February 2022

DSR flexibility for domestic heat pumps

PART 1

Executive summary and review of market, policy and situation today

Vaillant and geo white paper

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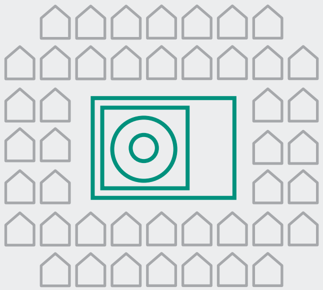
Contents

Executive summary

Comfort for your home

In April 2021, the UK Climate Change Committee's (CCC) sixth carbon budget[1] recommended that 21 million existing homes should be fitted with heat pumps as part of a low-carbon heating strategy for every home.



21 million

existing homes will need to have a heat pump fitted

Consumers are increasingly aware of the need to change their behaviour and reduce their carbon emissions and are looking for low-carbon heating solutions.

This paper sets out the case for mass deployment of domestic heat pumps as an integral part of the UK's net zero strategy.

The paper discusses that appropriate insulation, not just of existing housing stock, but also of new build properties, is prerequisite for such a deployment.

It also demonstrates that utilising the flexibility that heat pumps can offer is critical to managing the significantly greater peak demand that electrification of heat creates alongside the increased adoption of EVs.

The UK Government has announced plans to have 600,000 heat pumps installed per year by 2028. We believe this objective should go further and faster.

This paper identifies that the additional electricity demand from heat pumps (although individually relatively small) when applied to a significant proportion of the 21 million homes already built, would have a major impact on the adequacy of our Low Voltage (LV) electricity networks without the mitigations we propose.

Low voltage networks will be significantly impacted without DSR solutions

For this reason, we have examined smart grid technology which allows better control of heat pumps at the grid edge to manage the peaks of supply and demand to alleviate that stress. This technology offers the potential to save billions of pounds in electricity network infrastructure reinforcement.

The electricity network has been using Demand Side Response (DSR) flexibility for centrally managed large-scale grid batteries and controlling commercial and industrial loads, for several years already.

While residential DSR trials have taken place, much of the technology necessary to enable mass-market adoption is still in R&D labs and the lack of standardisation between manufacturers is a barrier to deployment.

Lack of standardised smart energy protocols between devices needs to be solved by industry

We have sought to address these challenges, and in developing an understanding as to how these systems could work, have produced a series of recommendations for a cross-section of stakeholders including government, consumers, media, house builders, energy retailers and those working in the heat pump sector.

#1

Low voltage networks may become overloaded when 10-20% of the existing 21 million homes have heat pumps fitted to them.

- While heat pumps can be made to be flexible with smart protocols (to reduce demand at peak times), the amount of flexibility is dependent on good insulation and thermal properties of homes.
- Additional thermal storage or battery storage will be needed to offset the impact of adding heat pumps to homes.

#2

Enabling Demand Side Response (DSR) control of Energy Smart Appliances is hampered by a lack of agreed protocols between manufacturers.

- We propose that industry adopts a set of existing standards (EEBUS, Matter and OCPP) with a flexible architecture supporting EV chargers, vehicle-to-grid (V2G), heat pumps, solar PV, battery storage and white goods.

#3

The GB smart metering system can help to enable domestic DSR, by providing core data to support peak load control in the home, base-lining data for DSR service and providing LV substation monitoring information to DNOs.

- Existing smart meters can share real-time power readings with home energy management systems, and avoid costly additional metering, which is currently needed for DSR services.

#4

The UK Government sponsored, PAS1878 for Energy Smart Appliances (ESA) has moved industry forwards, but the authors consider that it is insufficient for manufacturers to adopt.

- We propose that an industry consortium of willing stakeholders including DNOs, energy retailers, DSR Service Providers (DSRSP), Customer Energy Manager (CEM) and ESA manufacturers is formed to develop mass-market solutions capable of adoption in the UK and in international markets.
- This industry consortium should be responsible for selecting and developing the interoperable protocols and mass-market solutions with a "DSR ready" trust mark that enables consumer confidence when purchasing equipment.
- These solutions should be proven in large-scale, real-world trials centred around single substations to demonstrate the impact of additional load on the LV portion of the network and how best to mitigate it.

#5

The idea of allowing multiple CEMs per home proposed in PAS1878 may have undesirable outcomes including potentially safety issues.

- Multiple CEMs will encourage competition and innovation between vendors.
- Further work is needed to understand the practical implications of such a scheme at a system level.

Scope

This introductory white paper is the first in a series of three which are the output from a joint-project conducted by Vaillant and Green Energy Options (geo).

During our research into the topic of Demand Side Response (DSR) control of heat pumps, we uncovered a wealth of learnings which will help governments and industry to align around best practice and identify key steps towards decarbonisation of domestic heating, which represents around 15% of the UK's energy use and 21% of carbon emissions[10].

The subject areas cover commercial, procedural as well as technical barriers which need to be resolved to make a mass market heat pump deployment viable.

Paper 1 (this paper) – Review of market, policy and situation today:

- The current situation in the heat pump and DSR markets
- The potential impact of heat pumps on low voltage networks
- The need for scale
- The need for technical standards and interoperable protocols
- The need for a code of practice
- Recommended next steps

Paper 2 – Home thermal modelling and potential for DSR control of heat pumps:

- Building models, impact of insulation and heat losses
- Pre-heating homes and hot water to take advantage of Time of Use (ToU) tariffs
- Heat pump flexibility options
- Simulation results

Paper 3 – Smart home protocols and DSR:

- Use cases for EV, heat pump, solar PV & battery storage
- DSR control of in-home Energy Smart Appliances (ESAs) & PAS1878
- Review of standards and protocols
- Recommended architecture for smart home DSR solutions and heat pumps

Introduction

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Flexible grid & domestic DSR

As electricity grids become more reliant on renewable energy, and as society transitions from fossil fuels to electric transport and electric heating, then the demands on the grid from residential properties will increase while supply becomes more variable.

In the National Grid Energy Supply Operator's (ESO) ***Future Energy Scenarios***[2] (July 2021), the slowest adoption model predicts that there will be at least 4.7m EVs and 1.9m heat pumps in the UK by 2030. Other models put the deployment numbers at two or three times this level.

> “in 2050, system flexibility ... could yield up to £12bn per year reduction in costs”

In the UK Government's ***Modelling 2050: Electrical Systems Analysis report***[3] (Dec 2020), it states that in 2050, system flexibility (including Demand Side Response) could yield up to £12bn per year reduction in costs and reduced carbon intensity. It goes on to say that 'system flexibility is essential to bring down system costs in a low-carbon system'.

The ESO's Future Energy Scenarios also suggests that 6GW of new flexible residential demand reduction will be available by 2030.

As observed in the UK during the 2020 COVID-19 lockdowns, there were occasions where generation had to be curtailed due to excess wind and solar, illustrating that there is a need for an ability to switch on systems to create additional load (e.g. heating homes or hot water tanks to store the excess energy for later use, which in turn can reduce peak demand) rather than just the need to reduce demand and turn off appliances.

Combined with increased penetration of electric vehicles, there will be a need to provide a greater control of when our EV charging and heating appliances get their fair share of the power they need; taking it in turns to power up or down in an intelligent and optimised way, matching customer needs for comfort with the ability to balance the grid at both national and local levels.

To achieve this, DSR technology enables IoT connected appliances in our homes to become flexible assets which can vary their electricity demand and help flatten out peak loads on the grid.

By balancing these peak periods, electricity suppliers can reduce our dependency on fossil fuels and investment needed in nuclear power stations.

Emerging technology standards allow previously “dumb” domestic appliances to become Energy Smart Appliances (ESA).

These ESAs can provide DSR flexibility, creating an opportunity for manufacturers to enable domestic flexibility at mass scale, bringing new business models and revenue streams, and ways for manufacturers to innovate and differentiate themselves in a growing market.

Background

In the UK, the department for Business Energy and Industrial Strategy (BEIS) has funded the development of ***PAS1878*** (Publicly Accessible Standard) focused on kick-starting the domestic DSR revolution by defining an architecture for ESAs.

PAS1878 focuses on the minimal set of requirements to satisfy the UK Government's concerns around: ***interoperability, data privacy, grid stability*** and ***cyber security***. Its scope is broad and covers a range of domestic loads which can offer flexibility such as EVs, HVAC and battery energy storage systems.

In other markets around the world, DSR technologies already exist which can call on air conditioning to reduce its power demand, or solar PV inverters to reduce their generation output. These have traditionally involved a relatively simple 2-wire analogue control signal that ultimately provides the control, but does not allow a bi-directional conversation.

Newer technologies can call on the ESA to make flexibility offers (e.g. it would be possible to switch off for 20 minutes, and save 1kWh without significantly impacting user comfort). They can also call on the smart heating system to forecast how much power it is likely to need in the next few hours.

These forecasts may be based on a combination of pre-set desired temperature, the outdoor temperature, weather forecast, building thermal model and electricity tariff.

By using the extensive data available inside these intelligent systems, it is possible to provide far more accurate energy forecasts to energy retailers, national grid and DNO/DSOs.

This in turn will allow those operators to plan more effectively, reducing the degree of grid reinforcement required and allowing better matching of renewable energy supply with household demand, minimising costs and CO_2 emissions.

Load shifting & domestic flexibility

To date, DSR has been focused on industrial and commercial applications (e.g. reducing demand in fridge-freezers in supermarkets and factories, or centrally managed large-scale battery storage and back-up generators).

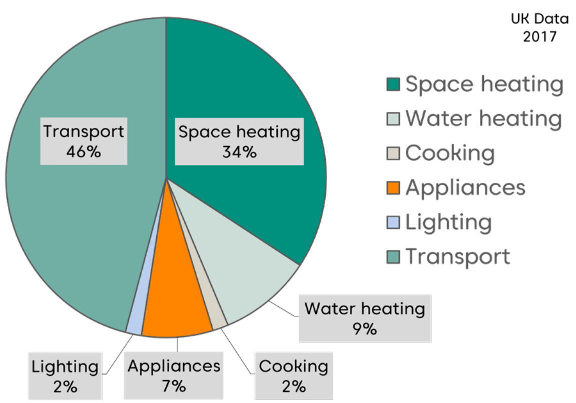

Figure 1 - Breakdown of UK domestic energy usage

Domestic assets have the potential to help balance the grid. Our transport (EVs), heating and hot water make up nearly 90% of our domestic energy needs today[9]. As we look to decarbonise and increase electrification, the need to shift when these loads are used in a coordinated fashion to balance the grid becomes ever more important. Consumers will need to be more aware of the impact of when they use their appliances and the resulting impact on grid carbon intensity.

> Half-hourly settlement (HHS) and ... Time of Use (ToU) will help to educate consumers

Market-wide half-hourly settlement (HHS) and the introduction of more ToU tariffs will help to educate consumers, but ultimately technology and automated Home Energy Management Systems (HEMS) will be needed to make load shifting automatic, so homeowners will not have to think about it.

> Home Energy Management Systems will be needed to make load shifting automatic

The domestic flexibility market also represents an untapped revenue stream that incentivises consumers to adopt the required Energy Smart Appliances. These can be enabled with good user experience ensuring that homeowners continue to get the features and comfort they desire (e.g. heating or EV charging) and can potentially benefit financially with reduced bills by trading the flexibility that their devices can offer.

Avoiding curtailment by exploiting flexibility

The consequence of a shift towards electrification of heating (e.g. heat pumps, panel heaters, storage heaters, Domestic Hot Water (DHW)) and transport (EVs) means that local substations will see an increase in load which they were not designed for.

User habits mean that when people come home from work, expecting a warm home, to cook their evening meal and plug in their EV, there is significant risk of brown outs causing grid instability at a local level.

With GB Smart Metering Equipment Technical Specifications (SMETS), this behaviour could potentially be managed by DNOs (e.g. the EV charger is controlled via an Auxiliary Load Control Switch (ALCS) or Home Area Network (HAN) Connected ALCS (HCALCS)), but an alternative solution to avoid curtailment and spreading the load over time would be to use ToU tariffs and better scheduling of these loads before a brown out situation is reached.

In Figure 2 overleaf, for example, an EV may need 20kWh of energy added every night, but with a 7kW charger, it only needs to be powered on for 3 hours in a given period sometime between 6pm to 7am.

By scheduling when individual EV chargers get switched on across the local low voltage transformer network, each EV can be charged sufficiently, avoiding the need for a more simplistic curtailment or significant reinforcement and large-scale investment in CAPEX infrastructure projects from the grid operator.

The financial benefit for providing flexibility is proportional to the amount of energy (and instantaneous power) being shifted.

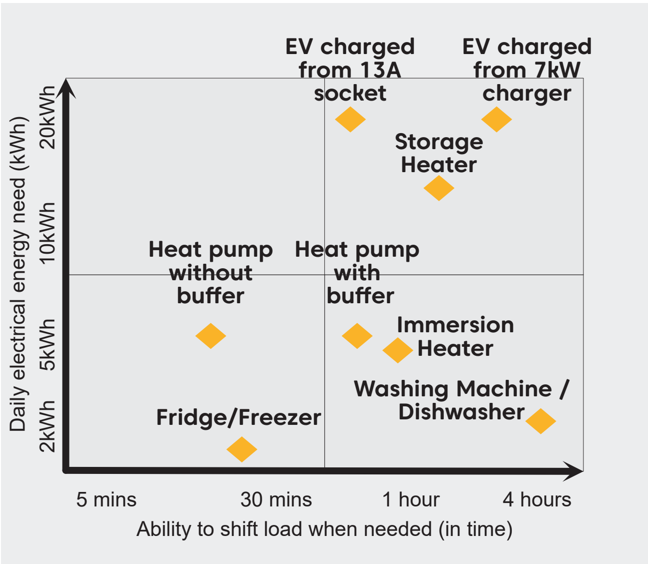

Figure 2 - Comparison of typical daily electrical energy demands and flexibility of domestic assets

EVs, heating and hot water storage are an obvious choice to integrate into domestic flexibility.

These appliances are already recognised as good domestic assets to provide flexibility control and several pre-commercial trials have demonstrated this.

The same is true of heat pumps to a lesser extent. These systems may consume 15kWh of heat per day, but only 5kWh of electricity (due to the greater efficiencies offered from heat pumps) – a home served with a heat pump which has a heat output of 5kW (working with COP of 3.0), will routinely only need to draw 1.6kW of instantaneous power from the grid.

> **"Homes with larger thermal storage capability ... can be more flexible"**

Depending on the individual property and its heat losses and thermal storage capability, these heating systems may offer differing amounts of flexibility (i.e. the ability to shift when the compressors are active or switched off).

Homes with larger thermal storage capability, such as heating buffers or concrete floors with underfloor heating, can be more flexible. The power demands of the heat pump compressor can be shifted a few minutes without any impact to user comfort or hot water needs due to the thermal lag in building and tank insulation.

Standardisation of heat pump control is a prerequisite to unlock flexibility at mass-market scale.

The UK Government (BEIS and OZEV) has sponsored the development of two Publicly Available Specifications (PAS). PAS1878[4] focuses on ESAs and PAS1879[5] focuses on the DSR - Code of Practice.

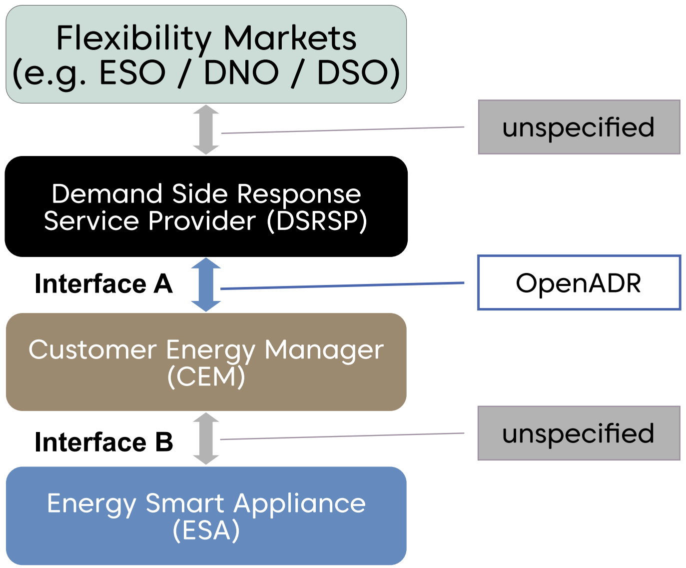

Figure 3 - PAS1878 high-level components and interfaces

Both PAS documents were first published in May 2021 with the aim of kick-start and standardising the control of energy smart appliances on the electricity network.

The PAS1878 architecture is shown in Figure 3, with the four main actors and the defined interfaces between them: flexibility markets, DSRSP, CEM and ESA.

Notably, only Interface A has been specified in PAS1878, with OpenADR being recommended. The flexibility markets in the USA (where OpenADR was initially developed) allow network operators to request service to their DSRSP's using OpenADR. In the UK, DNOs may not be aware of the standard and may be looking at building their own proprietary implementations.

> The key challenge for enabling mass-market control of a range of ESAs is the lack of an agreed interoperable protocol (Interface B) between a CEM and a variety of ESAs (be they EV chargers, heat pumps, solar inverters, battery storage or white goods).

The lack of a common standard means that CEM manufacturers today have to develop partnerships with many different manufacturers, gain access to their proprietary protocols and build bespoke solutions.

By buying a CEM from a given manufacturer, consumers may then unwittingly get locked into a specific set of brands of supported equipment (e.g. one type of EV charger with one type of solar inverter and one type of heat pump).

The cost for CEM manufacturers to develop, maintain and support a range of compatible devices, for example supporting heat pumps from several different manufacturers, starts to become prohibitive in this scenario.

The alternative of an industry-led open standard for allowing communication between the CEM and a variety of ESA types from many different manufacturers would help enable competition and reduce costs, in turn driving the much-needed uptake of Domestic DSR. It would also enable greater flexibility for users to choose their ESAs from different brands and swap them out over time, avoiding lock-in.

Direction of travel in UK regulation

At the time of writing this white paper, the UK Government has not formally stated its intention to mandate or regulate a particular direction. Development of PAS1878 and PAS1879 has opened up a number of potential options for the UK to follow.

However, the UK Government has recently legislated that all new EV chargers sold in the UK from June 2022 must meet minimum smart requirements. They have referenced some parts of the PAS1878 requirements (specifically around cyber security ETSI EN 303 645).

EV chargers must be connected and smart to avoid charging at peak times by default. Users can override these settings and will still be able to charge the vehicle if there is a communications failure.

As part of the EV Smart Charging Phase 2 consultation, due in 2022, BEIS has stated that it is likely to widen the scope to cover other domestic ESAs such as heat pumps.

There may be a further tightening of 'minimum requirements' over time which affects heat pumps as well as EV chargers.

While this document references PAS1878, it is not solely focused on its needs. It examines the wider ecosystem of ESAs to enable home energy management systems and heating appliances to exchange their data.

EEBUS, Matter and OCPP have been highlighted as examples of standard protocols which already exist. In this white paper we examine Matter and EEBUS in greater depth (see Part 3) as to their applicability for control of a heat pump system with a CEM.

This paper aims to serve as a useful reference architecture which standards may or may not be built upon and which may be applied not just in the UK, but also internationally in order to help accelerate the net zero journey in other countries.

The subject of electrification of heat is a wide topic and can cover multiple types of heating appliances (e.g. heat pumps, storage heating, immersion heaters, panel heaters).

The primary focus of this document is heat pump systems, but many of the principles discussed can also apply to storage, immersion and panel heaters.

This document assumes that a domestic property may include both a heat pump cylinder and immersion heaters (for DHW) and may include other ESAs, including some white goods, EV, solar PV and home battery storage systems which can be co-optimised.

EEBUS

matter

Business case

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This white paper does not extensively model the business case for enabling DSR in heat pumps as the business model will very much depend on the strategies and roles of various organisations that deliver heat pumps and DSR services. However, it is worth highlighting some of the considerations around the business model enabling DSR for heat pumps.

Why then do we need DSR for heat pumps?

The additional extra load at peak times that is put onto the existing low voltage network and transformers in the retrofit market will require demand side response when heat pumps hit mass-market roll-out, if extensive costly and environmentally damaging grid reinforcement is to be avoided.

Our modelling has shown that when 10%-20% of pre-existing homes have heat pumps retrofitted to them, this could cause peak time risk of brownouts on the legacy LV networks.

In much the same way as the transition to EVs will create additional load on the grid, heat pumps, which although using much less instantaneous power than an EV when charging, when added together at peak times are likely to overload existing substation transformers.

Direct electric heating has a more profound effect as these use 3 to 4 times the electrical energy compared to a heat pump, meaning transformer limits will be reached sooner.

Unlike EVs which can be shifted to off-peak overnight periods, poor insulation in our homes and general lack of thermal storage in most UK heat pump systems today means that reducing heating demand at peak times is more challenging.

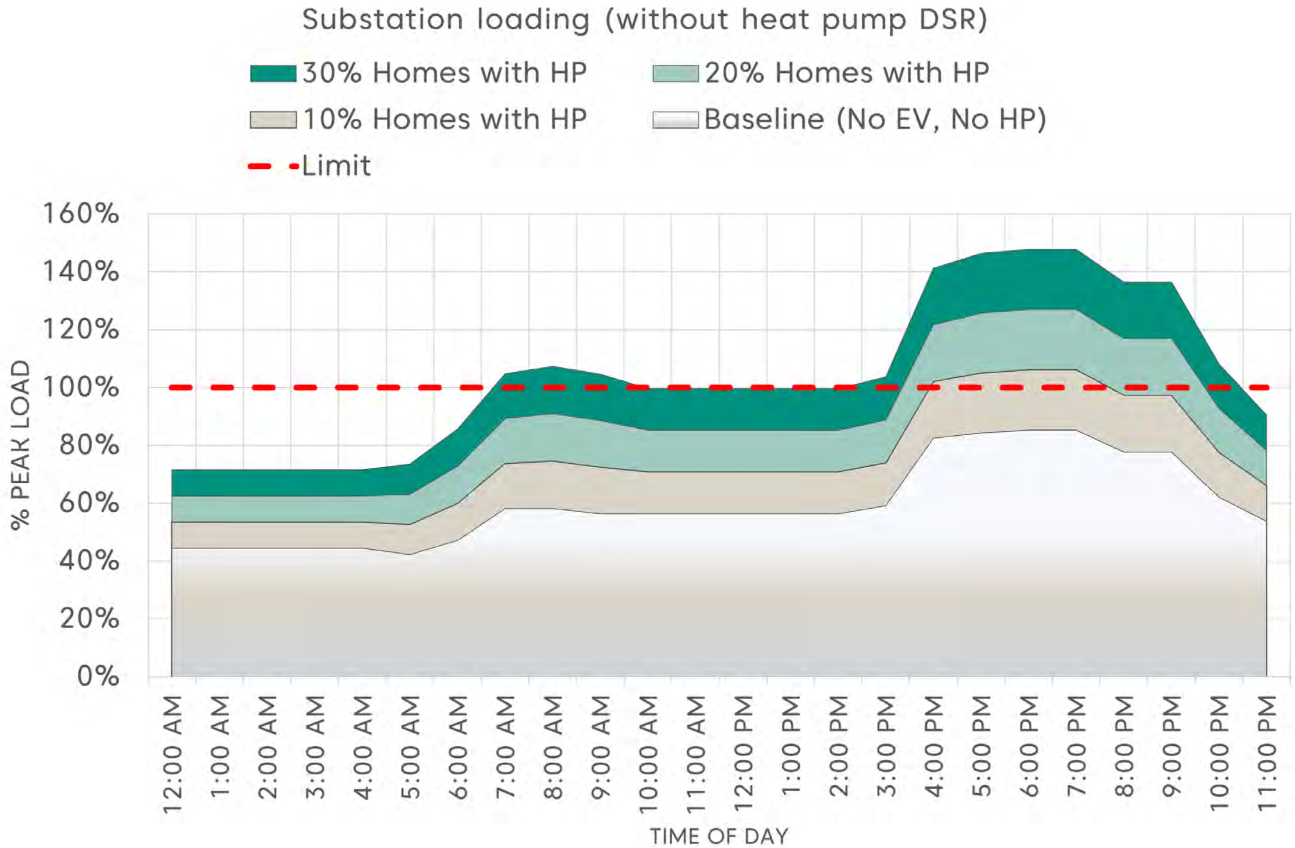


Figure 4 - LV substation transformer loading with additional heat pumps

How will DSR help?

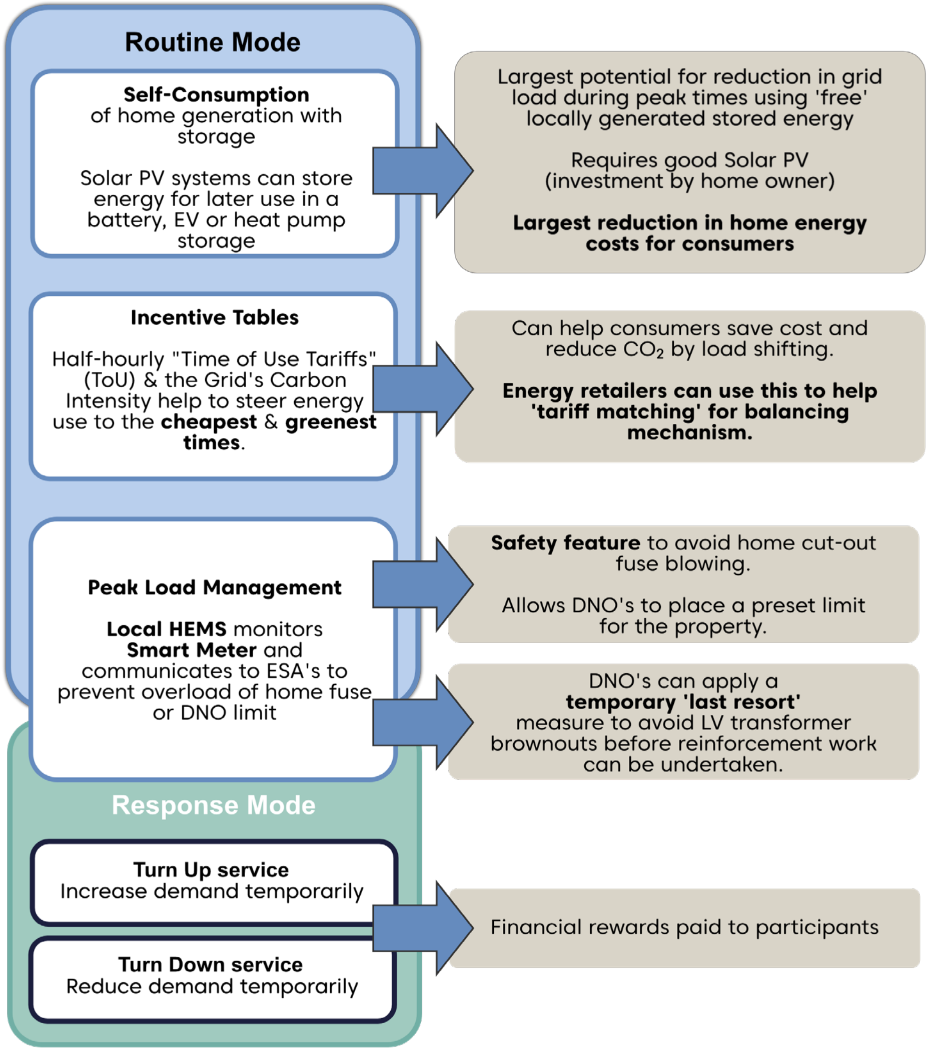


Figure 5 - Domestic DSR capabilities and benefits

With DSR control of the entire home's energy smart appliances, these issues could be avoided and the DNOs will not need to upgrade as many transformers or cause disruption by digging up roads and pavements in residential areas.

DSR can really be thought of as set of separate capabilities which are either locally controlled (routine mode) or explicitly controlled (response mode).

By avoiding peak times we can reduce CO_2 and minimise the impact on LV network

These use cases require a system to enable them, sometimes referred to as a HEMS or an EMS or CEM.

How will DSR help?

The HEMS is the central control point for the building (behind the meter) and needs to interface with the ESAs in the home, the grid control interface via the DSRSP and the grid or smart meter.

The smart meter allows the HEMS to monitor the total power being pulled from the grid and obtain the customer's ToU tariff information if available.

Incentive tables (such as ToU tariffs or grid carbon intensity forecasts) allow a HEMS to reduce the demand at peak times, without needing any explicit grid control, saving cost and carbon.

Peak load management is when a HEMS is used to keep the total home load under a pre-set DNO threshold by prioritising heating over other energy demands (e.g. deferring of EV charging, washing or dishwasher loads) thus mitigating the risk of LV network brownouts.

Homes with solar PV often produce more power than the home can use, and the excess is exported back to the grid.

A HEMS can implement self-consumption optimisation schemes which allows it to turn on devices (such as an EV charger, battery storage or a heat pump) to store the excess solar PV energy.

Similarly, for homes without solar PV, the HEMS can be asked by the grid operators to perform a turn up service from a DSRSP to store excess renewable energy on the grid (e.g. from too much wind power).

At peak times when the grid is under pressure, a DSRSP can ask for a turn down service to reduce demand, almost eliminating the need for additional grid reinforcement at the local level.

Heat pumps, solar PV and storage solutions

When a heat pump is coupled with thermal storage (for example, phase change material storage or large buffer tanks) or with electric storage (e.g. battery electric storage or vehicle-to-grid) then the HEMS can pre-charge the storage with excess renewable energy (e.g. from excess wind power or free rooftop solar PV), thereby almost eliminating the need for additional grid reinforcement at the local level.

It should be noted that many UK heat pump installers are not encouraged to fit larger buffer tanks, since these components add cost and take up more space.

Similarly, solar PV and battery storage are a sizeable investment which many homeowners either cannot afford or do not have space for.

It is therefore recommended that more work is done to determine how best to incentivise longer-term investments in these additional components, which will help to offset the DNOs future grid reinforcement costs.

For example, in the German energy market, the DNO can offer a reduction in the bill for homes that can use this technology to limit their import at peak times, or green loans or mortgages can enable consumers to cover the high initial outlay.

Today, early adopters who can afford storage systems are buying them and reducing their energy bills, but are also finding that their chosen equipment does not necessarily work together.

Early adopter sales are being driven by uptake of EV and solar (solar EV charging is popular and readily available), but also solar and home battery is starting to become popular (again available as off-the-shelf hybrid systems today).

When coupling EV + solar + battery + heat pump, few manufacturers or system providers today can provide solutions which enable them all to work well together across a broad range of manufacturer brands. This is where standardisation of DSR is important.

What impact does it have to the consumer?

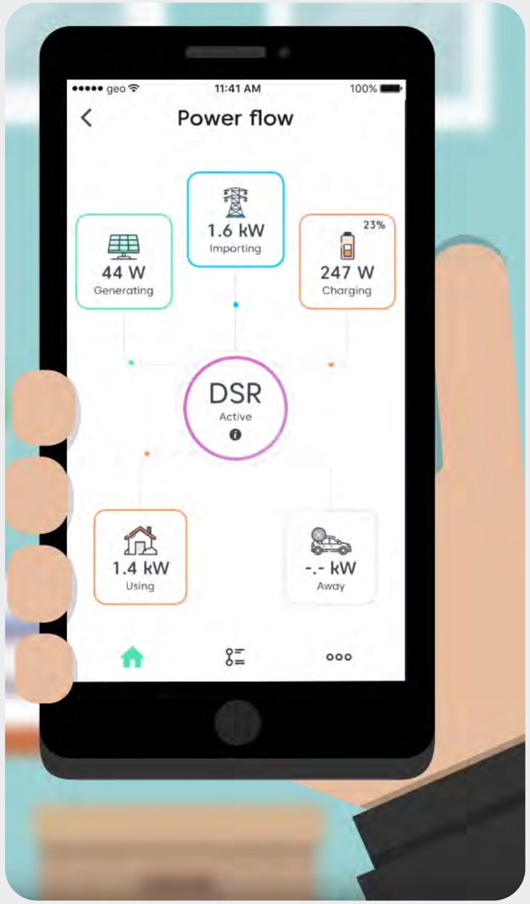
If the way DSR is used with heat pumps is well designed and thought through, then there should be little impact to the consumer's comfort. This is assuming that the heat pump control algorithm only makes offers that will not impact the consumer (i.e. getting too hot or too cold). Consumers will always have the option to opt-out, but this should be a last resort.

In routine mode, those who have PV systems may benefit from an integrated solution that utilises their PV to heat their homes and hot water intelligently, minimising the amount of PV being exported to the grid.

Market forces in a competitive landscape are likely to be needed to incentivise users to opt-in to a DSR service. This may require:

- initial financial incentives to persuade the consumer to join a DSR scheme (perhaps via their energy retailer, or third-party DSRSP).
- ensuring no negative user experience (well-designed algorithms that just work and consumers don't notice the difference).
- positive continued messaging to the end consumer (e.g. via an app or monthly email). Such messages should inform them that by being part of the DSR service they are helping to save CO_2 and have saved themselves some money.
- an ongoing reward scheme that can incentivise homeowners to continue to be part of the DSR service. This may use financial rewards (i.e. discount to their bill) or could be via other lifestyle rewards (e.g. vouchers or free cinema tickets).

Some existing schemes consider providing a revenue share from the DSR service - when the DSR aggregator gets paid, then the consumer gets a proportion of the profits for allowing the grid to use their ESAs.



How much does it cost to enable?

When using the PAS1878 architecture of a DSRSP, CEM and ESA, the heat pump (or more widely, the heating system) will act as an ESA and will need to communicate with the CEM over a standardised secure communication link (see Paper 3). The hardware may already have some cloud connected communications capability (e.g. built-in Wi-Fi or Ethernet) which could be used for remote diagnostics or for performing DSR services. However, the manufacturer is likely to need to invest in R&D to enable support of the new standardised and interoperable DSR protocols and functional control.

As such there may not be any actual increase in physical hardware costs, if the necessary capability already exists. However, it is possible that the additional security requirements imposed by PAS1878 (such as security hardening of the product) may mean that some manufacturers need to address these capabilities if their products do not already support them. For heat pump systems which are dumb today (i.e. not connected), then the consumer may need to spend extra on additional hardware.

The R&D costs would be amortised over the product range and such costs would need to be passed onto the consumer in some form (either by a one-off or regular license fee, or included the initial product outlay).

It should be noted that in some business models, the heat pump manufacturers may not directly benefit financially from supporting the DSR capability after the equipment has been sold. Heat pump manufacturers may therefore consider packaging DSR features with after sales service.

Furthermore, some heat pump manufacturers may be concerned that adding DSR support could adversely impact the performance and lifetime of the device with an associated increase in warranty claims.

> “manufacturers will be looking for an international standard ...rather than a UK specific version”

Therefore, to incentivise heat pump manufacturers to embrace and develop such a capability, it may be necessary for them to work with DSR aggregators as partners, and to have some revenue share.

Longer term, once a DSR market is proven, and consumers decide to opt for DSR enabled heat pumps (because of their CO_2 or revenue generating capabilities), it is likely that manufacturers will need to add support for DSR in order to stay competitive.

> “manufacturers will need to add DSR in order to stay competitive.”

Several heat pump manufacturers are embracing this future by adopting standardised protocols such as EEBUS (see www.eebus.org) in Europe (especially in Germany) where consumers are asking for such capabilities already. Additionally, some heat pump manufacturers are looking at the CSA's Matter 1.x roadmap as a future standard that will one day enable this.

This makes it more likely that heat pump manufacturers will be looking for an international standard to build upon, rather than a UK specific version. Furthermore, heat pump manufacturers will likely want to kick-start DSR with existing suitable established protocols rather than spending years trying to agree new standards which will impact their return of investment.

The myths around heat pump flexibility

Myth 1 - Heat pumps cannot be flexible

The traditional view is that heat pumps should be left alone and are always left on, needing to consume energy throughout the day, meaning that they cannot be flexible. This is not the case - heat pumps can play an important role in domestic demand flexibility

When choosing a heat pump, the installation engineer will need to calculate the required heat pump output that is appropriate for the heat loss of the property. This output power needs to be sized for the coldest day to ensure the end-user comfort levels are met, implying that on the coldest days the heat pump may need to be on maximum output for a continuous period.

Since not all days are extremely cold, then the opposite is true, that is to say heat pumps are not running at maximum output all the time, and in fact do switch off or reduce power output once the home has reached its temperature set point. This rather simple assessment leads to the basic conclusion that there is some degree of flexibility on the majority of non-extreme days.

Myth 2 - Switching heat pumps on and off can damage them

Some argue that turning heat pumps on and off will damage them. That may be true of older style fixed speed compressor systems, but most modern heat pumps have inverter-controlled compressors which can have their heat output set between 20-100%.

Thanks to this variable output, DSR can request that the heat pump increases or reduces its electrical power consumption without damaging the system.

> modern heat pumps have inverter-controlled compressors

While a heat pump heats the home much more slowly than a gas boiler, there is evidence to show that a heat pump with an inverter-controlled compressor can be used as a flexible asset.

In Paper 2, we examine some of the factors that impact flexibility in more depth:

- flow temperatures
- pipe diameter and flow rate
- better insulation in homes
- buffer tank sizes
- thermal inertia of buildings
- variable compressor output using ‘inverter’ technology which helps unlock DSR

Challenges to enabling heat pump DSR

What challenges are there to enable this domestic heat pump DSR capability?

1. The current installed base of heat pumps is small today (36,000 installed in 2020 in the UK). Retrofitting a DSR-capable heat pump requires homeowners to invest considerable time and effort in researching, selecting and installing a suitable solution.

   The projected growth of heat pump installations is expected to rise over time to just over 1m per year by 2030 [6].

2. In the UK, the current cost of gas being relatively cheaper than electricity means consumers will feel penalised for having heat pumps. This is a barrier to mass-roll-out of heat pumps.

3. There is no widespread de facto standard for communicating between the heat pump and the HEMS/CEM, although some standards do exist and may be able to support DSR.

4. To date, there is no proven scalable business case for residential DSR to encourage both consumers and manufacturers to invest in enabling DSR on their heat pumps.

5. DSR services currently require additional asset metering (depending on the type of service), which adds cost to the deployment.

6. Thermal storage (or battery storage) is not routinely fitted alongside heat pumps. Such storage is important in allowing heat pumps to offer flexibility.

Without scale, the market for domestic DSR is questionable, since many flexible assets are required to create a viable aggregated load for a DSRSP.

> “Without scale, the market for domestic DSR is questionable”

The early adopter market (looking to benefit from routine mode and self-consumption) may wish to buy home energy assets that work together. However, that desire may not be sufficient to pull through DSR standardisation into all manufacturer's products.

> Early adopters today risk buying very expensive products which do not work well together and ultimately need to be swapped out in the future.

Once sufficient numbers of DSR enabled heat pumps are available in the market, scale will come. With that volume, energy retailers and DSRSPs will be able to see commercial value over and above the benefit of the reduction in grid reinforcement costs borne by consumers and taxpayers.

Heat pump manufacturers also need to see this value.

Heat pump DSR

Comfort for your home

In this section we compare and contrast the key differences between homes heated with oil or gas and homes heated by heat pumps.

There are many possible combinations and variations in domestic heating systems to consider. Here we consider the key components needed in a typical heat pump home which provides heating and hot water and the in-home communication needed to optimise the behaviour of those components (e.g. between thermostat, heat pump control, heating diverter valve etc.).

Typical heating & hot water deployments today

In the UK today there are over 26 million hot water based (wet) central heating systems. The majority of heating systems are gas combination boilers (15 million), with around 9 million system/regular boilers (with DHW cylinder)[11].

Heat pumps currently only contribute a further 250,000 homes to this overall number, but with the challenge of net zero carbon and energy efficiency, this number is set to rise.

The UK Government has set targets for the installation of 600,000 heat pumps per year by 2028, which will represent one third of the annual heating installation market.

The market is divided into new homes (roughly 180,000 new homes are built each year in the UK) and retrofit to existing housing stock.

In new homes, gas boilers may be banned from 2025. Some house builders are already fitting heat pumps as standard. This is enabling them to get ahead of the curve as customers are increasingly looking for eco-friendly homes that do not require as much heating due to the more modern airtightness and insulation requirements in the current building regulations.

However, the larger retrofit market presents a significant challenge. Persuading homeowners to undertake the significant building work (e.g. installation of underfloor heating) and to cope with the time and inconvenience that work will impose, is a significant hurdle for heat pump providers and installers to overcome. This means that many consumers will naturally opt for a replacement gas boiler when their current one breaks down.

The UK Government is seeking to incentivise the retrofit market with the Boiler Upgrade Scheme (BUS) from April 2022 with up to £6,000 vouchers available to homeowners to help make it easier to replace existing gas boilers with heat pumps.

Gas & combi boiler systems today

Retrofitting existing homes requires an examination of the predominant heating systems already in homes. The large majority of heating systems today have a single zone heating circuit which is heated via radiators and has a single heating programmable thermostat, usually installed in a hallway as a reference point for the entire home. Individual thermostatic radiator valves may also have been fitted in order to influence temperatures in specific rooms.

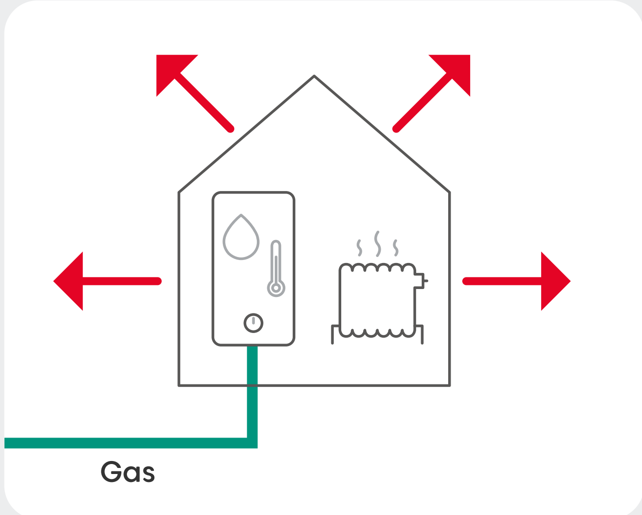
Properties over 120m^2 will likely have two heating circuits. In this case usually the upper floors will be heated via radiators and the ground floor will be heated by radiators or underfloor heating. Programmable thermostats are typically installed in a hallway on each floor of the building, operating as two separate reference points for each individual circuit for consumer comfort.

It is evident from this initial overview that heat pump systems are significantly more complex to plan and install than their less climate-friendly gas or oil-powered equivalents. To drive a significant increase in the pace of change, the full benefits of heat pumps need to be clearly and easily realisable for the overwhelming majority of households.

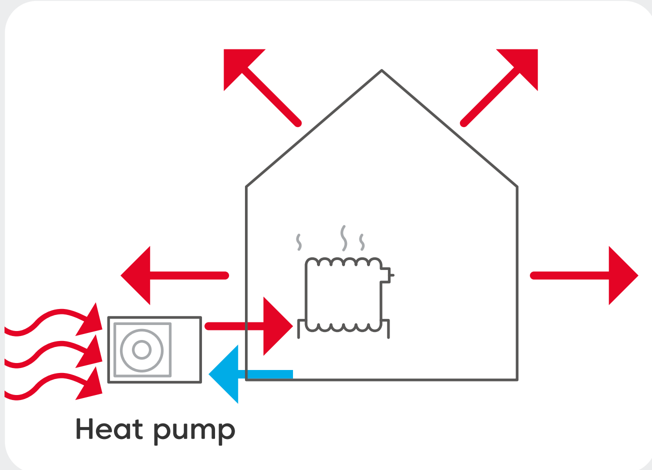
Heat pump efficiency & COP (Coefficient of Performance)

Understanding heat pump operation

Oil, gas, and direct electric or storage heaters produce new heat energy by burning fossil fuels, or passing electric current through a heating element. That heat energy escapes from our homes to the outside and is lost.



> heat pumps can be 300-400% efficient...



A heat pump is fundamentally different in that it effectively recycles the existing heat in the ground or ambient air and pumps it back into our homes at higher temperatures.

The heat will still escape back into the atmosphere eventually (which is why good insulation is important).

This process still works when it is cold outside (even at temperatures down to -20°C) although it becomes less efficient in air source heat pumps as the temperature drops below 0°C. This is where ground source heat pumps which extract energy using pipes buried deep below the ground can be more efficient, but are more costly to install.

The process to pump the existing heat energy into our homes is similar to how a fridge works (but in reverse).

The heat pump uses electricity to drive the compressor and motors to generate much more heat output than the equivalent amount of electricity would have produced from direct electric heating.

The heat pump's efficiency ratio depends on the ambient external air temperature (also known as Coefficient of Performance - COP). In the UK, climate heat pumps can have a COP of 3.0-4.0 (i.e. can be 300-400% efficient). This is because the heat pump is scavenging the 'free' heat energy from the air or the ground and so can be more than 100% efficient (in a similar way that a solar panel extracts free electricity from the sun). It requires 1kWh of electricity (running the fans and compressors) to produce 4kWh of heat output.

At very cold temperatures (-15°C or below) the COP can drop below 1.0 such that the heat pump uses more energy than it produces. Under these extreme cold temperatures, some heat pump manufacturers also have back-up heating elements (immersion heating).

Heat pump based systems

Figure 6 shows a heat pump system which is used to heat a home and DHW. The fan unit and compressor (1) is outdoors, and the extracted heat energy is transferred through pipes using a mix of water and antifreeze, to the indoor unit (2). The indoor unit comprises of a heat exchanger and expansion tank and may have an electrical back-up heating element.

The indoor unit then uses hot water to transfer the heat at the output of the heat exchanger into either a central heating buffer tank (3) or a DHW cylinder (7) using a controllable diverter valve. The buffer tank is used to store some heat before pumping it around the radiators (5) or under-floor heating (6) circuits.

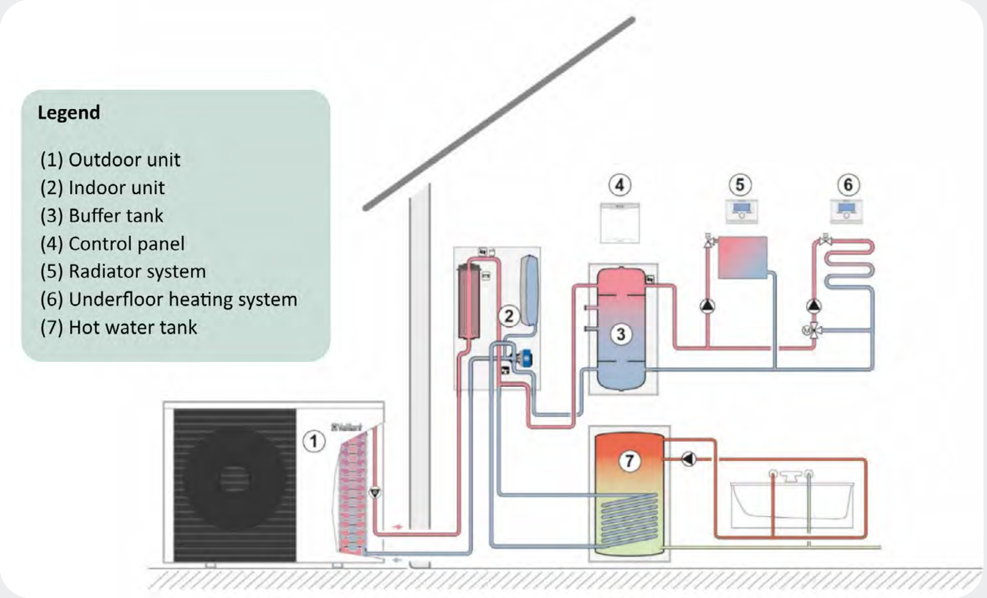


Figure 6 - Heat pump components

Note that this schematic shows all potential components - (2) and (3) are not always required.

Key differences between heat pumps and traditional boilers

One of the key differences when heating homes with heat pumps compared to gas boilers is the relatively lower water flow temperatures (typically 55°C). In a traditional boiler the output temperature of water can be as high as 75°C, which when pumped around radiators or underfloor heating means that consumers can feel the effect of this heat quickly.

Since heat pumps produce lower temperatures in the flow to radiators, radiators do not get as hot and so do not create the chimney effect that makes air flow circulate into the room. In addition, the heat transfer into the home is generally slower due to the relatively smaller temperature differential between the ambient air and the radiator temperature.

This means that heat pump based systems need to utilise correctly-sized radiators (with double panels) to radiate the same amount of heat energy from the heat pump system. Feeding the radiators with heat requires higher flow rates which normally requiring larger pipes. Some older homes may have these larger pipes, but more modern buildings have been fitted with 8-10mm microbore pipes which are more flexible to build with but have lower flow rates. As such, more modern homes may still need to replace the pipes and radiators (even though they are generally better insulated).

This is why heat pump based systems sometimes use underfloor heating in place of radiators on the ground floor, in effect using the concrete slab as a massive heat store. This can be installed in major renovation projects or new builds but is often impractical for retrofit projects.

Buffer tanks for flexibility

Flexibility requires the ability to store energy for later use. In a simple model, a battery can store energy – so it can be charged up when there is surplus energy on the grid and discharged when the grid is under stress.

Well-insulated hot water tanks also store heat energy much like a battery and can be pre-heated or charged to a higher temperature when there is low demand on the grid.

In the UK, these buffer tanks are typically relatively small in size (45 Litres), but it is possible to fit larger buffer tanks to provide extra thermal storage which would provide some level of flexibility.

In continental Europe, large buffer tanks (up to 500 Litres) are often installed, but in the UK (largely due to lack of space) are not commonplace.

Table 1 shows the amount of energy that can be stored in a hot water tank based on its size (assuming that the water is heated to 60°C).

Thermal storage solutions using phase-change materials are another option, which due to their relative smaller size are sometimes a more attractive solution. On average these store three times more energy than an equivalent sized cylinder.

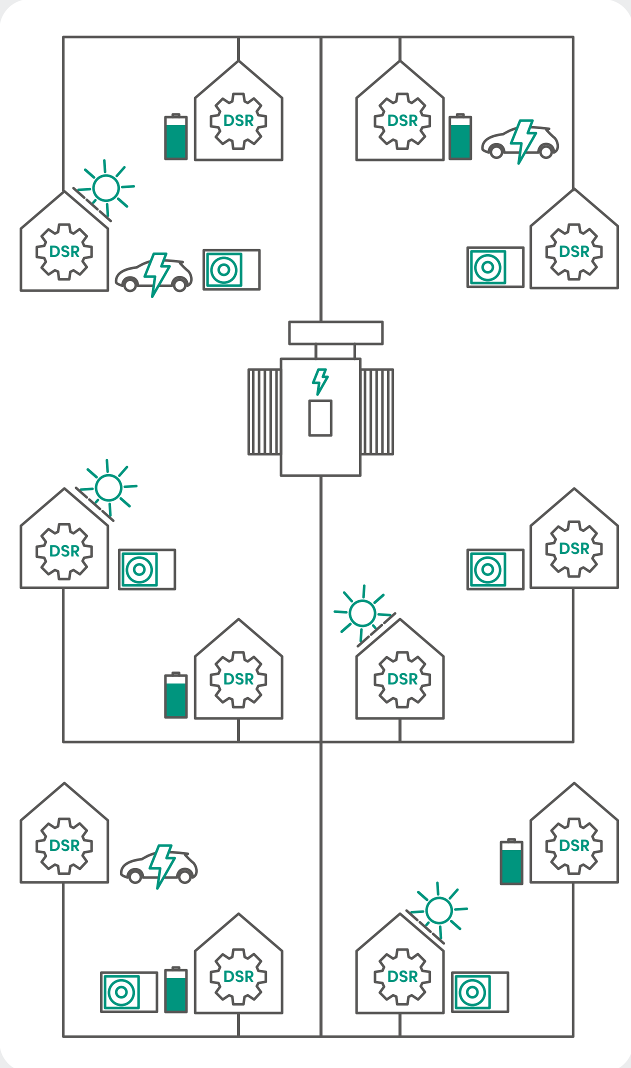
Tank size (Litres)	Temp. Incoming Cold (°C)	Temp. Hot (°C)	Temp. Difference (°C)	Stored Energy (kWh)
45	15	60	45	2.35
80	15	60	45	4.18
100	15	60	45	5.23
150	15	60	45	7.85
200	15	60	45	10.46
250	15	60	45	13.08
300	15	60	45	15.69

Table 1 - Impact of buffer tank size to stored energy

Domestic hot water energy storage

Older hot water cylinders do not have suitably sized coils to transfer the heat (at lower flow temperatures), and it is typical that in 80% of retrofit heat pump installations, the DHW cylinders will need to be replaced with newer heat pump ready designs which include larger coils.

Heat pump flexibility benefits the grid with thermal storage



Variable heat output using variable speed heat pumps

DSR aggregators would be able to pool many thousands of homes to relieve pressure on the grid if, rather than just cutting the power to the heat pump, they were intelligently controlled using IP networking protocols to adjust the heat output modulation level that is available in variable speed compressor systems.

A 5kW thermal rated heat pump operating with a COP of 3.0, when operating at 100% heat output, would consume 5/3 = 1.6kW of electricity. Asking the heat pump to drop its power to 20% for a short period of a few minutes would see a net electrical power reduction of 1.3kW.

By requesting a temporary drop in power from 100 to 20% output spread over 10,000 homes, represents a reduction of 13MW of power demand.

If the heat pump power is not restored at some point, the heat losses in the home would eventually mean that the home cools down to a point where the consumer feels uncomfortable.

The calculations to determine how long a heat pump can be turned down for are subject to heat losses and thermal storage capacity. This is examined in more depth in Part 2.

In reality, most heat pumps will not be operating at 100% all of the time (once the home has reached the set point temperature). The heat pump will back off to circa 50% output, and so the potential savings by dropping from 50% to 20% may be smaller in reality.

The variable power is more likely to be useful to ask the heat pump to increase output power (say from 50% to 100%) in the hours before the peak time, enabling heat to be stored in the building mass itself, or in buffer tanks or thermal storage.

If there is sufficient thermal storage, then the heat pump could potentially be switched off completely during peak periods on the grid for 1-2 hours. This could help alleviate the stress caused by installation of new heat pumps on the older stock of LV transformers.

Our key findings

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Key finding #1 - Energy smart protocol adoption

In the UK, there are no agreed energy smart protocols that work identically between manufacturers of heat pumps, which makes integration of DSR control challenging for HEMS vendors.

Furthermore, there are no widely adopted standardised data protocols that work between different components in a HEMS (e.g. solar PV, EV charger, battery storage and heat pump). While there are some close-coupled systems using basic Current Transformer (CT) clamps (e.g. between solar and EV chargers, or solar and battery), when multiple components are present in the same home, these systems can break down and behave in undesirable ways.

Our research into protocols that exist in other parts of the world has shown EEBUS as a leading contender. EEBUS is used in Germany and creates an Internet of Energy capability (specifically to control power flows around the home in an intelligent way). While some heat pump manufacturers, EV charging solutions and solar PV manufacturers which sell into the German market have adopted EEBUS, this is not the case in any other international market.

It is worth noting that many German automobile manufacturers promote EEBUS as their preferred solution for home EV charging.

We have also highlighted that the recently launched Matter standard (managed by the Connectivity Standards Alliance – CSA - and supported by Amazon, Apple, Google, Samsung and others) aims to be a smart home protocol which will start to see products available to buy in 2022. The Matter 1.0 data models today are focused on TVs, smart door locks, smart lighting and smart plugs and some HVAC applications (smart thermostats) and do not yet cover solar PV or DSR related functions.

It is highly likely that in future Matter 1.x updates, that there will be additional monitoring and control of home appliances, EV charging, solar PV, battery storage and HVAC systems.

The new Matter standard could potentially overtake the adoption of EEBUS if the major smart home assistant vendors decide to push in this direction, given it is available as an open-source project with tight security and stringent test and certification requirements for manufacturers to adhere to.

Our proposal

If enough manufacturers in the UK agreed to adopt a standard (be it EEBUS or an alternative such as Matter), then it would help to kick-start the domestic DSR agenda in the UK, as well as supporting the wider international move to establish a common set of DSR standards.

Key finding #2 - Industry led standards development

As noted previously, the UK Government sponsored PAS1878, is a minimum set of requirements, which provides a direction in which to take the actual implementation of domestic DSR. However, it does not provide enough detail for manufacturers and DSRSPs to provide integrated and interoperable systems which would necessarily work well in the real world.

PAS1878 has some specific proposals which should be re-assessed by industry as a whole to determine if this is the best approach or if alternative solutions can be found.

As one example, there are technical proposals in PAS1878 to allow multiple DSRSPs and multiple CEMs to control different loads in the same home at the same time. This approach has the potential to cause unwanted behaviour for the DNO's LV network, consumer assets and for competing DSRSP, which should be re-examined at a system level to find workable solutions.

Industry members need to jointly resolve deep technical issues, write the rules which can avoid the issues we raise, and build compatible products for consumers to buy, which meet the legal and safety requirements as imposed by grid operators.

Our proposal

We believe that an industry consortium should be formed of the various stakeholders:

- ESA manufacturers
- HEMS vendors
- DSR aggregators (DSRSPs)
- Energy retailers
- DNO/DSOs and ESOs

The consortium should work to harmonise on and promote key standards which can be adopted internationally, with the aim of promoting consumer awareness with a "DSR ready" trust mark to give consumers confidence that purchasing equipment will be compatible with each other and able to join into DSRSP offerings.

The consortium will need to operate in much the same way that other standards bodies do with steering groups, working groups and voting rights (the evolving generations of mobile telecommunications standards can be thought of as a model to follow).

Industry experts from manufacturer organisations write the specifications, have them peer reviewed, and challenge each other to develop world-class, high performing solutions with a roadmap of evolution. The consortium will need to have methods to recognise IPR claims from its members.

Key finding #3 - LV substation diversity killer

LV network diversity

Consider an EV fleet charging solution in a depot where all of the EV chargers are connected back to a single grid connection point: a single, load balancing controller would be used to coordinate all of the EV chargers to avoid blowing the fuse, while ensuring that all of the vehicles were sufficiently charged by the next day.

Now consider how our homes are connected to a single low voltage transformer. This is similar to the EV fleet charging depot from an electrical system perspective (all of the wires from the separate homes join back to a single LV transformer). However, in this setting there is no coordination between the homes (today there is no single coordinator controlling when we can turn on our appliances).

DNOs rely on diversity factors when sizing substation transformers which take account of the likelihood of appliances needing their peak power at a particular point in time (statistically, homeowners will not all use their electric ovens at the same time, but they may all want their lights and heat pumps operating simultaneously).

A centralised DSR turn down event may help the grid to reduce the load on the national or local network.

When the systems are restored to normal (at the end of a DSR event), then they may inadvertently become synchronised in their desire to consume more energy, creating a network event-induced peak.

This is especially true of heat pumps which are likely to detect that since they have been switched off, the house will have cooled down. There is a real risk that multiple heat pumps across multiple homes will need to go into a recovery mode (using more power) to bring the temperature back up.

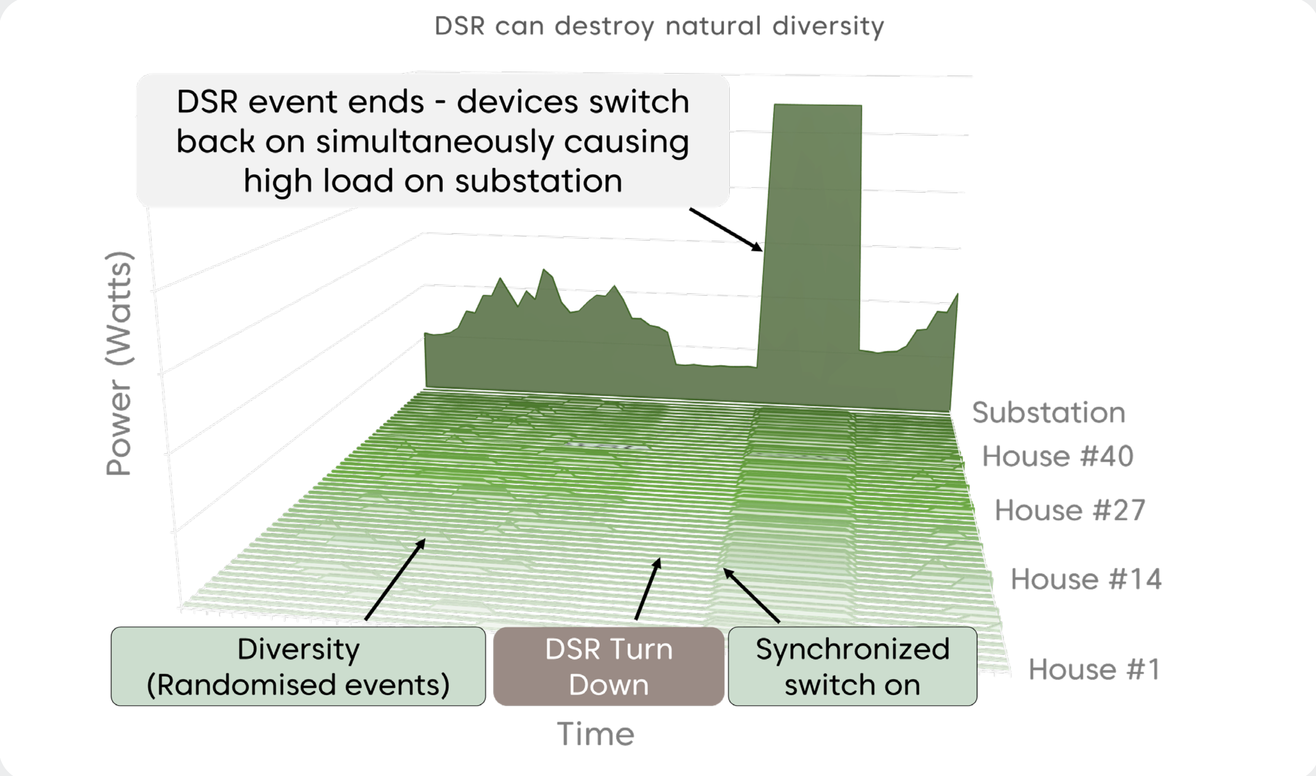

Figure 7 - Impact of loss of diversity when DSR event ends

Key finding #3 - LV substation diversity killer

When several independent DSRSPs (controlling entities) are connected to different assets in different homes on the same LV transformer, they may all respond to the same grid signals simultaneously (unaware that in neighbouring homes the same thing is happening).

At the end of the DSR event they can cause the systems to become synchronised in their power needs, in effect destroying the diversity assumptions that the DNOs rely on.

Note that a similar issue is true with ToU tariffs, which may incentivise home owners to switch on their EV chargers to run concurrently.

Example - Centralised DSR - Destroying Diversity:

There could be a DNO event to reduce demand in all homes for the peak hours 4-6pm. Many flexible assets are told to reduce power needs from 4pm - 6pm.

At 6.01pm, all of the assets complete their DNO service and revert back to normal, ramping their power demands back on. Unexpectedly, this results in an overload on the LV transformer or feeders.

This event could occur if the assets being flexed were heat pumps. It is likely that when returning to normal operation, the devices would detect that they had lost heat while operating at a lower power. In order to recover the temperature back up to consumer set point, variable compressor heat pumps may well in fact use more power than if they had not been part of the DSR service.

This would suggest that the DNOs need to carefully decide which homes and assets on a particular substation are being asked to respond to grid events (or potentially a single DSRSP should manage a particular substation area). This has implications around market competition, as multiple DSRSPs acting in multiple homes may be served by energy supplies with different, potentially competing, ToU tariffs and may be driven by different grid-originated balancing requests.

There may be obvious solutions to avoid this potential scenario, but this area needs further study and agreement by experts on a best practice approach.

Key finding #4 - Competing CEM issues

Competition between multiple CEMS controlling a single consumer's assets

Here we consider scenarios around multiple independent CEMs connected to different DSRSPs in the same home.

In the diagram opposite, both CEMs are technically performing correctly, but the consequences of controlling different equipment in the same home can have undesirable outcomes for grid and home owners.

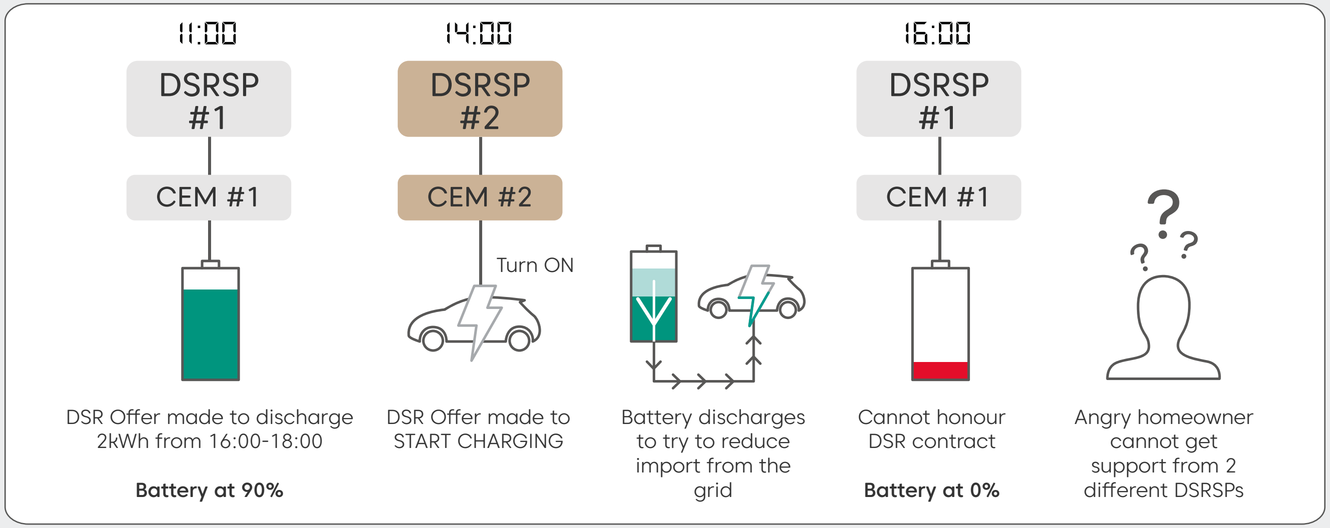

Figure 8 - Competing CEM issues

Example - Badly aligned CEMs can impact each other's business:

It is 11am, DSRSP #1 (battery controller) has forecast that between 4-6pm it will respond to a turn down (export) service. During the day, it has instructed the domestic battery to be in automatic load balancing mode (expecting that the home load is around 300W) and will still have sufficient stored energy at 4pm to be able to provide 2kW of service.

DSRSP#2 (EV charger controller) decides at 1pm to start charging the EV at 7kW to help with their tariff matching and balancing mechanism service. There is no coordination protocol between the two CEMs and DSRSPs.

Result:

- The battery responds to the EV charger load, and is now flat by 3pm, meaning that DSRSP#1 can no longer offer its service to the grid from 4-6pm.
- DSRSP#1 has lost money and breached its contract.
- The consumer has to pay for energy at peak times and is paying more for their energy.

Key finding #5 - Uncoordinated National vs. local DSR events

If independent DSRSPs controlling different CEMs in the same home can bid domestic assets on both national grid as well as local grid markets, this could lead to issues.

The ESO (national grid) may have different requirements to the DNO (local grid).

Example - Conflicting turn up and turn down events

DSRSP#3 (responding to National Grid contract) requests to increase consumption due to excess generation from wind during the day. This turns on several EV chargers that it operates in a local area.

DSRSP#4 (responding to a DNO local contract) has a request to export power onto the local grid due to local high demand on a particular substation and requests a domestic battery asset to discharge. There is no coordination between them.

Result:

- The EV charging consumes all of the power from the local battery and no power flows out to the local LV network. In fact, the EV (7kW) is offset by the local battery (3kW) so there is a net import of 4kW.
- The ESO has paid for a service to DSRSP#3, as has the DNO paid for a service to DSRSP#4, but the DNO has seen an increase in its loading on the substation and a brownout situation has occurred.

This would suggest that some coordination and checking between local and national market events is required. Perhaps the DSRSPs for domestic assets need to be restricted to providing services to DNOs only, and DNOs provide services to ESO in a hierarchical market structure.

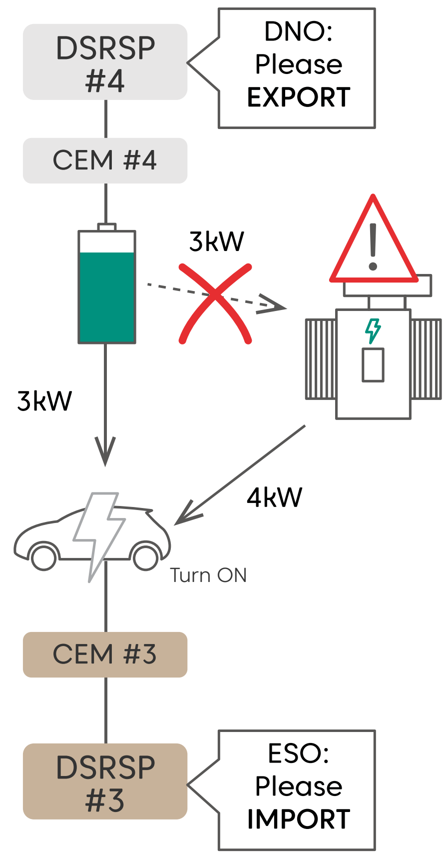

Figure 9 - Uncoordinated DSR events

Key finding #6 - Safety issues with multiple CEMs

There are potential safety considerations where multiple CEMs can cause circuits in the home to overload. To resolve this issue, a single CEM or coordination is required to manage an individual home's power control loops to avoid oscillations.

In the UK, the smart metering system could form part of the solution to provide the real-time 10s power measurements to a smart meter interface (such as a Consumer Access Device or connected In Home Display) which provides the data to a single CEM.

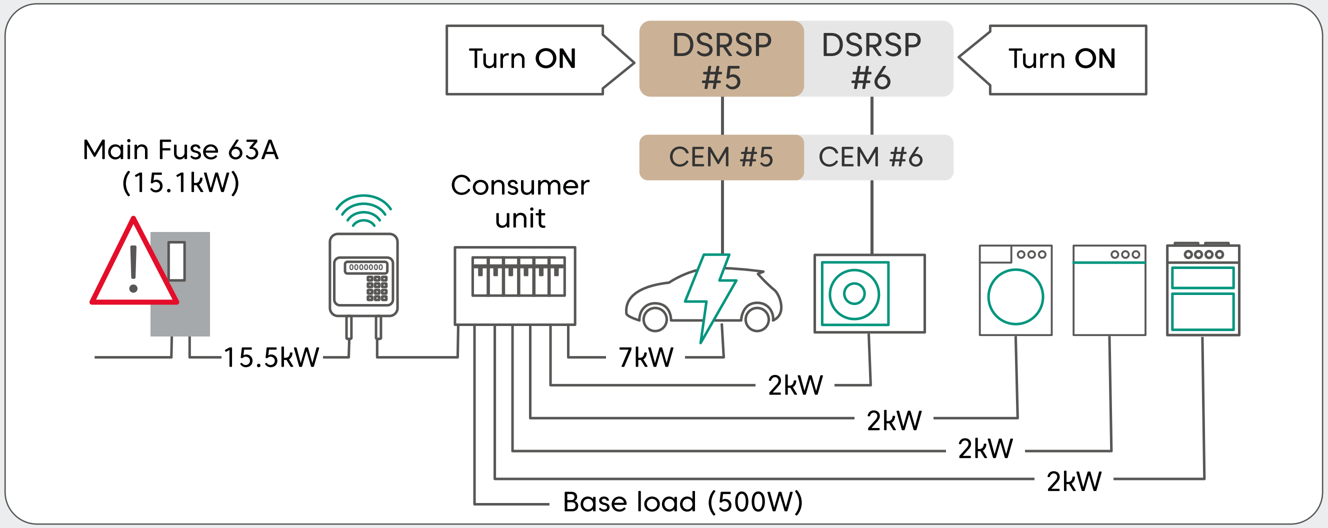

Figure 10 - Potential safety issues with multiple CEMs

Example - Multiple CEMs cause potential safety issues

A home is supplied via a 63A cut-out fuse (maximum power 15.1kW). The homeowner has a 7kW EV charger (controlled by DSRSP#5) and a 2kW (electrical load) heat pump (controlled by DSRSP#6). They also have several appliances (washing machine, tumble dryer and electric oven). They have a 500W base load.

- It is lunchtime on a particularly sunny day, and there is excess generation on the grid.
- The DSRSP#5 & DSRSP#6 both have offers accepted to increase the load by a total of 9kW.
- The homeowner decides to put their washing machine (2kW), tumble dryer (2kW) and oven (2kW) on at the same time.

Result:

All of these appliances, plus the heat pump and EV, have pushed the import to 15.5kW (above the cut-out fuse rating). Since there is no active load management import limit, this could eventually blow the main fuse, even though the other circuits individually are within their rated limits. With a single CEM this is readily solvable - with multiple CEMs the coordination is complex.

Key finding #7 - Flexible heat pumps need thermal storage

Thermal modelling demonstrates variable flexibility for different homes

Our thermal modelling of different UK home types has shown that the impact of poor insulation and lack of thermal storage in most UK properties means that there is less potential for DSR flexibility of heat pumps than in other European countries.

For example, in Germany it is common that larger heat buffer tanks are routinely fitted, which can act as a storage reservoir. Due to the lack of space in many newer UK homes and the additional costs of a buffer tank, these are not seen to add value. Newer thermal storage solutions coupled into the heat pump can offer space saving solutions which in a mass-market, could bring their costs down.

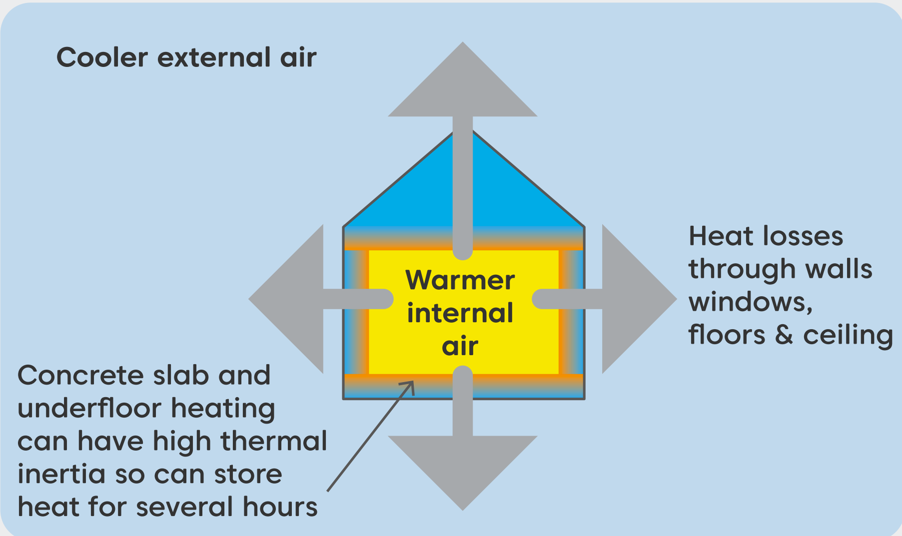

Figure 11 - Understanding heat losses in a building

Our proposal

We recommend that building regulators actively encourage better insulation and larger buffer tanks which reduce energy bills and help increase DSR flexibility. This recommendation supports UK Government ambition to take a whole-system approach.

The end user benefits of DSR flexibility (i.e. financial payback) for investing up-front in larger buffer tanks, thermal storage and better insulation, need to be made clear to house builders and householders.

We suggest that governments should consider ways to incentivise fitting either thermal or battery storage solutions at the time heat pumps are retrofitted to help enable DSR flexibility. Thermal or battery storage should also be recognised in SAP ratings to help incentivise their adoption. This is especially important on the legacy LV transformers to which heat pump homes will be retrofitted.

Key finding #8 - Heat pumps & smart thermostats

Today, smart thermostats can help save cost and carbon by intelligently controlling gas boilers using a simple relay control with on/off switch. Smart thermostats can save energy costs by knowing when the property is unoccupied, and can learn the thermal model of the home alongside weather data and thus enable more efficient operation.

Heat pumps are far more complex and may already have advanced capabilities, such as weather prediction, ToU tariff tracking, monitoring of flow and return temperatures to detect heat loss, for example. As a result, heat pump control systems already have many (if not more) of the 'smarts' that smart thermostats have.

Systems fitted with smart thermostats (many of which also try to predict heat losses and perform advanced pre-heating) and heat pumps (which try to do the same thing) can cause issues and sub-optimal performance of the heat pump.

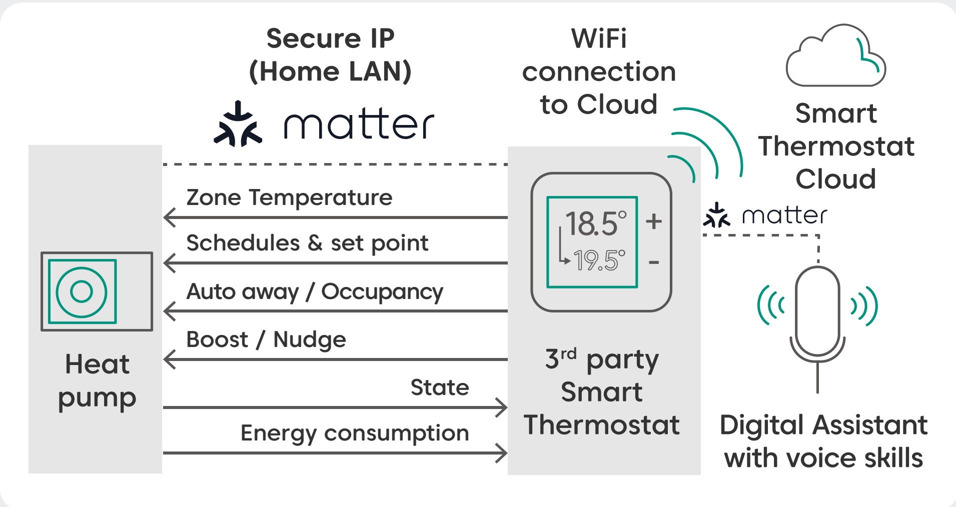

Figure 12 - Smart thermostat and heat pumps controlled using Matter

Heat pump manufacturers have often developed their own proprietary solutions, but consumers may already have had a smart thermostat and may prefer their features, appearance and convenience (e.g. with integration to voice assistants, away mode detection etc.).

Smart thermostat manufacturers are best placed to understand consumer requirements and can offer consumers a choice of user interfaces. Heat pump manufacturers know how best to control the flow of heat and refrigerant cycles and are unlikely to want to cede control to third parties which could cause higher maintenance, support and servicing costs.

Our research recognises that there is still a role for both parties.

Our proposal

We believe that the Connectivity Standards Alliance (CSA) Matter standard may hold the answer. It has data models that allow smart thermostats to send the user desired temperature and schedules over a wireless data-rich IP interface (rather than a 2-wire interface) to the heat pump control system. The heat pump may in return inform the smart thermostat about its power and energy consumption so that it can inform the homeowner about how much energy they are using and encourage them to change their behaviour appropriately.

This allows consumers to stick with their well-known and trusted smart thermostat brands, while obtaining optimally performing systems.

Key finding #9 - Hybrid smart home architecture

Energy smart home architecture

In Paper 3, we discuss different control architectures with which to enable energy smart homes. Trading off the in-home vs. cloud-2-cloud vs. hybrid approaches, and making use of the assets that need to be in the home and require high bandwidth, fast-response control and survive internet outages, vs. the clever data intense optimisation algorithms that can be in the cloud.

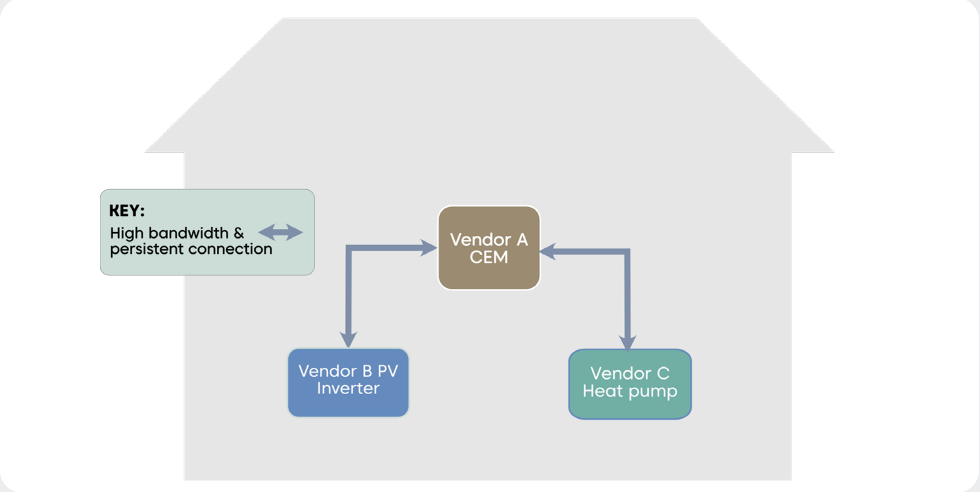

Figure 13 - Local home control using a CEM

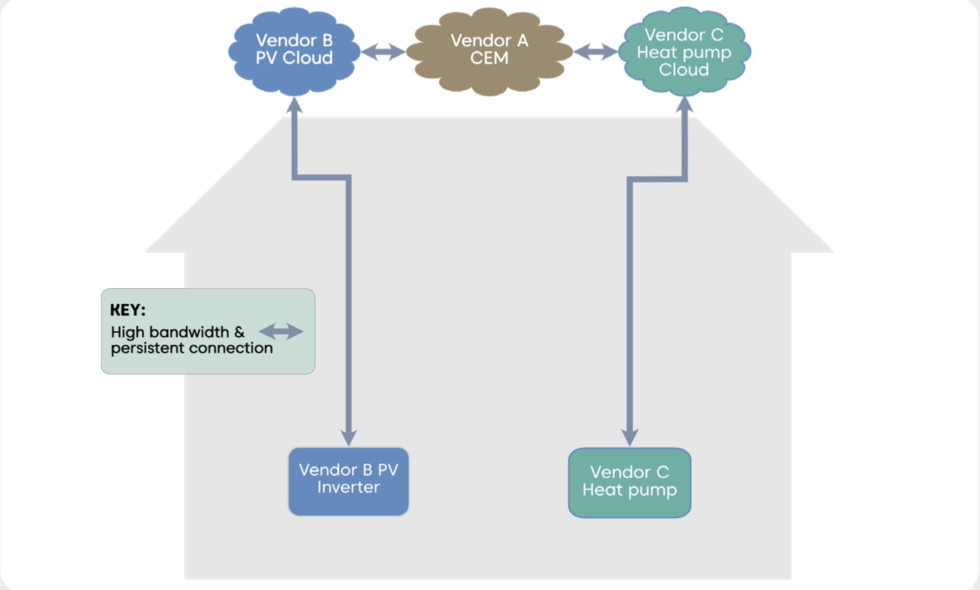

Figure 14 - Cloud-2-Cloud control

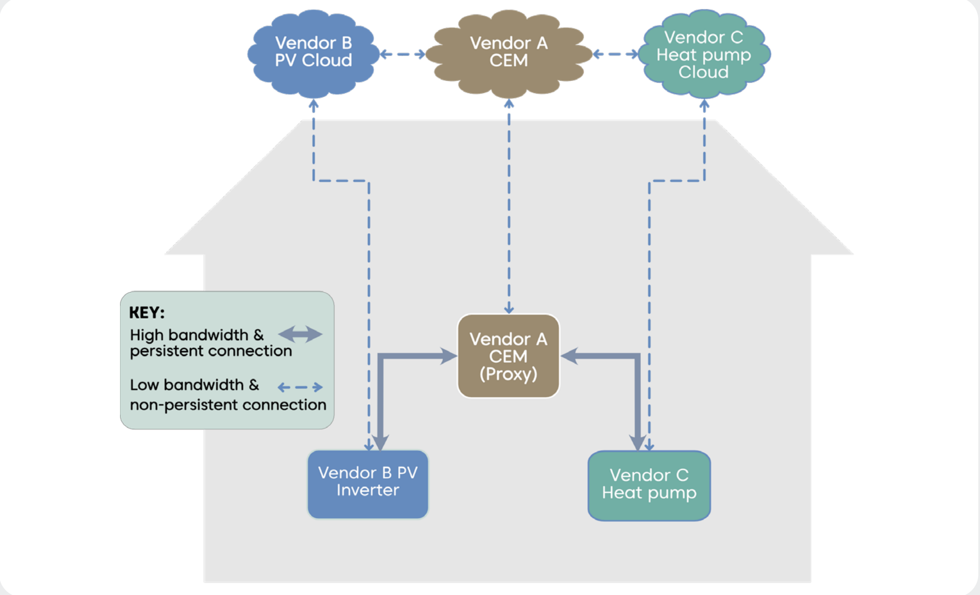

Figure 15 - Hybrid solution with local and cloud CEM

Key finding #9 - Hybrid smart home architecture

We have examined the use cases not just for offering grid services (use cases 1.x), but also considering those which homeowners want day in, day out (aka 'routine mode' use cases 2.x).

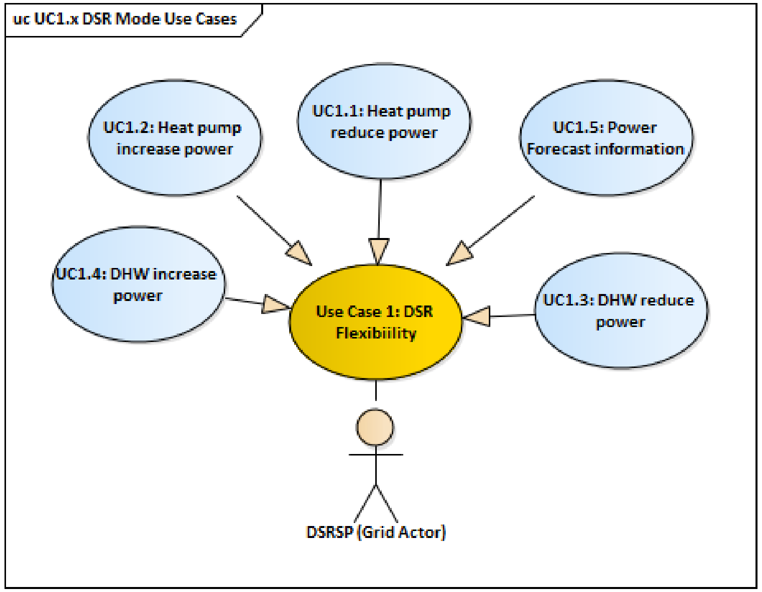

Figure 16 - Use Case 1 – benefits DSRSP (grid actors)

The routine use cases enable cost savings for the consumer. These savings were clearly demonstrated by the BEIS funded Core4Grid project in which homeowners with battery storage could save 49% on average on their energy bills with a ToU tariff.

Those with solar PV and an EV want the excess energy from the solar panels to charge their EV or heat their hot water. More environmentally conscious consumers want to reduce their CO2 impact by shifting when they use energy to help reduce grid carbon intensity by avoiding importing power from the grid at peak times.

> "consumers with battery storage could save up to 49% on their energy bills"

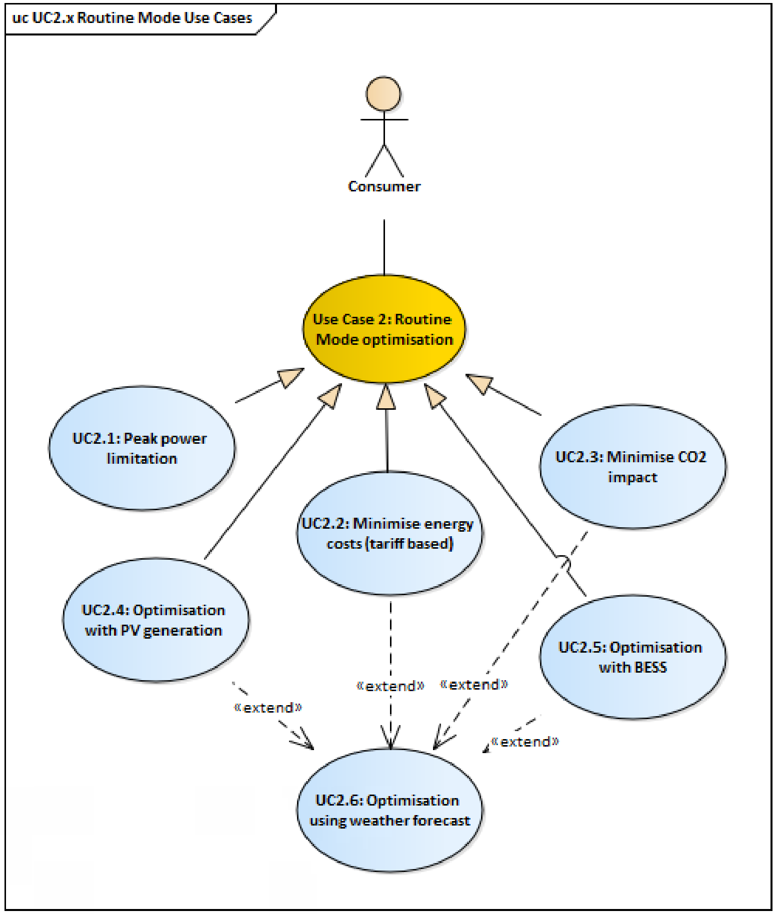

Figure 17 - Use Case 2.x benefits consumer (as well as indirectly benefiting DNO and ESO)

Key finding #9 - Hybrid smart home architecture

We considered how a common smart home standard can be used combined with GB smart metering and cloud architectures along with the principles of PAS1878, to construct a proposed energy smart home architecture for the UK.

Figure 18 opposite is explained in detail in paper 3. Our assessment is that this architecture would meet the minimum requirements of PAS1878 and enable not only routine mode but also grid actor control use cases, while having consumer friendly features (such as auto-discovery of ESA assets which can be joined to the CEM).

Note that the EVSE shown here is connected using OCPP via a cellular network to a charge point operator (CPO) and can be controlled via a Cloud-2-Cloud interface – in this setup it would not be discoverable by the CEM, so would need to be manually added by the user, and the CEM would need to have a partnership with the CPO cloud.

However, an EVSE could also be connected via EEBUS or Matter locally over Wi-Fi. In both cases, this would enable automatic discovery in the home and faster data updates to allow faster load control scenarios (e.g. reacting to intermittent solar PV generation on partially cloudy days).

Our proposal

We believe that a reference architecture consisting of a hybrid cloud and local CEM, coupled with auto-discovery of ESAs in the home and connections to a smart meter will enable future Domestic DSR.

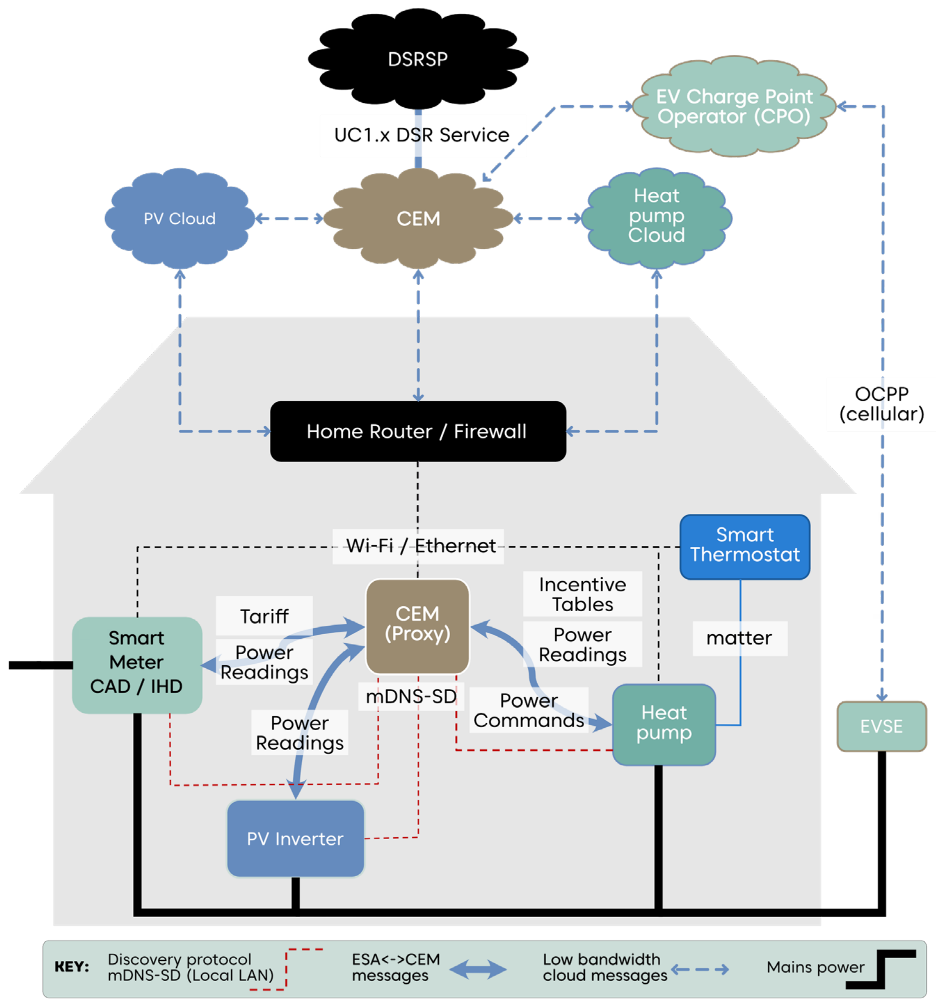

Figure 18 - Use Case 2.x benefits homeowner (also benefiting DNO and ESO)

Recommendations

Comfort for your home

#1

Heat pumps are inherently lower-carbon ways of heating our homes than gas and can play a big part in net zero pathways. They are today's "no and low-regrets" solution to a reduction of carbon in heating.

- The relative cost of electricity to gas (23% of electricity bills are made up from environment and social levies including the Climate Change Levy (CCL) vs. 2% on gas bills) is a specific barrier to adoption of heat pumps, which is in the UK Government's power to address.

#2

Industry needs to continue its work to debunk the myths and challenges that heat pumps present.

- The home mortgage and insurance industries which may see heat pumps as a risk rather than a value.
- Negative media reports of consumers being cold after having a heat pump installed imply inappropriate installation and should be challenged. Positive experiences should be promoted.
- Better education of consumers and critically of local tradespeople to help them to offer, explain the benefits of and properly designed low carbon systems for those consumers' homes where appropriate.
- The more positive arguments about long-term benefits and return of investment over several years should help green mortgage brokers kick-start the better insulation in homes and installation of heat pumps.

#3

Establish a code of practice for the heat pump industry and DSR providers to follow.

- Surveyors (for heat pump sizing and EPC), installers, manufacturers and companies offering finance or Heat as a Service (HaaS) offers, should sign up to an industry code of practice.
- Installers may need to take on the challenge of installing compatible CEM devices for homes, ensuring that multiple devices can be coordinated together.
- DSRSPs should have a code of practice which ensures consumer protection (e.g. compensating homeowners sufficiently so that any DSR service offered balances out the cost the user has to pay to replenish their energy at the more expensive tariff periods).

#4

Building regulations and Standard Assessment Procedure (SAP) should ensure that homes are well insulated and fitted with additional storage for greater flexibility.

- Review building regulations that today mandate the use of air vents to help reduce condensation, mould and improve air quality, and encourage mechanical heat recovery heat exchangers to help reduce heat losses.
- Homes should be encouraged to install larger buffer tanks, thermal storage (e.g. phase change materials) or battery storage which could add value in flexibility of heat pumps.
- Building regulations should include a series of improvements that enable new homes to be heat pump ready. This includes ensuring that correctly sized (larger) pipes and radiators are pre-installed so that it is easier to retrofit a heat pump at a later date. The current practise of fitting unsuitable narrow bore pipes for gas heated homes is unsustainable in the longer term.

#5

Solar PV, EV charging and heat pumps as well as battery storage or V2G/V2H technologies all mix in the home and can help balance the low voltage grid at the edge.

- Using these technologies in a smart way would reduce the need for LV network reinforcement.
- Today's commercial offerings don't work well together due to lack of standardisation between the different components in homes.
- Our third white paper proposes a smart home architecture and set of existing standards used in other countries that solves the standardisation challenge.
- Industry needs to convene and formally agree to build products against those standards.
- UK Government needs to encourage development of future products with innovation funding to prove the interoperability of ESAs in real world testing locations.

#6

The PAS1878 concept of multiple Customer Energy Managers (CEM) controlling a single home via different DSR Service Providers should be re-assessed at a system level.

- PAS1878 allows multiple CEMs per home, which opens up the possibility for safety issues and system performance issues (e.g. a battery storage ESA is impacted by an EV charger).
- Multiple CEMs per home can have a negative impact on the consumer's desired outcome. Consumers may struggle to get support from their multiple CEM and DSR service providers. It is essential that appropriate steps are taken to ensure that, if multiple CEMs are allowed, that respective installers have the responsibility to make the complete system work together seamlessly.
- As a result of allowing multiple CEMs per home, the UK PAS1878 introduces a new conceptual difference between a CEM and HEMS (adding increased system complexity). This does not conform to the underlying international standards (TC-405), and so creates a UK specific variation which is undesirable for industry to adopt.

#7

DNOs need to consider the positive impact that DSR flexibility at the grid edge, also known as Virtual Power Plant (VPP) may offer them.

- DSR today is focused on the centralised national grid generation challenges but seems not to consider the role of domestic assets at the grid edge as important.
- DNOs are therefore looking to make the LV network fully firm (i.e. cope with any scenario).
- DNOs size the local low voltage transformers (approximately 500,000 in the UK) based on averaging out our homes (using a home's maximum demand after diversity (modelling approach).
- A centralised and uncoordinated DSR approach (by independently operating DSRSPs) could negate the diversity factors assumed by DNOs, which risks overloading LV transformers.
- More research is needed to understand the potential impact of centralised DSR control via a multitude of DSR aggregators on the low voltage transformers and feeders and to identify suitable procedures to avoid this.

#8

Like EVs, heat pump roll-out across retrofit domestic property estates will add additional load which was not designed in when the homes were originally built.

- Due to heap pump operation, these will have a low diversity (high coincidence factor) - i.e. always on, especially at peak times, therefore adding to the After Diversity Maximum Demand (ADMD) figure.
- Coupling heat pumps with additional storage can offset this increased demand and either allow the heat pump to need less power during peak times (via thermal storage) or be offset by electrical battery storage.
- We suggest that governments should look for ways to incentivise thermal or battery storage as part of a retrofit heat pump installation to mitigate the effects it may have on the LV network at peak times.
- While DSR can play its part in reducing the need for low voltage grid reinforcement, schemes which encourage the use of solar PV coupled with battery storage (or V2G), along with heat pumps, can dramatically reduce the need for grid reinforcement.
- Such technical solutions need to be proven reliable for DNOs to gain confidence. The benefits of installing a HEMS to limit import on the grid at peak times, should create financial incentives which help justify the cost to fit and maintain them.
- DNOs should work with local authorities to ensure that they are ready to enable housing estates to take more heat pumps (and not become the blocker to new retrofit installations).

#9

Action is needed to ensure that the heat pumps and other assets being installed today can be made to support future energy smart appliance standards.

- Today's devices are 'dumb' (i.e. not controllable via DSR interfaces), and we risk deploying hundreds of thousands of devices into homes which will never support DSR.
- Any government funded or local authority incentive scheme should check that the appliances installed either already support DSR or can be upgraded (either with an additional control box or firmware update) to support DSR services and avoid expensive replacement in the future.
- The heat pump (and wider ESA) industry needs to urgently agree upon a DSR standard for interoperable ESAs.

#10

Existing GB SMETS metering is a key part of the future domestic DSR service.

- In some DSR markets today, there is a requirement for 1s meter readings, which is overkill for monitoring an individual home's DSR compliance.
- GB smart meters can provide 10s real-time data feeds (on the HAN) and can provide the proof that the assets have changed their behaviour from the baseline intended operation. There is already a feature which allows IHDs and CADs to deliver this data to consumers.
- GB smart meters also already provide a standardised route for energy retailers to publish their ToU tariffs to the energy management systems.
- GB smart meters could provide a lot more useful real-time data for DSR providers (such as voltage and reactive power), but the CAD/IHD interface is currently overly restrictive.

#11

Industry consortium should run large-scale trials in domestic settings (around single substation transformers).

- These should show that home energy management solutions coupled with a mix of EV, solar PV, battery or thermal storage and heat pumps can reduce import at peak times on the grid.
- The results can reduce the need for disruptive DNO reinforcement work.
- The solutions can have payback periods of a few years by reducing consumer energy bills.
- The technology can reduce a homeowner's CO_2 impact by load shifting energy demand away from high carbon intensity periods on the grid.

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Glossary

ADMD	After Diversity Max Demand
BESS	Battery Energy Storage System
BUS	Boiler Upgrade Scheme
CAD	Consumer Access Device
CEM	Customer Energy Manager (sometimes also EMS, HEMS)
COP	Coefficient of performance
CPO	Charge Point Operator
CT	Current Transformer (used for metering)
DHW	Domestic Hot Water
DNO	Distribution Network Operators
DSO	Distribution Supply Operator
DSR	Demand Side Response
DSRSP	DSR Service Provider
EMS	Energy Management System (sometimes also CEM, HEMS)
EPC	Energy Performance Certificate
ESA	Energy Smart Appliance
ESO	Energy Supply Operators
EV	Electric Vehicle
HEMS	Home Energy Management System
HHS	Half-hourly settlement
IHD	In-home Display
LV	Low Voltage (distribution network)
SAP	Standard Assessment Procedure
ToU	Time of Use
V2G	Vehicle-to-grid
VPP	Virtual Power Plant

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