Heat Pumps: the new Winter Peak

The Challenges

In the future, there are a number of energy trends that will result in big challenges in balancing the grid:

- The shift to renewable energy means that our power supplies will be more intermittent and cannot be scaled up in response to demand.
- The shift from gas boilers to heat pumps means that electricity demand will be higher overall, higher at peak times each day, and there will be a new winter peak – where electricity demand is much higher in winter than in summer.

This results in two grid-balancing challenges:

- **Winter peak challenge**: There will be a new winter peak caused by the conversion of gas-powered heating to electrically-powered heating.
- **Daily peak challenge:** The existing daily peaks in electricity consumption may be made much larger by heat pumps. The current gas peak demand is 4x higher than the existing electricity infrastructure [1].

This report examines the winter peak problem.

Executive Summary

- With electrified (heat pump) heating and electric vehicles, there will be increased demand for electricity. We estimate demand will increase from 268 TWh/year to 490 TWh/year.
- However, winter peak demand will increase from 982 GWh/day to 2329 GWh/day.
- In a renewable grid, the amount of generation must be enough to meet this winter peak – meaning that generation must be higher than needed during the rest of the year. We estimate that in order to meet demand during this new winter peak:
    - **With the existing building stock – we must generate 1275 TWh in order to meet this demand. This is 4.8x the current electricity supply.**
- Smart Retrofit can help reduce this:
    - **If we use Smart Retrofit to reduce overall heat demand by 36%, we reduce electricity demand by 73 TWh.**
    - **However, because this reduces peak demand - this reduces the total generation required from 1275 TWh to 933 TWh – a generation saving of 342 TWh.**
    - **This creates a saving of £434 billion over 20 years - £15600 per household (assuming a levelized cost of energy of 6.4p/kWh)**
- These figures assume both that residential heating is converted to heat pumps, and that existing vehicles become electric cars that can be used to actively balance the grid at times of highest demand. This is based on an even mix of wind, solar, and nuclear power generation.

Demand-side challenge

- In 2019, the UK grid supplied 268 TWh of electricity, and UK domestic consumers used 295 TWh of gas.
- If this heat demand were met through heat pumps, this would result in an additional 142 TWh/year of electricity consumption.
- However, this new demand would not be evenly spread throughout the year – since most heating demand is in winter.
- In addition, converting to electric cars would result in additional electricity demand of 80 TWh – an average additional daily demand of 219 GWh. [2]
- Combined – this results in peak demand rising to 2329 GWh/day, from an existing peak of 982 GWh/day.

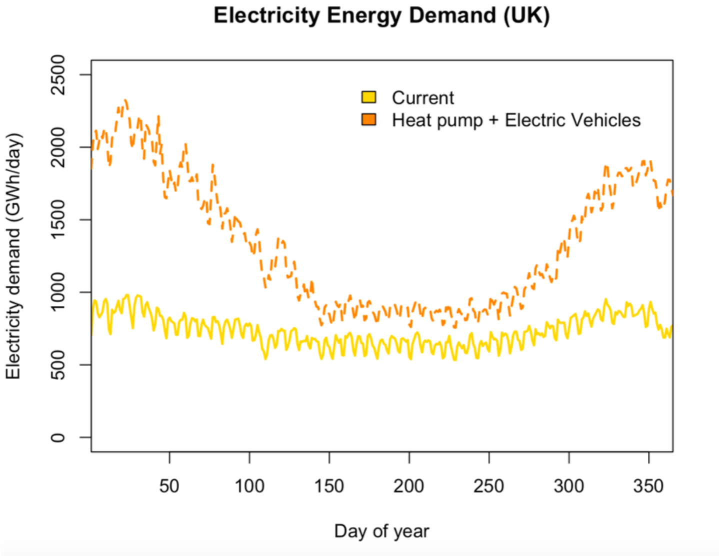

Figure 1: UK existing electricity demand (2019) (yellow), vs estimated electricity demand if all cars were replaced with EVs, and all domestic gas consumption were replaced with heat pumps(orange)

Supply-side challenge

- In periods of low sunlight or wind, these renewable sources produce substantially less energy.
- Around 27% of the time, in the UK, the energy generation of wind and solar are below 20% of their effective capacity (Figure 2).

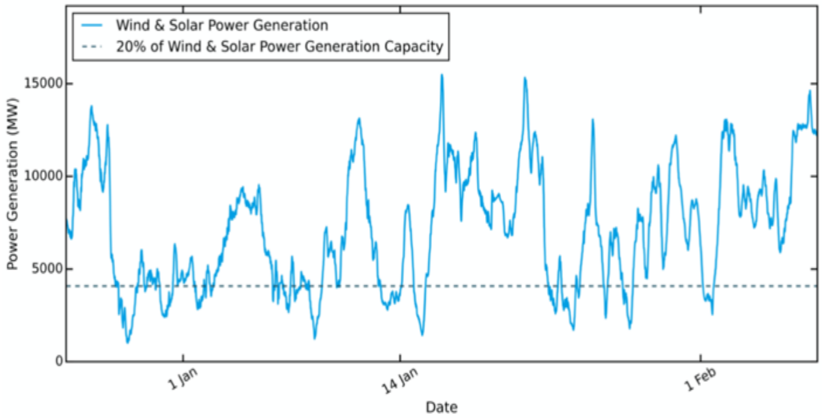

Figure 2: UK power generation from solar and wind in January 2021

The effect of Smart Retrofit in a Heat Pump World

A house with properly installed insulation can be heated with a lower radiator temperature – improving heat pump efficiency

- A heat pump running with a flow temperature of 45˚C instead of 35˚C results in a 41% energy consumption increase for the same heat output
- This reduction in flow temperature can be achieved by reducing heat demand by 40%.
- This means that a 40% reduction in heat demand can lead to a 57% electricity demand reduction – because the remaining heat required can be achieved more efficiently. [3]

A better-insulated house can retain its heat for longer – enabling better energy shifting

- The house, when optimised with an Algorithmically Controlled Smart Thermostat, can do more of its heating during off-peak times – taking advantage of cheaper electricity – as the house will then stay warm during peak times

However, poor quality retrofits that do not reach the level of savings described here cannot work.

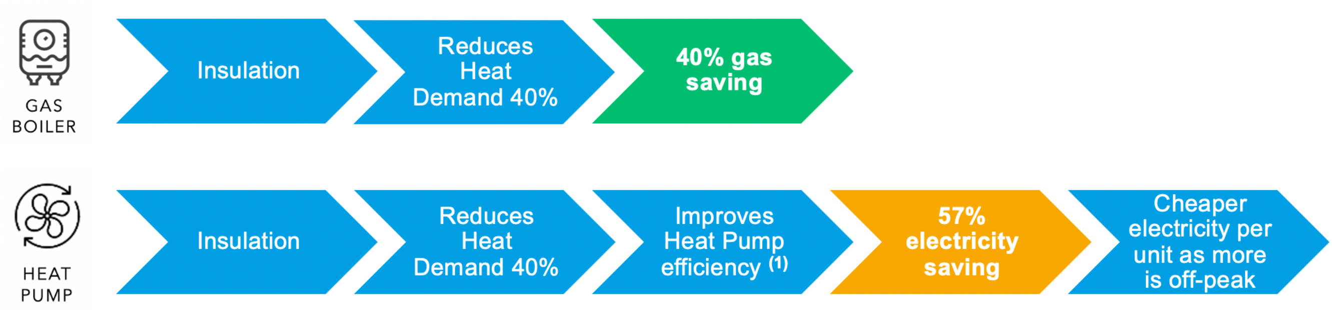

Figure 3: An illustration of how reducing heat demand by 40% can result in improved heat pump efficiency - resulting in a 57% electricity saving

Smart Retrofit and the Market for Lemons - Theory

There is a market failure at the heart of the retrofit market.

The savings attributable to retrofit are determined via “deemed savings” methods. These methods mean that a given insulation measure is always deemed to have made some level of improvement to the house – with no accounting for the actual performance of the retrofit.

This means that a retrofit installed to a low quality - that achieves little savings - is treated exactly the same as a retrofit installed to a high quality that does achieve good savings.

This is because customers (and the governments who encourage or mandate certain levels of insulation) cannot distinguish between high-quality retrofits and low-quality retrofits.

This is known in Economics as a “Market for Lemons”. It results in those who perform low-quality retrofits being rewarded – as they can be more competitive on price, but are never held to account for their low-quality retrofits.

This occurs until there are no sellers who provide high-quality retrofit – because those who provide low-quality retrofit are more competitive, and expand until the whole market is low quality.

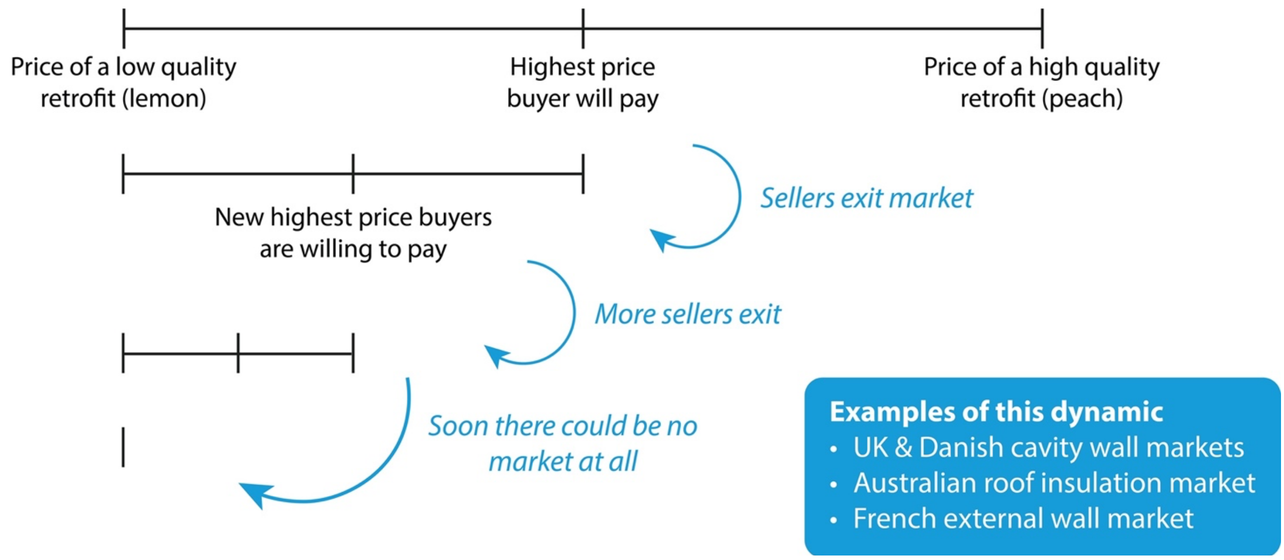

Figure 4: A diagram showing the market dynamics in a market for lemons. Because buyers are only willing to pay for the retrofit they expect to receive – the highest price they are willing to pay is the value of a retrofit in the middle of the market in terms of quality. However, this dynamic then forces the high-quality market participants to exit the market or reduce their quality – otherwise, they would be selling retrofits of a higher value than they will be paid. But then, because the highest quality market participants have exited, the average quality reduces – so the next highest quality sellers (who were previously of average quality) are then faced with the same choice. This cycle continues until only the lowest quality sellers remain – and the only market left is one that is the lowest possible quality. This happens regardless of how much extra a high-quality retrofit costs to provide.

Smart Retrofit turns this market dynamic on its head. This is because Smart Retrofit uses real performance monitoring to measure the actual savings attributable to the retrofit. This means that customers can distinguish between a high-quality and low-quality retrofit.

This means the provider can be held accountable for the quality of the retrofit – ensuring a high-quality retrofit.

Smart Retrofit and the Market for Lemons - Practise

In a trial in Eccles in the northwest of the UK, we tested whether a better install of existing insulation could improve performance in some nearly new housing.

We carried our monitoring of 12 houses that were built in the late 2010s to determine their real energy performance.

We then replaced their existing insulation to ensure a high-quality install.

Under a “deemed savings” method, this would have made no difference – the houses before and after our improvements would have appeared the exact same to an EPC assessor and received the same EPC certificate.

However – we continued our monitoring in order to find their real energy performance after we had re-installed the roof insulation.

We found an 18% energy saving after we had replaced the existing insulation with well-installed insulation.

This means that the original insulation was installed in a way that made the houses require, on average, 22% more total heat than under a high-quality install.

However, this performance gap is not captured in EPC certificates – because EPC certificates use deemed savings not real performance monitoring. Only real performance monitoring can distinguish between houses with well-installed insulation which perform as they should - and houses with badly installed insulation that do not perform as they should.

Electric Vehicles

One method that could be used to balance supply and demand is to use electric cars. If all 32 million cars in the UK become electric vehicles, and each one has a battery capacity of 50 kWh, then combined they would have a total capacity of 1600 GWh. This added capacity could interface with the grid – charging the batteries in times of surplus, and then discharging to power the grid when necessary.

However, there are some constraints:

- These cars are used – and so must always have enough battery power for the user of the car.
- If the entire battery capacity of a car were used every day, it would "age" the battery significantly – equivalent to driving around 100,000 km/year.
- At any given time, not all cars are connected to a charger and so cannot be actively managed.
- Some owners may not wish to participate in such a scheme.
- Electric cars often avoid charging above 80% or below 20% in order to reduce battery wear.

In our modelling, we have assumed that around 75% of this value – 1.2 TWh – is available to the grid for grid balancing. Our modelling shows that we would only need to take advantage of this when both renewable generation is particularly low, and the weather is very cold.

Modelling the Energy System

In this section, we estimate the required grid capacity in order to meet winter demand, according to different scenarios.

All of these estimates assume that we meet our energy generation needs from an even mix of wind, solar, and nuclear power. We also assume that we have 1.2 TWh of battery storage connected to the grid.

These are based on Smart Retrofits that achieve an average heat saving of 36% over the housing stock. In addition, we have accounted for the improvement in heat pump efficiency from reduced energy demand.

- Without Smart Retrofit, we have assumed that the heat pump would run at a flow temperature of 55˚C, achieving a COP of 2.08. [3]
- A house that previously required a flow temperature of 55˚C, following a Smart Retrofit which reduced heat demand by 36%, would require a new flow temperature of 42˚C. In this circumstance, the heat pump achieves a COP of 2.75. [3]

Table 1: Results of energy system analysis

Scenario	Today (gas boilers)	No retrofit	Smart Retrofit
Heat Demand	295 TWh	295 TWh	190 TWh
Electricity required to meet heat demand	0 TWh	142 TWh	69 TWh
Total electricity demand	268 TWh	490 TWh	417 TWh
Total generation required to meet peak demand	268 TWh	1275 TWh	933 TWh
Multiple of supply/demand	1.00x	2.60x	2.24x

Table 1 shows that the total electricity demand reduces from 490 TWh to 417 TWh – a saving of 73 TWh – but that the total generation required is reduced by 342 TWh.

In short, in this scenario, we have found that a retrofit saving of a total of 73 TWh, across the energy system, results in a reduction in necessary generation of 342 TWh.

This is 4.7x the impact that would be expected by the reduction in demand alone.

This is because the cost of generation in the future renewable world is driven by peak demand – which disproportionately comes from the seasonal winter heating peak – instead of total demand

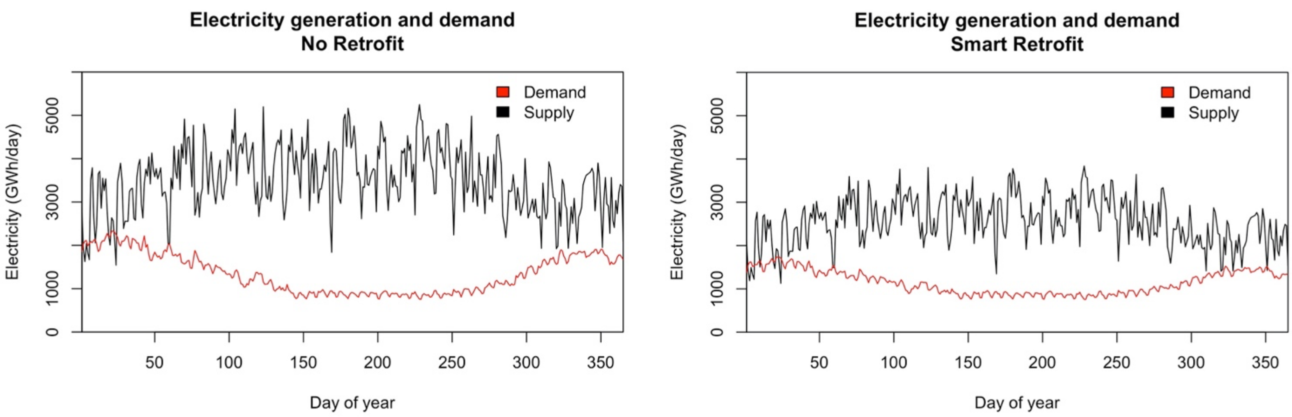

Figure 5: Modelling results - electricity supply and demand throughout the year under no retrofit and Smart Retrofit scenarios

Cost Savings (GBP)

With Smart Retrofit, we move from required generation capacity of 1275 TWh to 933 TWh.

In Table 2, we show the Levelized Cost of Energy, as determined by Lazard in their most recent analysis.

Table 2: Levelized Cost of Energy (LCOE) (Lazard [4])

Power source	Cost range ($USD/MWh)	Cost midpoint ($USD/MWh)	Cost midpoint (£/MWh)	Weighting in analysis
Solar (utility)	$28 - $41	$34.5	£25	0.33
Solar (rooftop)	$59 - $221	$140	£102	0
Wind (on-shore)	$26 - $50	$38	£28	0.16
Wind (off-shore)	$83	$83	£60	0.16
Nuclear power	$131 - $204	$167.5	£122	0.33

Using the mid-point values for this, and applying our existing assumption of 1/3rd solar (all utility), wind (of which half is on-shore and half off-shore), and nuclear, we find an LCOE across the energy system of £63.51/MWh – or 6.4p/kWh.

Applying this figure, we find that the Smart Retrofit **reduces grid cost by £434 billion over 20 years – or £15628 per household.**

- **This is based on a LCOE for electricity of 6.4p/kWh**
- **At an energy price of 9p/kWh, this increases to £22144 / household**
- **At an energy price of 15p/kWh, this increases to £36906 / household**

Table 3: Cost savings of Smart Retrofit

(LCOE = 6.4p/kWh)	**Required generation (TWh/year)**	**Cost of energy system (£/year)**	**Cost over 20 years (£)**
No retrofit	1275 TWh	£81 billion/year	£1620 billion
Smart Retrofit	933 TWh	£59 billion/year	£1185 billion
Saving	342 TWh	£22 billion/year	£434 billion
Saving (per household)	**12302 kWh**	**£781 /year**	**£15628**

Savings due to retrofit in a renewable world - Illustration

Our modelling shows that, with a high quality Smart Retrofit, we can significantly reduce our need to overbuild renewable generation to meet the peak demand in winter. **A 36% heat demand reduction leads to a reduction in electricity demand of 73 TWh - but by reducing peak demand, this translates to a reduction in required electricity generation of 342 TWh.**

This is because the way in which Smart Retrofit affects the energy system is fundamentally different in a renewables world – because energy generation must be large enough to meet the peak demand. Reducing this peak demand allows us to make generation smaller – reducing the amount of energy that is generated year-round – even in summer, when houses are not being heated at all.

With fossil fuels – if we decrease a house's annual energy demand from 20,000 kWh/year to 10,000 kWh/year – the saving is simply 10,000 kWh.

However, consider the same house and the same retrofit with a renewable grid. Before retrofit, the house, which used 20,000 kWh, would have used around 4600 kWh in the month of January. After retrofit, it would use only 2300 kWh in the month of January.

In a renewable grid, the 4600 kWh that the pre-retrofit house needed in January had to be generated year-round – because there is no way to scale up or down production. This is a total of 55,200 kWh/year.

But now, the house has been retrofitted – and it only needs 2300 kWh in January. This 2300kWh/month must still be generated year-round – which is still a total of 27,600 kWh. But this has been reduced from 55,200 kWh.

So, the retrofit – which reduced total energy demand from 20,000 kWh to 10,000 kWh, allows us to reduce energy generation for that house from 55,200 kWh to 27,600 kWh – a saving of 28,000 kWh.

This simple illustration does not account for peaks within January, or troughs in renewables generation – but illustrates how retrofit savings can cause much higher savings in required generation.

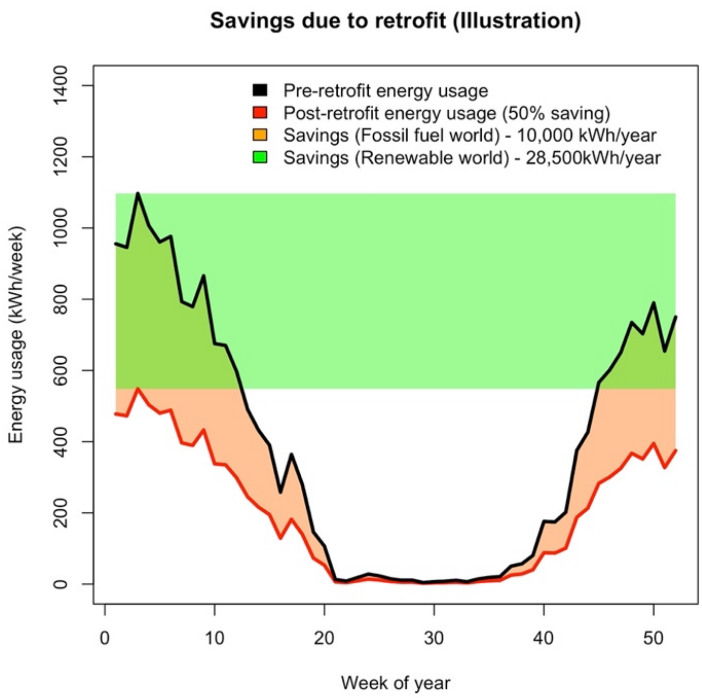

Figure 6: We examine a saving due to retrofit of 10,000 kWh/year. In a fossil fuel world, this would save us 10,000 kWh/year. But in a renewable world, our saving is much larger. This is because our 10,000 kWh/year saving corresponds to a January saving of circa 2300 kWh – but to meet the January demand, this extra 2000 kWh must be generated in every month – a total of 28,000 kWh.

Transmission Costs

The existing grid transmission network has a limited capacity – and there are concerns that this will need expensive upgrades in order to service additional demand due to heat pumps and electric vehicles.

We do not have the dataset required to conduct a full analysis of this. In order to understand this problem, we would need full data of the entire grid, so we could assess its bottlenecks and determine how many upgrades might be needed where, and their costs.

However, there have been other analyses of this problem – one report [5] estimates a cost of **£40 billion by 2035**, based on hybrid heat pumps which have much lower peak demand.

The highest rate of instantaneous electricity demand experienced in our dataset was 255 GW – at 12:10 on 24th January in 2013. If this were delivered continuously for an entire day, this would be a total of 6120 GWh – whereas, during the peak day in winter in our no-retrofit scenario, we forecast 2329 GWh total daily energy demand.

This does not take into account location – we do not know whether the peak was experienced all over the network - or was only serviceable because it was in locations with good infrastructure.

But it illustrates that the issue around transmission is closely related to the daily peaks problem.

In short - If we can mitigate the daily peak demand problem, we also mitigate the transmission costs problem – since both are related to reducing peak load.

Caveats

There are several caveats to this analysis.

In particular:

- We do not have data showing much gas is used domestically each day in the UK. We have approximated this using the total amount used in a year, and then distributed this across each day of the year based on a typical profile – as determined via an analysis on our own dataset.
- Heat pumps have been assumed to have a constant coefficient of performance (COP) over the year. In practice, this may be lower during the coldest days of winter – increasing energy demand even further in winter. In addition, if heat pumps are installed in houses that are unsuitable for them, this may decrease even further. Smart Retrofit can measure the energy performance of the house to understand what heat pump is required and what intervention may be necessary to ensure good heat pump performance.
- This analysis works from the basis that the hourly peak problem has been solved, and the only challenge remaining is to ensure that enough electricity is generated each day. In practice, we may have to consider both problems (and their interactions) at once.
- There is some existing electrically powered heating in the UK. This is not included in this analysis. If these houses were retrofitted, the effect of Smart Retrofit would be even higher.

Sources

[1] "Heat decarbonisation challenges: local gas vs electricity supply" – UKERC, 2018
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[2] "Electric vehicles: Ofgem's priorities for a green fair future" – Ofgem, 2021
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[3]" Lazard's Levelized Cost of Energy Analysis – version 15.0" – Lazard, 2021.
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Exchange rate of £0.7259/USD used (average exchange rate 2021, HMRC)
Exchange rate of €0.8415/USD used (average exchange rate 2021, HMRC)

[4] Based on an external temperature of 2˚C, data taken from the technical guide for the Veissmann Vitocal 200-A heat pump, unit type AWO-M 201.A04.

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[5] "Accelerated electrification and the GB electricity system" – Vivid Economics and Imperial College London, 2019
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