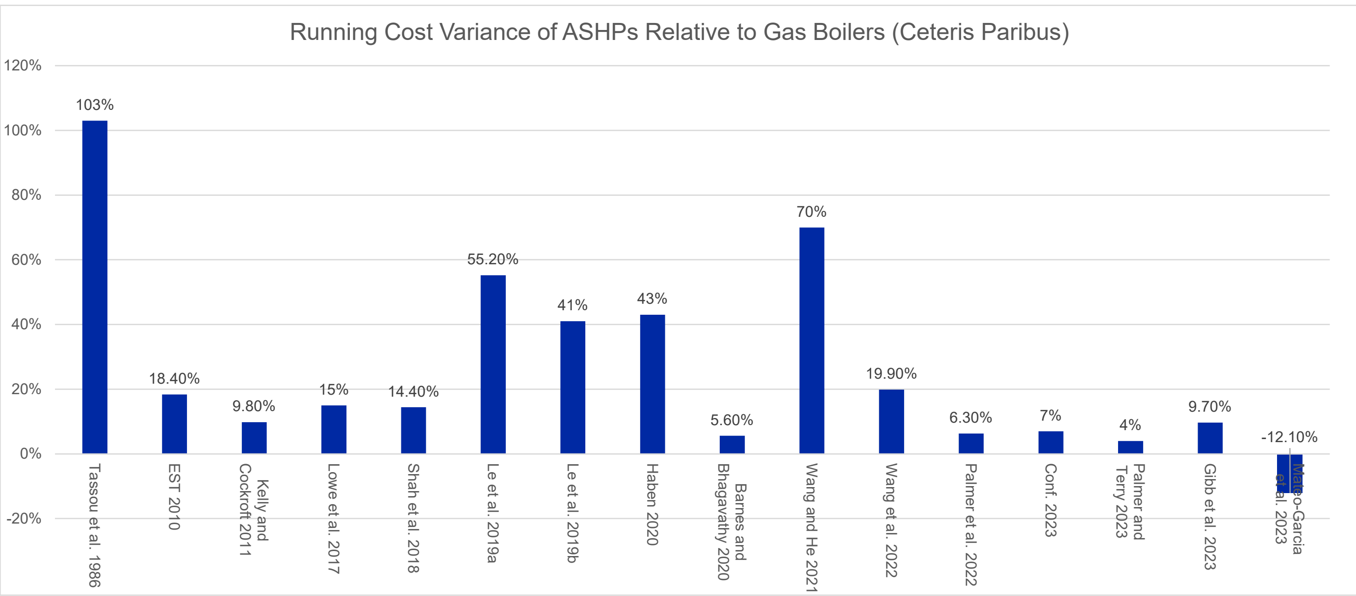
3. Although not uniform, the general trend in heat pump running costs relative to efficient gas boilers is one of improvement over time. That is to say, over the last twenty-five years, the data suggests heat pumps have become a more competitive heating system in terms of running costs compared to efficient gas boilers;

4. If we restrict our sample only to studies of heat pump performance reporting in the last two years (i.e., 2022 and 2023), the data indicate that heat pumps are somewhere between 12% cheaper and 20% more expensive to run than an efficient gas boiler (all else being equal).

5. Based upon this restricted two-year sample, the data indicate that under a best-case scenario, a heat pump could save a UK homeowner up to £103.24 per annum on their heating bill if they replaced their gas boiler, and under the worst case a heat pump may cost an additional £169.80 per annum to heat the same home (Based on the average UK gas bill being £853.30 per year, as at 1 January 2024)[34] ;

6. As things stand, presently – i.e., given the prevailing electricity-to-gas price ratio, as well as the relative efficiency of heat pump technology – the data does not support the argument that a heat pump will reduce a householder's heating expenses compared to heating the same home with an efficient gas boiler.

Figure 1. Running Cost Variance of ASHPs Relative to Gas Boilers (Ceteris Paribus).



34 https://www.uswitch.com/gas-electricity/guides/average-gas-and-electricity-bills-in-the-uk/

Integral Findings, by Study

1. Tassou et al. (1986) found a heat pump was 103% more expensive to run than gas heating (ceteris paribus);

2. The EST (2010) found a heat pump was on average 18.4% more expensive to run than gas heating (ceteris paribus)[35]

3. Kelly and Cockroft (2011) found that following fabric upgrades, a retrofit ASHP was on average 9.8% more expensive to run than gas heating (ceteris paribus);

4. Lowe et al. (2017) found that on average ASHPs were around 15% and GSHPs around 11.5% more expensive to run than gas heating (ceteris paribus)[36] ;

5. Shah et al. (2018) found that on average an ASHP was 14.4% more expensive to run than gas heating (ceteris paribus);

6. Le et al. (2019a) found that an ASHP was 55.2% more expensive to run than gas heating (ceteris paribus);

7. Le et al. (2019b) found that a cascade HP was 41% more expensive to run than gas heating (ceteris paribus);

8. Cui et al. (2020) found that the combined savings of both the ASHP and PV was £2,260 after the first year, giving a PBP of 4.15 years for the system.

9. Haben (2020) found that on average a heat pump was 43% more expensive to run than gas heating (ceteris paribus);

10. Barnes and Bhagavathy (2020) found that an ASHP was on average 5.6% more expensive to run than gas heating (ceteris paribus);

11. Wang and He (2021) found that an ASHP was 70% more expensive to run than gas heating (ceteris paribus);

12. Wang et al. (2022) found that an ASHP was 19.9% more expensive to run than gas heating (ceteris paribus);

13. Palmer et al. (2022) found that on average an ASHP was 6.3% more expensive to run than gas heating (ceteris paribus);

14. CONFIDENTIAL (2023) found that on average an ASHP was 7% more expensive to run than gas heating (ceteris paribus);

15. Palmer and Terry (2023) found that on average an ASHP was 4% more expensive to run than gas heating (ceteris paribus);

16. Gibb et al. (2023) found that installing an ASHP resulted in a total estimated annual energy expenditure 9.7% greater than gas heating (ceteris paribus);

17. Mateo-Garcia et al. (2023) found that on average an ASHP was 12.1% less expensive to run than gas heating (ceteris paribus).

Tabulated Evidence

This section of the report provides a tabulated summary of each study investigating the running costs of heat pumps in the UK (Table 3.) – indicating each study's methodology, the date of publication, a quotation summarising the relevant finding/s, and the results that indicate the relative economic performance of the heat pump as compared to a gas boiler. It is important to note that the figures provided within the column headed "Expressed Saving" are recorded here as they appear in the relevant study and have not been normalised for inflation or a changing electricity or gas price over time. Furthermore, in certain cases, the proportional figure has been determined arithmetically by the author of this report and was not, therefore, an express feature of the original study in question. The nominal figures and associated comments appear as they do in the "Expressed Saving" column so the reader can confirm the working out of the proportional figure, as well as understand other pertinent facts (such as SCoPs, retrofit costs, or housing types) that may influence the economics and performance of the heat pump as disclosed in the respective studies.

35 This figure has been calculated using the EST's estimate that a "mid-range efficiency [heat pump] can be expected to use only a third of the energy of an average existing gas boiler (78% efficient) or oil boiler (82% efficient) to produce the same amount of heat." (EST 2010, 19)

36 These figures have been calculated applying Lowe et al.'s ASHP and GSHP premiums in the context of an average UK annual gas bill in 2017 of £581.

Table 3. Key Findings of Studies into Heat Pump Running Costs in the UK (1986 – 2023).

No.	Study Ref:	Method	Date	Summary Finding	Expressed Saving
1	Tassou et al.	Modelling estimate	1986	"At current electricity and natural gas prices… The heat pump is not economic when compared with economy 7 electric night-storage heaters and gas-fired central-heating systems" (Tassou et al. 1986, 137)	£565.48 (HP in Croydon) £278.47 (gas in Croydon) = £287.01 > gas 103% > gas
2	Energy Saving Trust (EST)	Field trial	2010	"… heat pumps have achieved reductions in heating bills for some customers – especially those… replacing heating fuels such as electricity, LPG and oil" (EST 2010, 6)	£212.93 HP (space) £179.88 Gas (space) [estimate on figures where mid-range efficiency HP = 1/3 the energy of an average existing gas or oil boiler] = £33.05 > gas 18.4% > gas
3	Kelly & Cockroft	Simulation & field trial	2011	"ASHP running costs were 10% higher than the gas-condensing boiler system, but 55% lower than direct-electric heating (using 2009 UK average electricity and fuel prices)" (Kelly & Cockroft 2011, 244)	£197.51 HP (space) £179.88 Gas (space) = £17.63 > gas 9.8% > gas
4	Lowe et al.	Field trial Modelling	2017	"Based on the assumed tariffs, estimates of bill savings relative to oil and gas are negative" (Lowe et al. 2017, 30) "13% of ASHPs with SPF 2.44 are expected to yield energy cost savings relative to gas" (Lowe et al. 2017, 18) "35% of GSHPs with SPF 2.71 are expected to yield energy cost savings relative to gas" (Lowe et al. 2017, 18) "An SPF of 2.82 is needed from an HP system (on standard tariff electricity) in order to outperform gas" (Lowe et al. 2017, 16)	£109 > gas (detached) £83 > gas (semi-detached) £70 > gas (terrace) [ASHP @ SPF 2.44] 15% > gas [37] £28 > gas (detached) £21 > gas (semi-detached) £18 > gas (terrace) [GSHP @ SPF 2.71] 11.5% > gas[38]
5	Shah et al.	Field trial Modelling	2018		£1,087.00 (gas boiler) £1,243.24 (HP) [approximated for COP of 2.2. N.B. 75°C flow temperature] = £156.24 > gas 14.4 > gas
6	Le et al. (a)	Modelling (Shah et al., field trial data)	2019	"The retrofit HT-ASHP cannot attain cost savings compared to the gas boilers" (Le et al. 2019a, 3884)	£460 (gas) £714 (ASHP + TS) [SPF (2.03), gas boiler eff. 90%] = £254 > gas (heating only) 55.2% > gas

37 Based on an average UK annual gas bill in 2017 of £581. Source: https://assets.publishing.service.gov.uk/media/6582c32623b70a0013234cb5/table_231.xlsx.

38 Based on an average UK annual gas bill in 2017 of £581. Source: https://assets.publishing.service.gov.uk/media/6582c32623b70a0013234cb5/table_231.xlsx.

7	Le et al. (b)	Modelling (Shah et al., field trial data)	2019	"… the cascade heat pump (CAWHP) could not defeat gas boilers and high-efficiency oil boilers (90%) in terms of operating costs" (Le et al. 2019b, 633)	[CAWHP with weather compensation in Belfast] 41% > gas @ 90% eff. 29% > gas @ 80% eff. 2% < oil @ 90% eff. 10% < oil @ 80% eff
8	Cui et al.	Modelling	2020	"The economic assessment results clarify that the system achieves a net present value (NPV) of £38,990 and has a payback period (PBP) of 4.15 years" (Cui et al. 2020, 1)	£2,260 surplus per annum (Photovoltaic/thermal assisted heat pump + RHI + FiT calculation)
9	Haben	ESC field trial	2020	"For a heat pump to be cost effective the cost of electricity must be less than 3.2 times the cost of gas" (Haben 2020, 3)	[CoP of 2.78 (7°C outdoor temp.), av. of 5 households with one on a preferred electricity tariff] 43% > gas [CoP of 2.87 (12°C outdoor temp.), av. of 5 households with one on a preferred electricity tariff] 38% > gas
10	Barnes and Bhagavathy	Modelling (select field trial averages)	2020	"The economic competitiveness of HPs is largely dependent on the SPF achieved… Where higher SPFs can be achieved, all HPs have an economic advantage over gas boilers under current government policies, potentially being nearly a quarter cheaper than gas boiler annual fuel costs. Where lower SPFs are achieved, all HPs have higher annual fuel costs than gas boilers" (Barnes and Bhagavathy 2020, 6; 9)	£712 (gas) £752 (ASHP) £684 (GSHP) [ASHP: 6 kWth, SPF 3.0; GSHP: 6 kWth, SPF 3.3; semi-detached household] ASHP = 5.6% > gas GSHP = 3.9% < gas
11	Wang and He	Modelling (UK field trial data)	2021	"ASHPs, H-GSHPs, and V-GSHPs are more expensive heating solutions in the considered locations compared to gas boilers" (Wang and He 2021, 6)	[Levelised costs of heat (LCOH); SPFs 1.7–2.2 for ASHPs; 2.6– 3.2 for GSHPs] ASHPs = 70% > gas H-GSHPs = 81% > gas V-GSHPs = 73% > gas
12	Wang et al.	Modelling	2022	"The energy efficiency benefits of heat pumps are compromised by the high cost of electricity" (Wang et al. 2022, 10) The energy efficiency benefits of heat pumps are compromised by the high cost of electricity" (Wang et al. 2022, 10)	£800 (ASHP) £600 (GSHP) £667 (gas boiler) [90% eff. gas boiler; yearly heating thermal energy consumption of 15,000 kWhth; ASHP COP 3.0; GSHP COP 4.0] ASHP = 19.9% > gasGSHP = 10% < gas £800 (ASHP) £600 (GSHP) £667 (gas boiler) [90% eff. gas boiler; yearly heating thermal energy consumption of 15,000 kWhth; ASHP COP 3.0; GSHP COP 4.0] = 19.9% > gGSHP = 10% < gas

13	Palmer et al.	Field trial (demonstrator project)	2022	"… heating costs for Sutton homes during the trial were very high, and probably not representative of performance once [the heat pumps] are working properly… Happily, mild sunny weather when the trial finished means that residents are now benefitting from PV generation, so bills are reportedly similar to pre-retrofit bills" (Palmer et al. 2022, 42)	£3,730 (ASHP) 3,510 (gas) [Combined Nottingham homes average; not incl. PV; 85% eff. gas boiler] 6.3% > gas £5,870 (ASHP) £4,820 (gas) [Combined Sutton homes average; not incl. PV; 85% eff. gas boiler] 21.8% > gas £725 (ASHP + PV) £926 (pre-retrofit gas) [Project average including PV]
14	CONFIDENTIAL	Modelling estimates survey	2023	"In most cases it is possible to achieve lower running costs than the gas baseline with some additional capital cost" (Palmer and Terry 2023, 66)	£1,361 (gas combi) £1,456 (ASHP) [Mid-floor flat; 80% eff. Gas boiler; 300% eff. ASHP] 7% > gas £2,018 (gas combi) £2,158 (ASHP) [Semi-detached house; 80% eff. Gas boiler; 300% eff. ASHP] 7% > gas
15	Kelly & Cockroft	38% > gas	2023		[Detached with solid walls; Upgrade cost = £15,130; COPs of a Mitsubishi Ecodan heat pump] 33% < gas [Modern Semi-Detached; Upgrade cost = £470; COPs of a Mitsubishi Ecodan heat pump] 4% > gas [Tenement-flat with solid walls; Upgrade cost = £290; COPs of a Mitsubishi Ecodan heat pump] 2% > gas [Modern Tenement flat; Upgrade cost = £0; COPs of a Mitsubishi Ecodan heat pump] 23% > gas [Mid-terrace house with timber frame; Upgrade cost = £370; COPs of a Mitsubishi Ecodan heat pump] 4% > gas
16	Gibb et al.	Field trial (demonstrator project)	2023	"It was too early to say anything definitive about their energy costs" (Gibb et al. 2023, 5)	£627.30 (ASHP) £571.73 (gas) [average estimated total annual energy cost for homes with ASHP and gas boilers] 9.7% > gas

17	Mateo-Garcia et al.	Field trial (demonstrator project)	2023	"The Eco Drive households are achieving a small saving in heating cost" (Mateo-Garcia et al. 2023, 24)	£1,006.90 (gas) £898.13 (HP) [cost for sample 7 months] = -£108.77 12.1% < gas £796.08 (HP + PV) [cost for sample 7 months] = -£210.82 26.5% < gas

Table 4. Electricity-to-gas price ratio in the United Kingdom: 2008–2021. Source: Nesta [39].

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Ratio	3.51	3.37	3.43	3.18	3.15	3.16	3.15	3.31	3.59	3.82	3.98	4.35	4.63	5.05

Evaluation of Evidence

Given that the seventeen (17) studies investigating the running costs of heat pumps in the UK span a considerable period (i.e., 1986–2023, with most of the data being from 2015 to 2022), it is reasonable to question how well these studies can be compared to one another. In other words, can Lowe et al.'s (2017) analysis of field trial data from 2015 be compared to the work Mateo-Garcia et al. (2023) undertook with data from their 2022 demonstrator project? The answer is yes, with an important proviso: we must understand the physical and structural context within which each study took place. When evaluating the data from a study into heat pump running costs we must take account of (1) the electricity-to-gas price ratio; (2) the thermal efficiency of the home in question; and, (3) the SPF or SCoP of the heat pump itself[40] . This is simply because – all else being equal – the lower the electricity-to-gas price ratio; the higher the home's thermal efficiency; and/or the higher the SPF or SCoP of the heat pump, the more cost-effective a heat pump becomes when compared to a gas boiler in the same property. The reverse is also true. All else being equal, the higher the electricity-to-gas price ratio; the lower the home's thermal efficiency; and/or the lower the SPF or SCoP of the heat pump, the less economically competitive a heat pump becomes when compared to a gas boiler in the same property.

Electricity-to-Gas Price Ratio

Based upon data collected by Nesta[41] , the United Kingdom has experienced the following electricity-to-gas price ratio over time:

The first observation is that over the last fifteen years, the electricity-to-gas price ratio has trended higher and in such a way challenged the business case for heat pump adoption (bearing in mind that the 'ideal' electricity-to-gas price ratio is 2.5[42]). The second point is that the electricity-to-gas price ratios for 2019, 2020 and 2021 are historically high and, therefore, any running cost data from these years out to be interpreted in this context (ceteris paribus). The final point is that study 17 reported that their analysis had been performed using the UK's energy price guarantee (33.2p per kWh electricity and 10.3p per kWh for gas), which equates to an electricity-to-gas price ratio of 3.22.

Study 17 (Mateo-Garcia et al. 2023) reports on a Birmingham demonstrator project where 12 homes were designed and built to the Future Homes Standard (FHS) 2025 to assess the economic and carbon emissions savings that could be expected from the anticipated UK building standards. All of the homes achieved an airtightness measure better than the 5.0 m3/h.m2@50Pa guidance offered by the NHS 2025. All homes had heat pumps installed as well as PV systems. The authors calculated the annual energy costs for the homes using the price guarantee of 33.2p/kWh for electricity and 10.3p/kWh for gas. Using estimates for gas consumption given heat requirements, the authors report that homes built to NHS 2025 with heat pumps installed can achieve a small saving in their annual heating bills (not including the additional energy rebate generated by the PV) in the context of the electricity price guarantee.

The heat pump running cost findings of study 17 must, therefore, be interpreted in the context of what ought to be considered a historically low and subsidised electricity-to-gas price ratio (in light of Table 4.).

*Study 17: An ASHP was 12.1% less expensive to run than gas heating***.**

Thermal Efficiency

Turning to thermal efficiency comparisons, we can see that studies 3, 13, 16 and 17 report on heat pump data from homes with much higher than average levels of thermal efficiency. All four studies performed analysis on monitored data from heat pumps that had been installed into homes that were either newly built or 'deep' retrofit specifically to assess the thermal and energy efficiency of well-insulated and airtight homes. The heat pump running cost findings from these studies ought

39 Ibid

40 One must always bear in mind that SPF of a heat pump will be affected by the size of the emitters which in turn determine the appropriate flow temperature. Therefore, a higher SPF might be achieved in the same home by increasing the size of the emitters and decreasing the flow temperature.

41 https://www.nesta.org.uk/report/how-the-uk-compares-to-the-rest-of-europe-on-heat-pump-uptake/electricity-gas-and-other-fuel-prices-across-europe/

42 https://www.nesta.org.uk/blog/the-electricity-to-gas-price-ratio-explained-how-a-green-ratio-would-make-bills-cheaper-and-greener/

to be considered reflective of heat pump performance in an optimal fabric setting (rather than representative of the wider UK housing stock).

Study 3 (Kelly and Cockroft 2011) used data from a West Lothian District Council field trial of 8 ASHPs to simulate the performance of an ASHP when retrofitted into a dwelling with particular characteristics: two-leaf, 100mm brick; 120mm cavity wall insulation; pitched concrete tiled roof; 200mm loft insulation; suspended timber floor; upgraded fabric and airtightness. They found that under these conditions, the average annual COP of an ASHP was 2.7 (slightly below its nominal COP of 3.0).

Study 13 (Palmer et al. 2022) reports on a demonstrator project where 11 homes (6 in Sutton and 5 in Nottingham) underwent a 'deep' retrofit according to a method known as 'Energiesprong.' The homes were super-insulated to an airtightness measure of better than 5.0 m3/h.m2@50Pa, with new windows, doors and roof. The heating system included PV, energy storage, and a heat pump. The project encountered technical problems with the heat pumps in the Sutton homes, greatly reducing their performance. Overall, including the PV and energy storage, the heat pumps in the retrofit homes were saving an average of £201 on their heating bills (or 21.7%) compared to their pre-retrofit state.

Study 16 (Gibb et al. 2023) report on a demonstrator project on Niddrie Road, Glasgow, where a pre-1919 tenement block of 8 flats underwent a 'deep' retrofit. Four of the flats had a heat pump installed, four had gas boilers installed. Following the retrofit, the annual energy demand for the flats was around 19.89 kWh/m^2. Based on monitored data, the authors estimated the total annual expenditure on energy for each of the units. The average total annual energy expenditure for the units with heat pumps was £627.30 (heating, lighting, appliances and cooking), while the average annual energy expenditure for the units with gas boilers was £571.73 (heating, lighting, appliances and cooking).

Study 3: An ASHP was 9.8% more expensive to run than gas heating.

Study 13: An ASHP was 6.3% more expensive to run than gas heating.

Study 16: An ASHP resulted in a total estimated annual energy expenditure 9.7% greater than gas heating.

Study 17: An ASHP was 12.1% less expensive to run than gas heating.

Seasonal Performance Factor / Coefficient of Performance

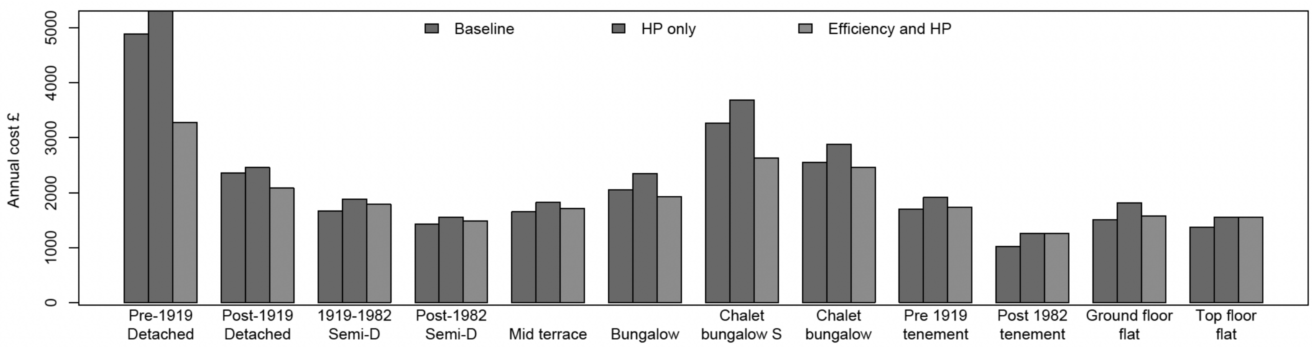
The preferred measure of heat pump performance in a field trial or demonstrator setting is the seasonal performance factor (SPF). The SPF is the annualised efficiency of a unit in a particular location considering the typical variation in performance between the warmer and colder months. The coefficient of performance (CoP) measure is more appropriate for laboratory settings – and flow and source (i.e., projected outdoor) temperatures must be given to render the figure meaningful. It can be seen that studies 8, 10, 12, 14 and 15 report SPF or CoP figures that reflect exceptional heat pump performance – i.e., performance figures above those to be expected across the wider UK existing housing stock. The SPF/CoPs for these heat pumps ranged between 3.0–3.62. Study 10 was the lowest with a SPF of 3.0 for their ASHP. Study 8 was the highest with a CoP of 3.62 for their ASHP. Averaging the running cost variance of the five studies undertaken in the context of optimal SPF/CoPs, we find ASHPs are 9.1% more expensive to run than gas heating (ceteris paribus). When interpreting the running cost findings of these studies it is important to acknowledge that a heat pump installed in the average home in the UK is unlikely to achieve these kinds of SPF/CoPs (ceteris paribus) unless additional fabric and/or heating system (emitters) upgrades were made. In other words, to ensure a heat pump achieves an SPF of 3.0 or above, additional fabric and heating system upgrades are likely needed for the average UK home.

Study 8 (Cui et al. 2020) performed a Monte Carlo simulation to estimate the life cycle cost of a PV / Thermal-assisted ASHP over a 25-year period. Using Ofgem data from the Feed-in Tariff (FiT) and Renewable Heat Incentive (RHI) schemes, the authors tested for income and payback period (PBP), as well as annual energy savings. The model simulated a detached house in Nottingham with an annual thermal energy demand of 22,087 kWh. The authors found that the total annual electricity load for the home (incl. household usage, heat pump consumption and circulation pump) was 10,611 kWh per annum, while the PV arrays generated a total output of 7,430 kWh per annum. The authors found their heat pump operating at a mean COP of 3.62, consumed 6,736 kWh of electricity per annum. This is equivalent to £2,384.67 in Jan 2024 (@ 35.4p per kWh for electricity). British Gas suggests the average annual gas bill for a 5-bedroom house accommodating 4–5 people is £2,839.74[43] .

Study 10 (Barnes and Bhagavathy 2020) modelled the economic performance of heat pumps based on data obtained from a selection of past trials. The authors suggest that the business case for a heat pump is largely driven by its SPF – i.e., the higher the SPF the more competitive the heat pump's running cost becomes compared to a gas boiler. Furthermore, the authors argue that the taxes and levies included in the price of electricity have an adverse impact on the business case for heat pumps. The authors found that a 6 kWth ASHP operating at a SPF of 3 is slightly more expensive to run than a gas boiler; while a 6 kWth GSHP operating at a SPF of 3.3 is marginally less expensive to run than a gas boiler, all else being equal.

43 https://www.britishgas.co.uk/energy/guides/average-bill.html

Figure 2. Comparison of Annual Running Costs Between (A) Gas Boiler in Baseline; (B) Heat Pump in Baseline; and (C) Heat Pump in Upgrades Archetypes. Source Palmer and Terry 2023, 54.



Study 12 (Wang et al. 2022) modelled the running costs of an ASHP, GSHP and a gas boiler assuming annual thermal energy consumption of 15,000 kWhth, a COP of 3.0 for the ASHP, a COP of 4.0 for the GSHP and 90% efficiency for the gas boiler. The authors found that according to these parameters, the GSHP was 10% less expensive to run than the gas boiler. The authors found that the high price of electricity was a major impediment to the economic viability of heat pumps.

Study 14 (CONFIDENTIAL 2023), prepared for a large housing association, was provided on condition of anonymity. The authors discuss data generated from 60 surveys returned by housing association tenants in 2022, reporting on user experiences with a variety of heating systems (including ASHPs). In addition, the authors perform a technical analysis of the same heating systems based on monitored data. The authors report that 55% of customers with an ASHP as well as PV and a storage battery considered such a heating system "very good" value for money. This was the highest possible rating. On the other hand, more than 50% of those surveyed who had an ASHP (but no PV or battery) did not consider their heating system good value for money. For their analysis, the authors gave the ASHP a nominal efficiency of 300% and the gas boiler an efficiency of 80%.

Study 15 (Palmer and Terry 2023) used a Cost Optimal Domestic Electrification (CODE) model – specifically designed for the Scottish context (i.e., ScotCODE) – to understand the comparison running costs between gas boilers and heat pumps across various housing archetypes. The authors established a thermal efficiency baseline for 12 housing archetypes: pre-1919 detached, post-1919 detached, 1919-1982 semi-detached, post-1982 semi-detached, mid-terrace, bungalow, chalet bungalow 1, chalet bungalow 2, pre-1919 tenement, post-1982 tenement, ground floor flat, and top floor flat. The authors then modelled the thermal efficiency for these archetypes based on modest fabric improvements. The authors used a nominal COP of 3.5 (at 40°C) when modelling the performance of the heat pump (Mitsubishi Ecodan). The authors found that in almost every case the running costs of the heat pumps in the 'upgraded homes' were lower than the heating costs for gas boilers in the baseline archetypes. On the other hand, the authors found that in every case installing a heat pump into the baseline home resulted in slightly higher running costs than the gas boiler, all else being equal (see figure 2). The authors argue that fabric upgrades are both "cost effective" and a "pre-requisite" for heat pumps to "operate efficiently" in most house types.

Study 8: An ASHP and PV saved £2,260 on annual energy expenses.

Study 10: An ASHP was 5.6% more expensive to run than gas heating.

Study 12: An ASHP was 19.9% more expensive to run than gas heating.

Study 14: An ASHP was 7% more expensive to run than gas heating.

Study 15: An ASHP was 4% more expensive to run than gas heating.

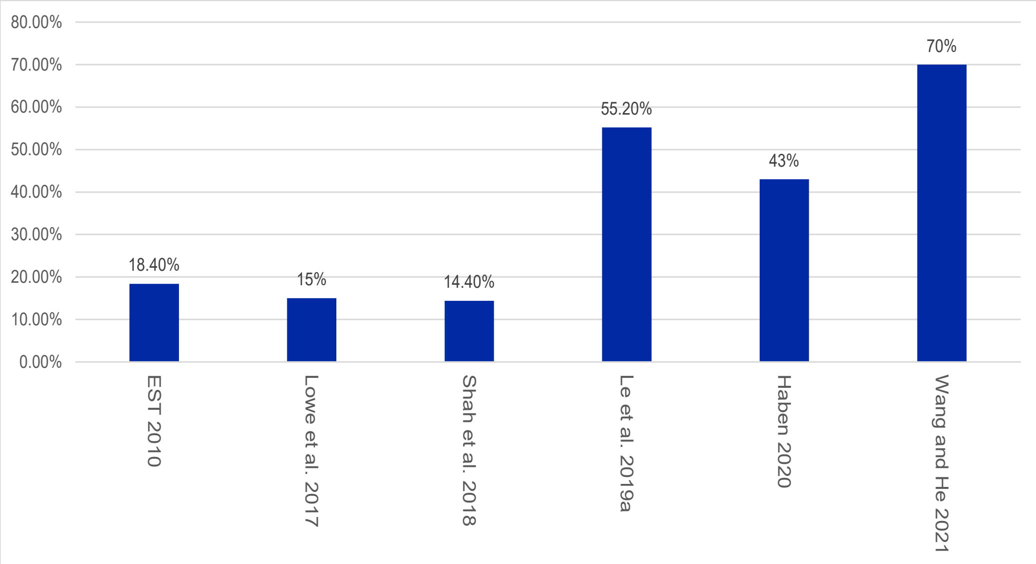
Averaging the running cost variance of the nine (9) studies undertaken in the context of 'ideal' circumstances (i.e., optimal SPF, high thermal efficiency, and/or low EtGPR), we find ASHPs are 9.3% more expensive to run than gas heating (ceteris paribus). Because these studies relate to data from ideal circumstances, this finding should not be considered applicable to the wider, unimproved UK housing stock.

Unexceptional Circumstances

Removing from our initial sample of seventeen (17) studies those which (a) indicate optimal levels of thermal efficiency; (b) those which report optimal SPF, SCoP or CoP figures; (c) studies with an energy price guarantee; and (d) those undertaken before 2008, we are left with what this report refers to as studies into heat pump running costs in the context of unexceptional circumstances. Namely studies 2, 4, 5, 6, 9 and 11.

Given the existing UK housing stock is heterogenous (in terms of its condition, airtightness and insulation), homes that fall into this "unexceptional circumstances" category should be understood as those in good repair and condition with adequate insulation. Although an imprecise measure, parallels might be drawn with homes in EPC band 'C' or higher with cavity and loft insulation and double-glazed windows. Homes that fall into EPC band 'D' or below should not be included in the "unexceptional circumstances" category and are unlikely to achieve such a high level of heat pump performance. Homes that fall into EPC band 'D' or below are 'exceptional' insofar as their thermal efficiency is likely so low as to directly and adversely impact the economics of heat pump performance.

Figure 3. Running Cost Variance of ASHPs Relative to Gas Boilers under Unexceptional Circumstances.



Study 2 (EST 2010) involved year-long monitoring of 83 heat pumps by the Energy Saving Trust (EST) and is the foundational large-scale field trial of the technology in the United Kingdom. For the first time, the authors generated monitored data on heat pump performance in real-life UK conditions. The EST field trial included 29 ASHPs and 54 GSHPs from 14 different manufacturers across a variety of housing conditions and archetypes. The authors found that while heat pump performance varied greatly between sites, the general observation from the data was that heat pump performance in this UK trial fell considerably short of heat performance in similar German and Swiss trials. In addition, the authors found that GSHPs performed slightly better than ASHPs, all else being equal. The mean efficiency for the GSHPs was a COP of 2.3–2.5. The mean efficiency of the ASHPs was a COP of 2.2. The EST found that heating a home with a heat pump was more economical than an equivalent house using direct electricity, oil or LPG.

Study 4 (Lowe et al. 2017) analysed field trial data generated by the Energy Saving Trust. The EST monitored 700 heat pumps between 31st October 2013 and 31st March 2015 as part of the Renewable Heat Premium Payment Scheme (RHHP) field trial. The heat pump performance data from this trial was slightly improved upon that which the EST has undertaken in 2010. The average SPF for an ASHP was 2.65 (up from 2.2), while the average SPF for a GSHP was 2.81 (up from 2.3–2.5). The authors found that based on the 2017 electricity-to-gas price ratio (i.e., 31/3:1), a heat pump would need an SPF of 2.82 to be considered a more economical heating system. On the other hand, an SPF of 1.77 was all that was needed for an ASHP to outperform direct electric heating, and an SPF of 2.11 to outperform coal. The authors modelled estimated heating costs for an ASHP operating at an SPF of 2.44 for three archetypes: detached, semi-detached and terrace homes. The authors found that both ASHPs and GSHPs were moderately more expensive to run than both gas and oil heating across the three archetypes.

Study 5 (Shah et al. 2018) analysed data from a year-long field trial where two mid-terrace test homes were built in Ulster, Northern Ireland, to 1900 building standards (i.e., to reflect a typical 'hard to treat' high U-value, poor airtightness home). One home was equipped with an ASHP and Thermal Energy Storage (TES), while the other installed a gas boiler. The heat pump averaged a COP of 2.2 for the year and provided a flow temperature of 75°C. Had the COP of the heat pump increased beyond 2.5, the running costs would have approached parity with those of the gas boiler.

Study 6 (Le et al. 2019a) used TRNSYS software to perform simulations of high-temperature heat pump performance which were validated against data from the same field trial discussed in Shah et al. (i.e., the two terrace homes built on the Jordanstown campus of Ulster University, Northern Ireland). The authors simulated both direct and in-direct mode settings for the heat pump, finding the direct mode permitted a higher SPF of 2.03 (which was below the HPs nominal COP of 2.5). Overall, Le et al's simulations produced results indicating lower heat pump performance than Shah et al.

Study 9 (Haben 2020) reports on a trial undertaken by Energy Systems Catapult from 1st March 2020 – 22nd April 2020 referred to as the 'Living Lab.' The trial included 5 homes with a hybrid heating system consisting of a gas boiler and a heat pump. The heat pumps were set to a flow temperature of 55°C but otherwise, no modifications to optimise performance were made. One of the homes (home 41) had an electricity-favoured tariff, lowering the electricity-to-gas price ratio in this case. Haben reports that home 41 was virtually 'cost neutral,' with the heat pump costing only 4% more to run than the gas boiler. For the remaining homes (not on the favourable tariff), the heat pumps were between 35%–64% more expensive to run than the gas boilers at a COP of 2.78 (ext. temp 7°C); and, 30%–58% more expensive to run than the gas boilers at a COP of 2.87 (ext. temp 12°C). Haben concluded, based on their results, that the electricity-to-gas price ratio would need to be 3.2:1 for heat pumps to be considered "cost effective."

Study 11 (Wang and He 2021) modelled the economic viability of transitioning of a variety of heat pumps at a national scale. The authors made use of national weather data, NASA's MERRA-2 and satellite imaging data, ground temperature readings, as well as national heating demand datasets. Using a levelised cost of heat (LCOH) measure, the authors found that both ASHPs and GSHPs are considerably more expensive to run than gas boilers. The ASHPs were simulated at an SPF of 1.7–2.2 and the GSHPs were simulated at an SPF of 2.6– 3.2. The authors argue that the economic competitiveness of heat pumps compared to gas boilers can be improved in one of two ways: (1) by increasing their COP; or (2) by reducing the cost of electricity. Study 2: An ASHP was 18.4% more expensive to run than gas heating.

Study 4: An ASHP was 15% more expensive to run than gas heating.

Study 5: An ASHP was 14.4% more expensive to run than gas heating.

Study 6: An ASHP was 55.2% more expensive to run than gas heating.

Study 9: An ASHP was 43% more expensive to run than gas heating.

Study 11: An ASHP was 70% more expensive to run than gas heating.

> Averaging the running cost variance of the six (6) studies undertaken in the context of 'unexceptional' circumstances, we find ASHPs are 36% more expensive to run than gas heating (ceteris paribus). Because the data underwriting this finding were obtained from unexceptional circumstances (see Figure 3.), there is a greater likelihood this result reflects what might be expected in terms of comparative heat pump running costs in the context of the wider, unimproved UK housing stock.

Final Thoughts

Heat pumps – be they air- or ground-source – are a perfectly suitable technology to facilitate the decarbonisation of domestic space and water heating in the United Kingdom. While there are certain settings where individual units may not be the most practical, efficient or cost-effective solution (e.g., older tenements with smaller flats, or locations designated for heat networks), heat pumps nevertheless represent a proven technology that will lower the UK's CO2 emissions while (theoretically) reducing household heating bills.

This review and evaluation of all available evidence concerning the running costs of heat pumps in the UK has revealed that certain conditions must be met for a heat pump to generate economic savings for consumers (when compared to the cost of running an efficient gas boiler). In the first instance, an electricity-to-gas price ratio of no more than 3:1 is required. In addition, the heat pump must operate with a seasonal performance factor (SPF) of 3.0 or higher. The last fifteen years of data relating to heat pump running costs have highlighted the critical role the price of electricity plays in their economic viability. Unfortunately, the United Kingdom has been plagued by chronically high electricity-to-gas price ratios for the last decade – at times being 5:1 and higher. Electricity-to-gas price ratios in the range 4:1 – 5:1 render the economic competitiveness of heat pumps (despite their considerable CO2 savings) virtually impossible. When the price of electricity is 4 times higher than gas, the data suggests no level of insulation, emitter size, airtightness, or thermal efficiency can compensate for the economic drag such an electricity-to-gas price ratio places on the economic competitiveness of a heat pump.

The electricity price dilemma is fundamental to the UK's decarbonisation agenda since it profoundly undermines the two initiatives critical to achieving net zero: fabric improvement of the UK's existing housing stock and the installation of zero-carbon heating systems. A severely under-researched yet pertinent question is: 'how much on average would it cost a UK homeowner to upgrade their home's fabric and heating system to ensure a heat pump would deliver an SPF of 3.0 or higher?' In the absence of direct evidence, we can suggest an estimate by proxy. According to analysis by Dashly (based on data from the English Housing Survey) the "average cost in the UK for homeowners needing to improve their Energy Performance Certificate ratings currently stands at £13,981[44] ." This cost would bring the average home into EPC band B. Bear in mind, applying this proxy to the question at hand assumes that homes with an EPC 'B' rating are sufficiently thermally efficient to ensure an SPF of 3.0 or higher from a heat pump. This however, may not be the case. Even homes in EPC band B may lack the airtightness and suitable U-value to achieve an SPF of 3.0 or greater (irrespective of emitter size), while also providing adequate warmth.

With an electricity-to-gas price ratio of 4:1, even if the average homeowner spent this proxy figure of £14,000 to improve their home to a point where a heat pump might deliver an SPF of 3.0 or higher, their ongoing heating bills would still be higher than if that homeowner had undertaken no fabric improvements and retained their gas boiler.

Consider this situation in the context of the private rented sector (PRS). What is the business case for the average landlord to spend £14,000 on fabric improvements plus an additional £12–£15,000[45] for the heat pump unit and its installation, only to render their property less commercially attractive to prospective tenants? The situation is equally frustrating in the social housing sector (SHS). In the context of such a high electricity-to-gas price ratio, it seems inevitable that housing associations and local authorities pursuing decarbonisation initiatives will increase the financial burden on their social tenants – either directly through rent increases to compensate for the costs of fabric and technology improvements to their housing stock or indirectly if the cost of heating increases through the adoption of heat pumps.

In the final analysis, the last fifteen years of evidence suggests that because the UK has such a high electricity-to-gas price ratio, field trials, demonstrator projects and desktop modelling of monitored performance have failed to demonstrate that

44 https://www.propertyreporter.co.uk/epc-improvement-costs-hit-almost-14k-for-the-average-homeowner.html; https://assets.publishing.service.gov.uk/media/62d166e3d3bf7f28661f0942/Energy_Report_2020_revised.pdf

45 https://www.evergreenenergy.co.uk/heat-pump-guides/much-heat-pump-cost/

heat pumps can compete with efficient gas boilers in terms of running costs (ceteris paribus). In unexceptional circumstances – i.e., in situations representative of the wider existing UK housing context – a heat pump is approximately 36% more expensive to run than an efficient gas boiler, all else being equal. In ideal situations – i.e., homes where an appropriately sized heat pump can achieve an SPF of around 3.0 – a heat pump is approximately 9% more expensive to run than an efficient gas boiler, all else being equal.

Further Research

Writing this report suggests several areas for further research and questions related to its findings:

1. What economic, structural and regulatory factors explain/drive the UK's historically high electricity-to-gas price ratio?

2. What policy interventions have been proposed to address the electricity-to-gas price ratio in the UK?

Since the UK's persistently high electricity-to-gas price ratio is the aspect of the social system that fundamentally frustrates efforts at decarbonising domestic heating and meeting our Net Zero obligations, we must identify and understand the factors that determine the present situation. Whatever policy interventions are recommended to rectify the UK's unfavourable electricity-to-gas price ratio must pay due attention to the prospect of unintended outcomes, rebound effects, market distortions, and inequitable burdens in the context of an equal society. There is no sense in closing the gap between the price of electricity and gas if it undermines investment in energy and industry, consumers are worse off, or fuel poverty is exacerbated.

3. How much would it cost the average UK homeowner to improve their home to a level where heat pump running costs approximate those in the upper range of this report (i.e., 9% more expensive to run than an efficient gas boiler, all else being equal)?

4. What proportion of homes in the UK fall into the "unexceptional circumstances" category described in this report, and where are they located geographically?

Any strategy to decarbonise heating involves some kind of assessment on the part of the homeowner of the trade-off between gains from energy and thermal efficiency improvements and the cost of such upgrades, on the one hand, and simply paying more for heating but avoiding additional capital expenses when installing a heat pump, on the other. Consequently, homeowners require two different kinds of financial advice. In the first instance, homeowners need to understand how much it costs to run a heat pump. Furthermore, they need to know how much it might cost them to undertake the necessary upgrades to achieve a certain heat pump running cost. While this report provides insight into the first issue, reliable information about the cost of fabric upgrades is lacking.

Finally, since governments and local authorities are (more than likely) going to have to subsidise or fund either fabric improvements or heating bills for a great many UK residents, it would be helpful for policymakers to understand how the thermal efficiency of the existing housing stock is patterned and what kind of sums are required.

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